DESIGN OF A PORTABLE ELECTROTACTILE STIMULATOR FOR SENSORY SUBSTITUTION APPLICATIONS

R. J. Onesti, W. J. Tompkins, J. G. Webster, J. J. Wertsch*

Department of Electrical and Computer Engineering, University of Wisconsin, Madison
WI 53706
*Rehabilitation Medicine Service, Veterans Administration Medical Center,, Milwaukee
WI 53295

ABSTRACT

Using commercially available components, we have designed, built and tested an electronic stimulator for use in sensory substitution applications. The device is housed in a 5 × 10 × 15-cm plastic housing, weighs less than 1 kg and is battery operated. The unit works with Interlink pressure sensors being used by our group to function as part of a feedback system for people with insensate feet. By use of a special cable, this device can also be used in conjunction with the portable data-acquisition system previously developed. Controls were also incorporated to allow the researcher to determine the effect of various parameters on the quality of stimulation. The device produces a biphasic pulse with a maximal current amplitude of 20 mA and can operate for approximately 3 h. Multiplexing of the 16 input and output channels minimizes component count as well as power consumption.

DESIGN REQUIREMENTS

The goal of this project was to produce a device which could be easily carried by a patient with insensate feet to provide sensory feedback through an alternative tactile pathway. From previous research, we determined that the most convient way of performing this feedback was through electrotactile stimulation via an electrode belt attached to the abdomen [1]. To be acceptable as part of a viable system, the device had to be light weight, portable and capable of several hours of continuous operation.

CIRCUIT DEVELOPMENT

Figure 1 shows the block diagram of the stimulator circuitry. The circuit consists of four specific sections; (1) sensor interface, (2) digital control, (3) output drive, and (4) power supply. The sensor interface section of this unit was designed to be used with Interlink pressure sensors. By modifying this portion of the circuitry, any type of sensor could be used as the input to this device.

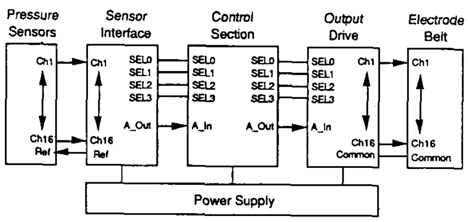

Fig. 1 Circuit Block Diagram

The Interlink sensor's no-load resistance is very large, typically ≤ 10 MΩ. Increasing the pressure decreases the resistance logarithmically. The sensor circuit in Fig. 2 provides improved linearity compared to the sensor connected to common. The noninverting op amp amplifies the output voltage prior to further signal processing by the following stages. A connector at the output of this section bypasses the sensor interface electronics and thus allows the unit to be used in conjunction with the data-acquisition system [2].

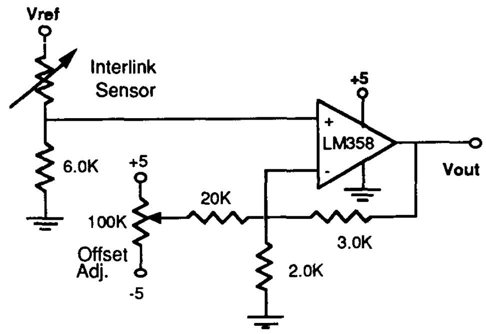

Fig. 2 Interlink Sensor Circuit

After amplification by the sensor interface electronics, the analog signal is then processed by the digital control section as shown in Fig. 3. An LM7555 is used as a free-running oscillator to provide the master clock for the system. Potentiometer (R4) controls the repetition rate. The output from the oscillator is then fed into a 4-bit counter operating in continous mode. The output from the counter provides the addressing controls for the input and output channel multiplexing. By adding some additional circuitry, the counter can be set to any value thus providing an easy means of debugging the multiplexing circuitry.

The least significant bit of the counter is also used to trigger a one-shot multivibrator (U3A). Potentiometer R14 controls the interpulse delay created by the one-shot over a range of 5 to 20 μs. The output from U3A triggers another one-shot (U3B). Potentiometer R15 controls the pulse width over a range of 50 to 230 μs. The positive pulse generated by U3B causes U3A to be retriggered on the falling edge of the pulse. A flip-flop (U4A) inhibits this retriggering after every other pulse and it also determines which analog signal to gate through to the output drive section. A series of NAND gates (U5) generate the actual gating control signals.

