Design of a CMOS Circuit for Generating Electromyography for Diagnosis of ALS

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Abstract. As a neurological disease, amyotrophic lateral sclerosis (ALS) causes the patients' motor neurons to be damaged to varying degrees, so that they cannot control the muscles, resulting in motor disorders and muscle atrophy. In the diagnosis of ALS, Electromyography (EMG) is the main part. A small electrode delivers a stimulus to a particular part of the nerve and receives a signal at another part of the nerve. At present, the commonly used method to judge nerve injury is to measure its conduction velocity and time. This paper provides an overview of ALS, delves into the details of EMG generation, and provides a practical CMOS circuit for EMG generation. The circuit uses a current mirror to generate a band of electrical stimulation. This design is stable, cheap, and programmable.

Keywords: ALS, EMG, CMOS, electromyography

1. Introduction

ALS is a common neurological disease. Its pathogenesis is caused by blocking the transmission of neurons in patients, resulting in different degrees of muscle atrophy and uncontrollable symptoms. Electromyography refers to the bioelectric pattern of muscles recorded with electromyography, which is an important examination item used to diagnose ALS, which is based on the principle of light electrical stimulation by attaching electrodes to the surface of the skin and using a stimulator to record the signals produced by muscles and nerves (nerve conduction testing), and then analyzing them and making diagnostic conclusions.

A neural stimulator is a very important part of the composition of the electromyograph. The neural stimulator is designed to be implantable, through the microelectrode on the stimulator to the nerve to send a controllable regular bipolar current stimulation signal, so that the nerve produces a corresponding stimulus-response, which can be processed and displayed by the subsequent circuit part of the electromyograph. This neurostimulator can be used not only for the diagnosis of ALS but also for treatment in some cases.

In this article, the main purpose is to design a circuit of the neural stimulator used in the analyzer for the diagnosis of ALS. The COOLSPICE simulation results demonstrate that the circuit mirror used in the project exhibits good stable and dynamic performance. The circuit mirror structure is a significant optimization of the EMG device designed. In addition, some technical details are discussed and their feasibility is proved theoretically.

2. ALS requirements

ALS is one of the most common chronic neurological diseases in the world, and its patients lose control of their body parts because their neurons are blocked [1]. It is a morphic disease in neurology. It is often manifested by the combined damage of upper and lower motor neurons, resulting in progressive and aggravated muscle weakness, muscle atrophy, and muscle bundle fibrillation [2].

ALS is the most common motor neuron disease, most of which are sporadic and a few are familial. The etiology of most patients is not very clear, and only a small number of patients are related to genetic factors [3]. At present, ALS is still an incurable disease, but there are many ways to improve

the quality of life of patients and delay the progress of the disease. ALS needs early diagnosis and treatment, and timely neuroprotection and supportive treatment [1].

At present, the diagnosis of ALS mainly depends on clinical manifestations and combined with neuroelectric-physiological examination [1]. ALS with typical systemic muscle weakness, muscular atrophy, muscle bundle fibrillation, and pyramidal bundle sign is easy to diagnose clinically, but it is extremely difficult to diagnose in the early stage of the disease due to the atypical and diverse symptoms [3].

The electromyography (EMG) examination of ALS is mainly based on two interrelated pathological processes that inevitably occur, namely the evaluation of denervation and reinnervation. The importance of quantitative EMG in the diagnosis of ALS cannot be replaced by other examinations [4]. Evidence of lower motor neuron damage can be found through examination, and it can be distinguished from cervical spondylosis, peripheral neuropathy, and other diseases with similar clinical manifestations [3]. EMG manifestations of lower motor neuron damage mainly include spontaneous potentials (acute denervation changes) such as positive sharp waves and fibrillation waves in the corresponding affected muscles, and/or increased time limit and amplitude of MUPs, abnormal recruitment phase of vigorous contraction, etc. (chronic denervation changes) [5].

In addition to the diagnostic significance of EMG examination for ALS, it is also helpful to identify specific susceptible motor neuron regions, because ALS often selectively invades certain motor neuron regions, and this seems to be closely related to the site of onset [4]. The E1 Escorial diagnostic standard divides the lower motor neurons into four different segments: medulla oblongata, cervical spinal cord, thoracic and lumbosacral. According to the number of the four segments involved, the diagnosis is divided into different levels, i.e., positive ALS, suspected ALS, possible ALS, and suspected ALS. The positive diagnosis of ALS requires evidence of neurogenic damage in at least three of the above four segments [1]. Clinical observation found that the affected range of ALS patients was different with different onset sites. Some scholars also reported that the abnormal EMG distribution in the lower motor neuron innervation area was different in ALS patients with different onset sites [5]. In addition to typical clinical symptoms, EMG is also of great value in the diagnosis of ALS. The purpose of EMG examination is to: confirm the lower motor neuron damage in the clinically affected area; Search for evidence of motor neuron damage in clinically unaffected areas. Other lesions causing neurogenic damage, such as peripheral neuropathy, were excluded [5].

