ARNOLD L. NEWMAN

SELF-INJURIOUS BEHAVIOR INHIBITING SYSTEM

APL has designed and developed a system that efficiently and consistently inhibits self-injurious behavior (head-banging) in severely retarded and autistic patients through the extensive use of microelectronics.

BACKGROUND

Self-injurious behavior is a hidden problem. Most people have never heard of it, and yet approximately 14% of mentally handicapped, institutionalized patients compulsively engage in this behavior, which is characterized by physical abuse and mutilation. As many as 61% of these people are head-bangers.[1] Starting in the crib, a child may eventually beat himself severely enough to threaten blindness, brain hemorrhage, and even death. Self-injurious behavior is a horrifying, life-threatening problem of psychopathology with no known cure. To address the problem, APL is developing a self-injurious behavior inhibiting system.

There is a great need for successful self-injurious-behavior therapy. Currently, patient care is very expensive, labor intensive, and time consuming. It is also emotionally demanding. Physical restraints for immobilizing hands, arms, or legs and protective shielding and padding are often used. These protect the patient but neither eliminates the behavior or permits rudimentary education and social interaction.

BEHAVIORAL CONDITIONING

Behavioral conditioning is a form of therapy that has been used with some success in the treatment of self-injurious behavior. In this paradigm, an aversive stimulus is delivered to the patient in close temporal association with the undesired behavior, and the patient responds by decreasing the frequency of the behavior. Ideally, the inhibiting stimulus should be delivered automatically and consistently.

Initial application of behavioral conditioning to this problem employed a therapist to close the loop in a simple biofeedback system by administering a stimulus at the onset of the behavior. Aversive stimuli that were tested included loud noises, hair pulling, slapping, noxious odors, and aromatic ammonia, but none has been as effective as electric shock.

Lovaas and Simmons, two investigators in this field, have concluded: "First, the use of shock, given contingent upon self-destructive behavior, brings about an immediate cessation of that behavior. Second, the effect of shock appears specific to the situations in which it is administered."[2] Investigators have found a very quick cessation of self-injurious behavior when the child was shocked with a hand-held "shock stick" by his therapist or attendant. The shock used as an aversive stimulus is described by Carr as an "electric shock of sufficient strength to give an unpleasant, though very brief, sensation, but not to cause injury."[3] However, the behavior returned when the attendant who had delivered the stimulus left the room or when the child left the room. Suppression was effective only in the therapy room, not elsewhere.

It is thus clear that therapist-administered shock is not the optimal therapy. In this situation, the shock becomes psychologically paired with the therapist and the environment. Furthermore, there are variable delays between head-banging and shock; the inhibiting stimulus cannot reliably be delivered automatically and consistently.

A further advance in behavioral-conditioning therapy of self-injurious behavior was made when the American Foundation for Autistic Children developed a device that sensed abnormal accelerations of the head and delivered a shock to the arm. Such a device obviates the need for the therapist to observe the behavior and eliminates human delay in delivery of the aversive stimulus. This ensures that the stimulus will be automatically paired to a specific behavior (head-banging) and also will be delivered consistently.

The device consists of a helmet connected by wires to an arm electrode. The helmet contains an accelerometer and also serves to protect the head. The accelerometer switches a power circuit on the patient's back, which is connected by wires to the electrode assembly on the arm.

Several of these devices were built and have been found to inhibit self-injurious behavior successfully. In fact, patients feel so safe and secure with the device that they struggle to keep it when it is removed. With these successes, the Foundation, advised by

NASA, approached APL with the idea of further developing, through the application of state-of-the-art technology, a Self-Injurious Behavior Inhibiting System (SIBIS).

SIBIS DESIGN

The basic configuration of SIBIS is shown in Fig. 1. When the sensor module, contained in a headband, detects abnormal accelerations (2 g or more) due to head-banging, it transmits a digitally coded signal to the stimulus module on the arm. On receiving this signal, the stimulus module checks the signal code with a stored identification (ID) code and delivers a shock and sounds a buzzer if the codes match. The sensor module electronically counts each transmission, and the stimulus module counts each shock. An equal number of counts in each module, as shown on the display unit, verifies proper system function.