CH2770-6/89/0000-1439 $01.00 C 1989 IEEE

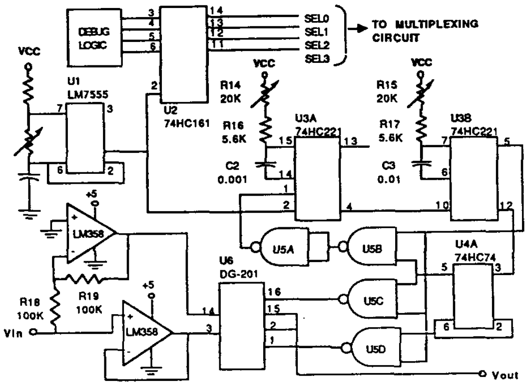

Fig. 3 Digital Control Circuit

The input analog signal from the previous section is fed into an inverting op amp configuration to provide both a positive and negative control signal. An analog switch (U6) controls the gating of the analog signal. Potentiometer R7 provides a gain control and also functions as a pull-down resistor when the analog switches are open.

The biphasic analog pulse generated by the control section then feeds into a high-voltage op amp connected in a current source configuration as shown in Fig. 4. This op amp (APEX model PA88) is capable of differential power supply potentials of ±225 V thus providing the compliance needed to drive the high skin impedances encountered. The output from the op amp is then switched to one of the 16 possible output channels via high-voltage transistors. Because the gate of the output transistor needed to float with the output, the control signal from the 16-channel demultiplexer was coupled to the output transistors via a pulse transformer (PICO model 5878). High voltage diodes were used to control the direction of current flow.

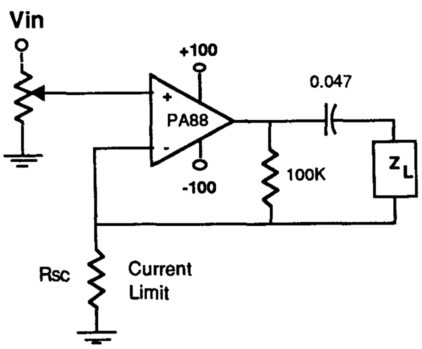

Fig. 4 Current Source Configuration

We used rechargable batteries for portability. The power supply consists of 12 NiCad AA batteries connected in series. The ground connection was located in the center of this series to provide both a positive and negative supply without the need for an inefficient inverter. These supplies were then regulated to ±5 V to provide the power to the other circuits. High-voltage dc-to-dc converters (PICO model 5A100S) provide the high-voltage rails required by the output drive section.

ASSEMBLY

The device is constructed on three separate circuit boards which are sandwiched together before this assembly is placed into the plastic housing. The battery pack was designed to be the most accessible due to the need to change the batteries. The center board contains the sensor interface and output drive circuitry. The digital control circuit was isolated from the analog section by placing it on the top board and communicating between the two boards via ribbon cables. The output gain control is attached to the housing via a hole at the end of the box.

APPLICATIONS

Loss of sensation can cause many problems. Because of diabetic polyneuropathy [2], a patient may lose sensation in the feet and thus receive inadequate information about pressure under the foot during walking or standing. Moreover, the blind diabetic frequently has disturbed gait due to insufficient sensory feedback from the feet. By using the portable electrotactile stimulator, a patient could regain a substituted sensation which may help that person overcome the problems caused by the lost senses.

Another possible application would be with telerobotics which are used extensively in high-risk situations such as radiactive and/or space environments. In order for a human to work in such an environment, the person must be shielded by protective clothing or equipment. The major drawback to such protective devices is that in protecting the person, they also interfere with the sensory feedback on which the person depends greatly to perform tasks. By applying sensors to the end effectors of the remotely controlled robots and using this information to provide stimulation to the operator, this major drawback could be minimized.

DISCUSSION

This is only one possible design for a portable electrotactile stimulator. See for example a description of the Tacticon circuit [3]. A major drawback in our design is the rather limited duration of operation. There are two possible solutions to this problem. By replacing the high-voltage op amp in the output drive section by a low power current source an improvement in power consumption could be made at the cost of increased component count. The duration could also be extended by using higher capacity batteries, such as lead-acid, specially manufactured for this type of operation.

ACKNOWLEDGMENT

This investigation was supported by Contract Number V695-P2906 from the Rehabilitation Medicine Service, Veterans Administration Medical Center, Milwaukee, WI.

REFERENCES

[1] J. J. Wertsch, P. Bach-y-Rita, M. B. Price, J. Harris, and J. Loftsgaarden, "Development of a sensory substitution system for the insensate foot, *J.Rehab. Res. Dev.*, Vol. 25, no.1, pp. 269–270, 1988.

[2] H. Zhu, N. Maalej, J. G. Webster, W. J. Tompkins, J. J. Wertsch, and P. Bach-y-Rita, "A microprocessor-based data-acquisition system for monitoring foot pressures," *Proc. Annu. Conf. IEEE Eng. Med. Biol. Soc.*, Vol. 10, pp. 1599–1600, 1988.

[3] H. Zhu, "Electrotactile stimulation," in J. G. Webster (ed.), Tactile sensors for robotics and medicine, Wiley, New York, 1988.