3. EMG design details

Electromyography (EMG) is one of the most important detection methods of clinical neuron electrophysiology [5]. It is currently recognized as an extension of the localization diagnosis of nervous system diseases, and an objective detection method for the diagnosis and differential diagnosis of neuromuscular diseases and neuromuscular junction diseases. Histochemistry, biochemistry, genetic testing, and imaging can not replace it [6]. Electromyogram (EMG) is a science to judge the functional changes in the neuromuscular system by detecting and studying the bioelectrical activities of muscle. Generalized EMG also includes repetitive electrical stimulation and electromyography (nerve conduction velocity, H reflex, F wave, blink reflex, etc.), and the results of electromyography should be comprehensively analyzed in combination with other clinical data [7].

The commonly used EMG is to insert the same core needle electrode into the muscle to collect the electroactive action analysis of the nearby muscle fibers [6]. In addition, there are single fiber EMG, giant EMG, and scanning EMG [5]. The object of EMG examination is motor unit potential (MUP), which refers to the comprehensive electrical activity generated by the muscle fiber group innervated by a lower motor neuron. The number of muscle fibers innervated by the axon of each lower motor neuron is different, which can be expressed by the innervation value (IR) [7]. The normal limb is 1000, the facial muscle is 700, the sphincter is 50, and the extraocular muscle is 6-30. Therefore, A lower motor neuron, together with the muscle fibers it innervates, constitutes a functional unit, called the motor unit [6]. The size of the area occupied by each motor unit in EMG is different, and its diameter

is 5-7mm in the upper limb and 7-10mm in the lower limb. The muscle fibers of different motor units are staggered (one muscle fiber can be dominated by several motor units) [7]. Therefore, the electrical activities of 10-20 motor units can be elicited when EMG is performed with the same core needle electrode.

Electromyography consists of an amplifier with a monitor device, a neural stimulator, a power supply system, and an image display recording system [7]. The amplifier amplifies the weak EMG signal emitted from the guide electrode by millions of times without causing distortion to the oscilloscope; At the same time, enough electrical signals are sent to push the speaker to monitor [8]. The EMG amplifier needs the following: the voltage gain of the amplifier is high, and the adjustment range is wide. Not only the action potential of the motor unitbut also the nerve potential in the EMG signal [9]. Electromyography amplifiers are typically required as follows: The voltage gain of the amplifier is high, there is a wide adjustment range, and there is not only the action potential of the unit of motion but also the nerve potential in the EMG signal [7]. The amplitude of the action potential varies by about 60 dB in the range of tens of microvolts to a few millivolts. The nerve potential is relatively weak, reaching less than 1μV, so the amplifier's gain must be adapted to this situation.

The amplifier has a wide pass frequency band and a rich spectrum of EMG signals, with a low limit frequency of 2Hz and a high limit frequency of up to 10kHz.

Stimulator: Its role is to induce the body to produce electromyography.

Listening device: its role is to distinguish electromyography for hearing.

Image Display Recording System: Photographic recording of EMG graphics.

Power supply system: Provide a stable power supply for the whole machine.

Here the project only involved the design of the nerve stimulator part of the EMG. After consulting the data [5], the best scheme is to stimulate the nerve with the stimulation waveform shown in the following figure:

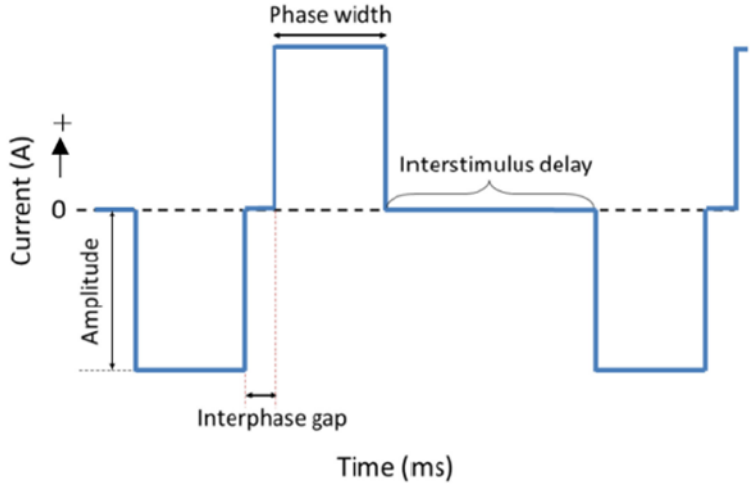

Figure 1. Ideal Oscillogram [6]