The design goals for SIBIS were as follows:

- Miniaturize
- Develop a wireless communications link
- Provide for data recording and display
- Keep the device inexpensive

We have accomplished these goals through extensive use of microelectronics. At the heart of SIBIS is a custom-designed, large-scale integrated circuit called a gate array that contains the bulk of the communications and control circuitry (see Fig. 2). Instead of designing two integrated circuits, one for the sensor module and one for the stimulus module, we designed only one that contains all the circuitry for both sensor and stimulus functions. The chip's identity is 1 bit programmable; i.e., the logic state of input SEN/STIM determines whether the chip has a sensor function or stimulus function (see Fig. 2). This approach not only minimizes development costs but also simplifies the whole manufacturing process.

The gate array and other components (amplifiers, resistors, etc.) are secured with epoxy and soldered into hybrids that are microminiature, multilayer printed circuit boards. They consist of several layers of ceramic

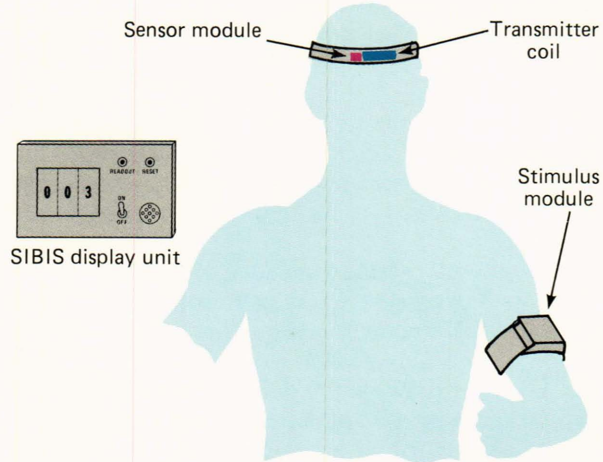

Figure 1—Sensor module senses abnormal accelerations of the head and transmits a coded signal to the stimulus module, eliciting a shock to the arm.

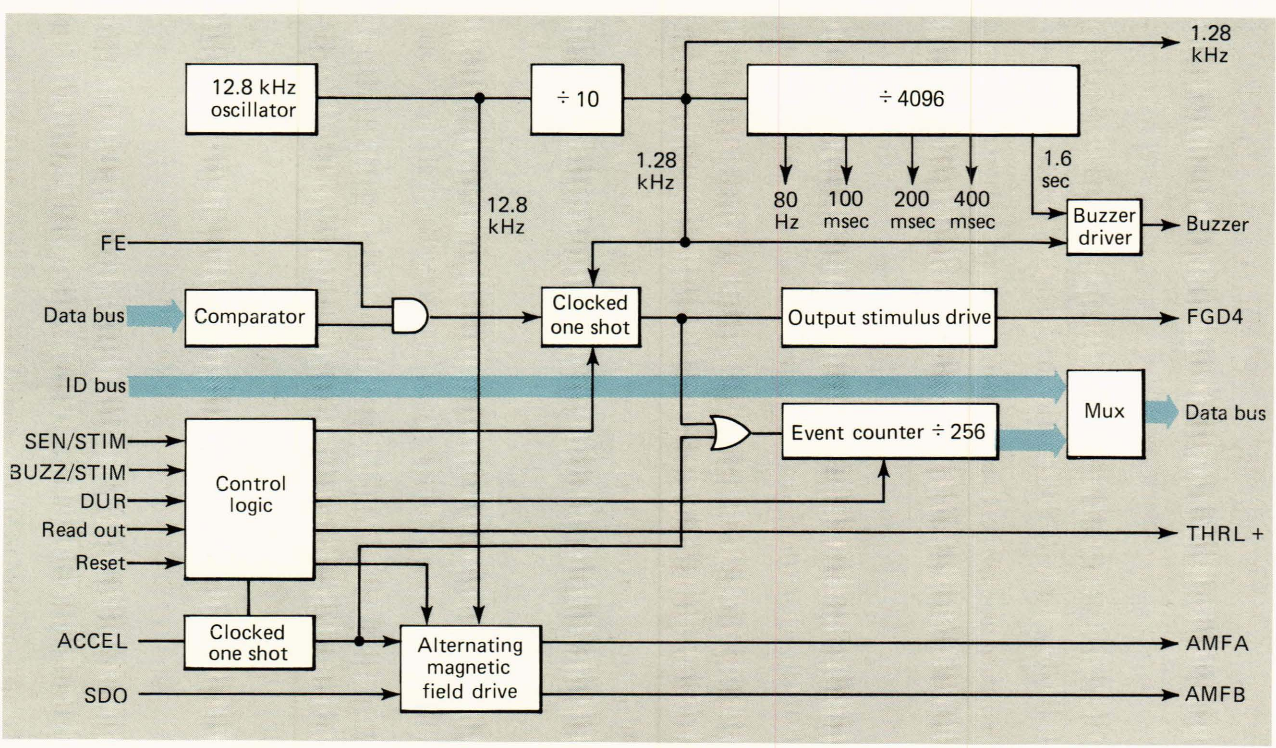

Figure 2—Simplified block diagram of the SIBIS gate array input SEN/STIM programs. This integrated circuit performs a sensor or a stimulus function.