In Figure 1, the horizontal axis represents time, and the vertical axis represents stimulation current. The parameters of stimulation current are as follows: Current amplitude: 100 μA; Phase width: 200 μs; Interphase gap: 50 μs; Interstimulus delays:1 ms

By analyzing the stimulation waveform, the data shows that the bipolar current stimulation waveform can be considered as a combination of two unipolar pulse current waveforms [8]. The two unipolar pulse currents are both 100μA in size and have a period of:

$$T = P_{W1} + P_{W2} + T_G + T_D = 1450\mu s \quad (1)$$

The pulse current effective duration is 200μs, and the pulse duty cycle is $200\mu s/1450\mu s = 13.8\%$.At the end of the negative pulse, at intervals of 50 μs, positive pulses appear. It can also be understood as the time of the positive pulse hysteresis of the negative pulse:

$$T_D = P_{W1} + T_G = 250\mu s \quad (2)$$

Therefore, designers only need to use two current sources with opposite directions and control them on and off to meet the requirements of this neurostimulator.

Because the human nerves are relatively fragile, so the size of the stimulation current requirements are relatively high, cannot be too large, resulting in damage to human nerves, cannot be too small, too small if the effect of nerve stimulation may not be achieved, so it is necessary to design a constant current source circuit with a certain accuracy to achieve the current pulse [9], and the current source has a certain stability, is not easy to be affected by the external environment, in various environmental conditions can maintain accuracy, and can meet the requirements of generating dual-phase current [10].

In summary, the current mirror circuit is a useful choice for generating a current source [11], using a current mirror with a switching control circuit to complete the entire design, the circuit diagram is as follows in Figure 2.:

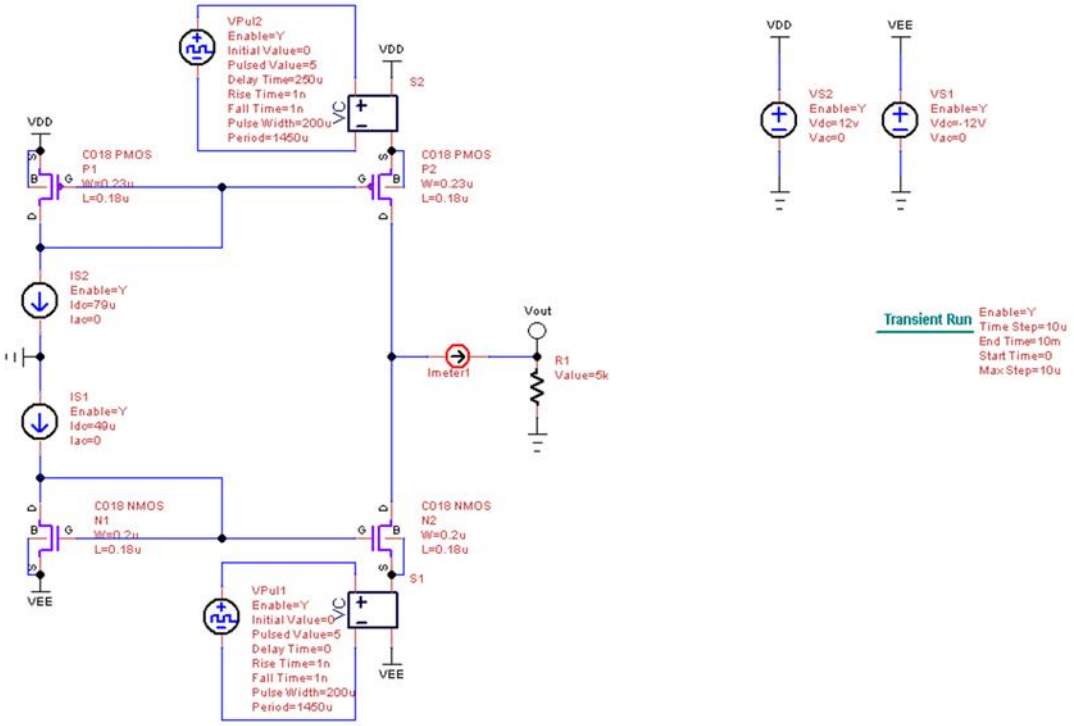

Figure 2. Design Circuit with Circuit Mirror Made By COOLSPICE

The circuit is symmetrically designed with R1 as a resistor that simulates a human nerve load. The current source IS1, N1, and N2 is a current mirror circuit composed of two NMOS for generating negative current, and the pulse signal source VPul1 controls the voltage control switch VC to generate the negative current pulse signal required by the stimulator. The current source IS2, P1, and P2 is a current mirror circuit composed of two PMOS to generate forward current, and the pulse signal source VPul2 controls the voltage control switch VC to generate the negative current pulse signal required by the stimulator. VPul2 is 250μs slower than VPul1.