substrate (aluminum oxide) with three layers of conducting traces that are analogous to wires. High reliability is ensured by using gold for the conducting traces because it does not tarnish. Two hybrids were designed, one for the sensor module and one for the stimulus module. Each module contains the gate array as well as the discrete components (resistors, capacitors, etc.) and circuitry for supporting it and defining its function.

A low-power, crystal-controlled 12.8 kilohertz oscillator and an associated frequency divider produce different clock frequencies required by various parts of the system. This oscillator, designed at APL by A. F. Hogrefe, draws approximately 10 microamperes when powered by a 9 volt battery. It is comprised of a Pierce oscillator and a buffer stage biased for extremely low power (see Fig. 3). The transistors are located on the gate array, and the 12.8 kilohertz crystal, resistors, and capacitors are contained in the hybrid. Each P and N channel metal oxide semiconductor field effect transistor (MOSFET) pair is complementary; that is, they are critically matched to ensure a symmetric switching characteristic. An important feature of this circuit is the split gate configuration of the buffer amplifier transistors that allows for the low-power biasing.

SENSOR MODULE

An accelerometer switch, located on the headband, detects the patient's head-banging (see Fig. 4). Comprised of a cylinder with a terminal on each end, it is designed to be sensitive to radial accelerations. The accelerometer switch is closed when an acceleration causes the steel ball to roll up the slope of contact cone 1, completing the circuit to contact cone 2. The switch can be set to close at a desired acceleration by adjusting the position of the magnet. Experiments indicate that normal behavior, including vigorous exercise (tennis), does not yield head accelerations greater than 2 g, while injurious head-banging exceeds this threshold.

The accelerometer switch clocks a digital one-shot on the gate array (input signal ACCEL, Fig. 2). This enables a transmission gate and the alternating magnetic field drive circuit on the chip that, concurrently, is digitally coded by the modulating signal SDO. The

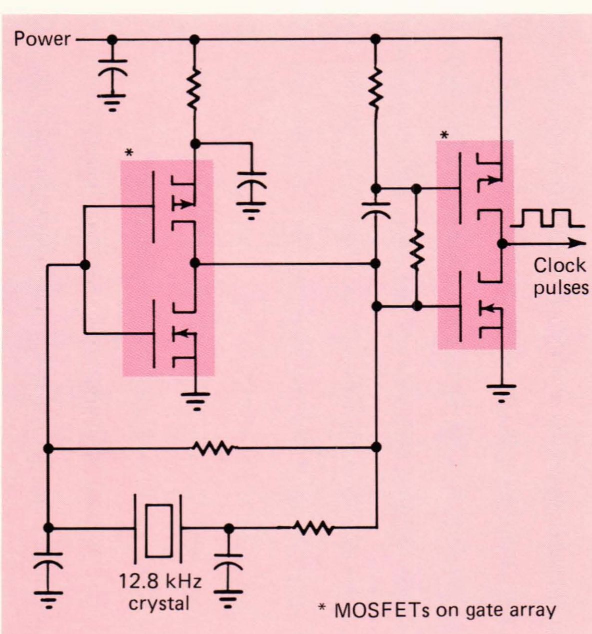

Figure 3—Pierce oscillator circuit biased for very-low-power operation. The transistors are located on the gate array.