4. EMG device Result and analysis

4.1. Simulation result and analysis

Based on the above-designed circuit, simulated using COOLSPICE software, the current waveform on the load can be observed as shown in Figure 3.:

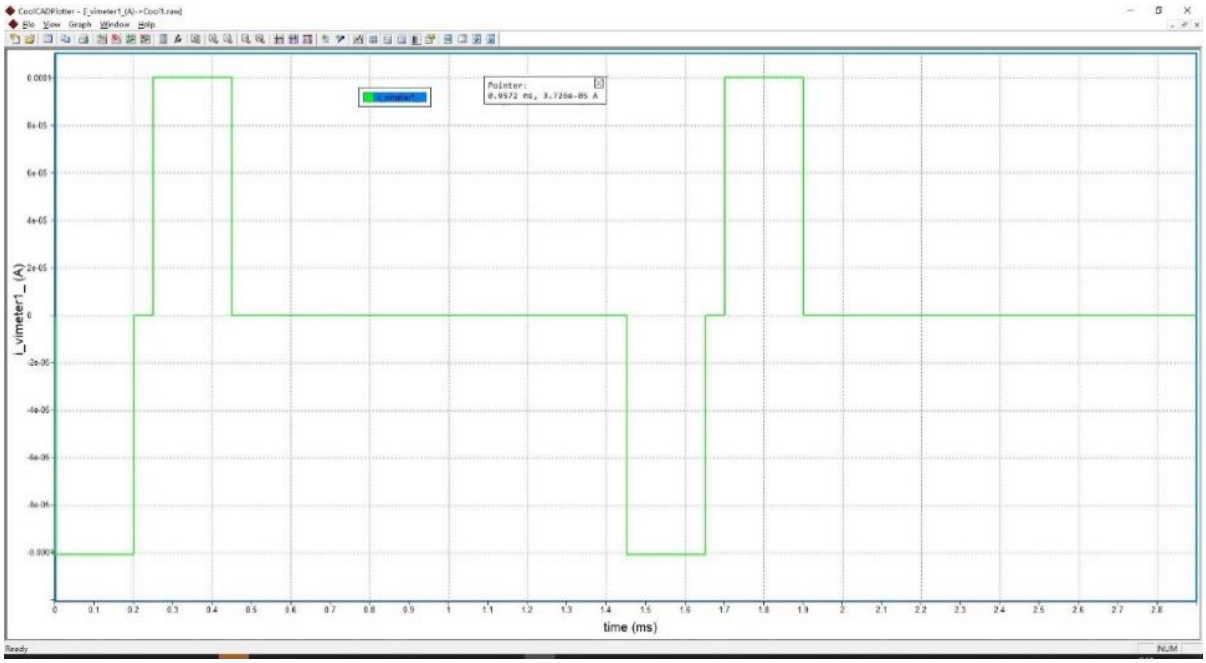

Figure 3. Emulation Oscillogram

It can be seen that the pulse current waveform fully meets the requirements of the topic, and the output current error is almost negligible.

4.2. Device characteristic and analysis

Since the actual device is not an ideal device, it is for a current mirror circuit:

$$I_o = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1} I_{REF}\left(1 + \frac{V_O - V_{GS}}{V_{A2}}\right) \quad (3)$$

When the output current is 100 μA, the selected reference current source is not 100 μA, and after calculation and adjustment here, the output current is approximately equal to about 100 μA when IS1 takes 49 μA and IS2 takes 79 μA.

5. Conclusion

After consulting the information, this paper has a certain introduction of the background of the project, and then analyze the target requirements of the specific circuit to be achieved and make a suitable program from the principle, and finally, through the rational application of the knowledge learned, the scheme is successfully concretized into a circuit, and the simulation software is built and run, and the simulation results successfully meet the requirements of the topic. The whole process has enabled the reader to have a concrete understanding of the application of the knowledge that have learned in practice, and have a deeper understanding of the design of the actual circuit. This paper provides constructive suggestions for the application of CMOS circuits in EMG design, and catalyze the progress of the medical semiconductor industry by making a front view for future large-scale applications.

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