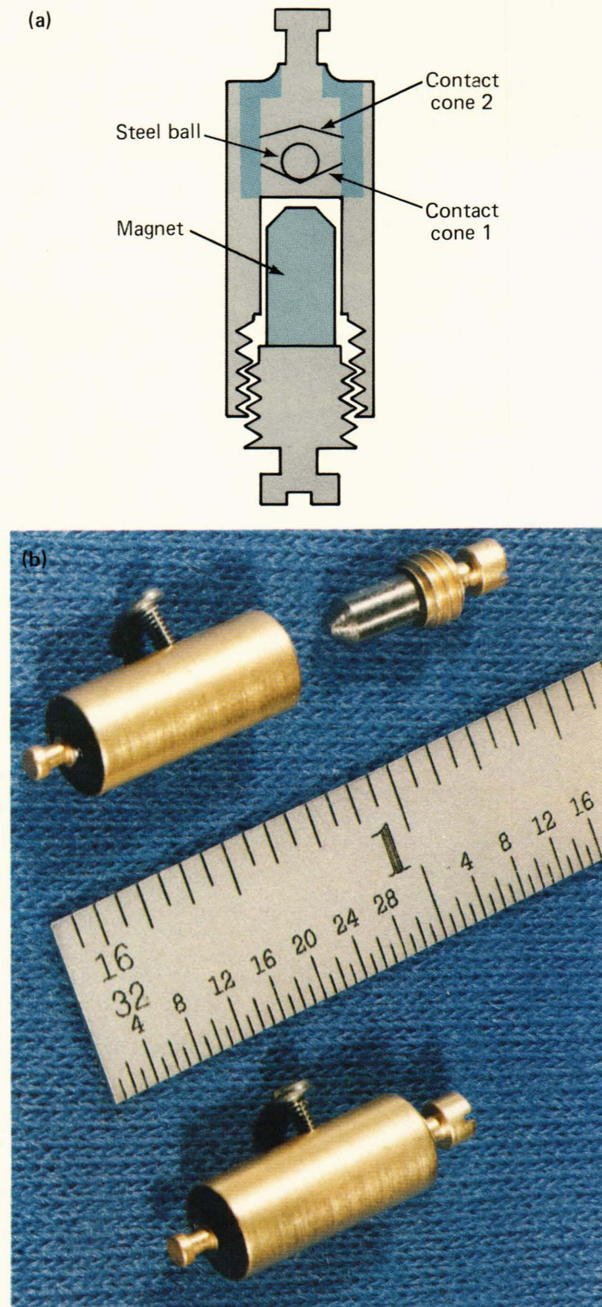

Figure 4—(a) Internal configuration of the SIBIS accelerometer switch. The permanent magnet's position determines the acceleration threshold at which the steel ball contacts the two cones. (b) Photograph of the accelerometer switch showing external dimensions and calibration magnet.

structure of a possible transmission is shown in Fig. 5. The different parts of the original device are connected by wires, an approach that is unwieldy and unreliable. In SIBIS, the coded, alternating magnetic field serves as the communications link, and connecting wires are avoided. The code, different for each patient, prevents a patient from receiving inappropriate shocks because of another patient's behavior. It also helps keep SIBIS immune to electromagnetic interference, both natural and man-made.

The coding of the sensor module's transmitted signal and the decoding of the stimulus module's received signal are performed by a universal asynchronous receiver transmitter. This is a large-scale integrated circuit, contained in each hybrid, that is used to transmit and/or receive asynchronous data, parallel or serial, and convert it to serial or parallel form, respectively.

The circuit for producing the alternating magnetic field is shown in Fig. 6. It is a full bridge circuit of complementary MOSFET pairs that, driven by a modulated 12.8 kilohertz square wave signal, switches current one way and then the other through a parallel resonant circuit. MOSFETs are very efficient in this application because they have an extremely low "on resistance" (0.6 ohm), and they are driven directly from the logic circuitry of the gate array. A third harmonic filter is placed in series with the transmitter coil to remove higher frequency components from the driving square wave. This produces a sine wave across the transmitter coil.

STIMULUS MODULE

The signal sent by the sensor module on the head is received by the stimulus module on the arm with a pair of orthogonal coils. Therefore, the link between both modules is essentially a loosely coupled transformer. The orthogonality of the receiver coils allows

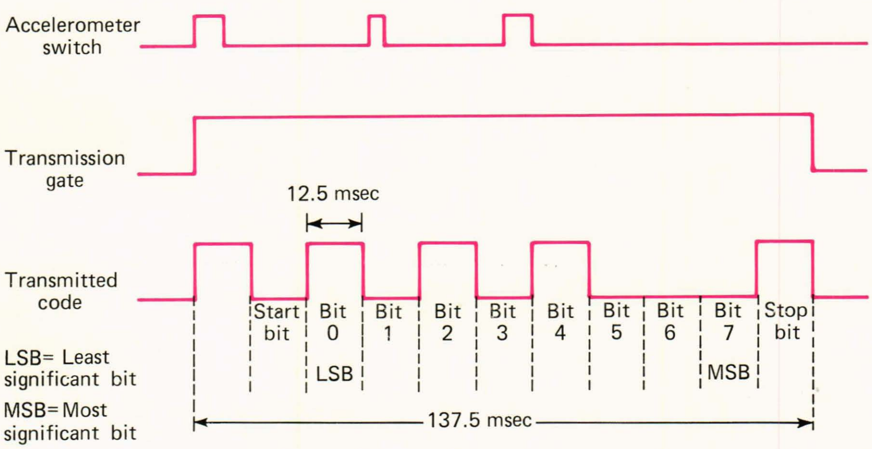

Figure 5—Example of a SIBIS transmission signal code. The alternating magnetic field produced by the sensor module is modulated with the code.

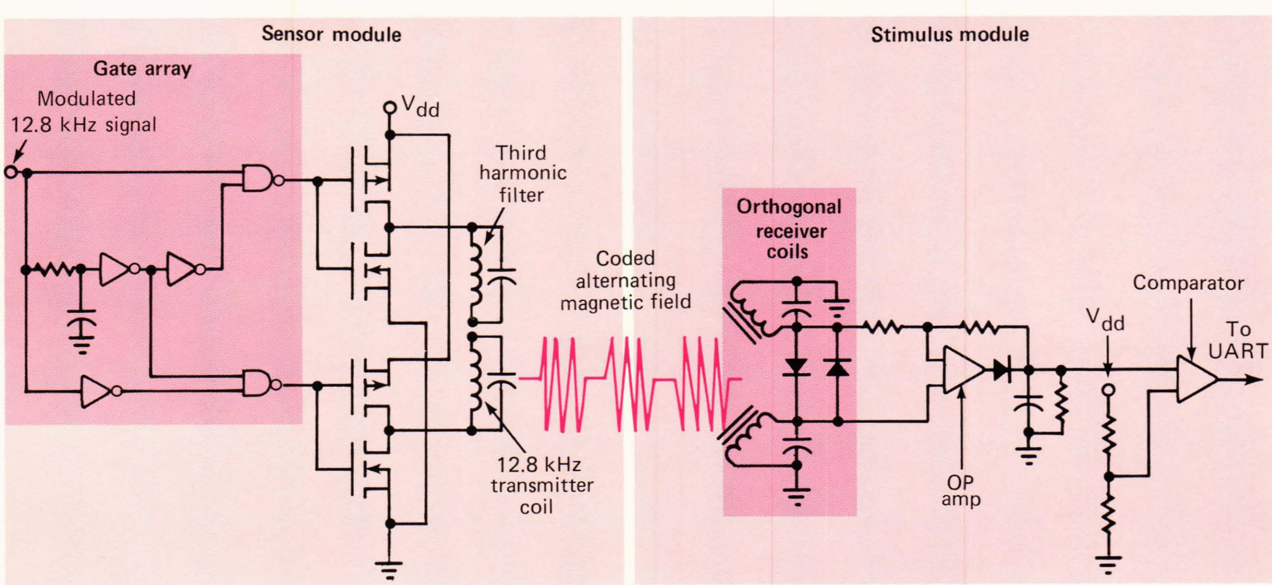

Figure 6—The alternating magnetic field is produced by two pairs of complementary MOSFETs that switch current through the 12.8 kilohertz coil. A sine wave is produced by the third harmonic filter, which removes higher frequency components from the signal. The alternating magnetic field is received by the tuned orthogonal coils. The signal code is then detected and conditioned for verification.

a wide range of effective angles between the two modules because the received signal is the detected voltage difference between the coils. This voltage is amplified and detected, and the extracted code is checked by a digital comparator on the gate array. If there is a match with the code stored on the ID bus (see Fig. 2), a one-shot is clocked. This enables the output stimulus drive to drive, via signal FGD4, the shock-producing circuitry.

From a series of experiments we found that the subjective intensity of pain from shock is a function of shock duration. We allowed a choice of only two shock durations, 100 and 200 milliseconds (msec), each shock accompanied by a buzzer sound. The buzzer can be programmed, with signal BUZZ/STIM, to occur without a shock. A goal of SIBIS is to produce a psychological pairing of the shock with the tone so that the tone itself becomes aversive. The circuitry providing this limited choice (100 msec, 200 msec, or no shock) is "locked" on the silicon of the gate array in order to prevent abuse of SIBIS. Shock duration is programmed through input DUR. This device cannot produce a more painful shock than the one lasting 200 msec.

Human skin has a dynamic impedance. Measured between the button and the concentric ring electrode of the stimulus module (see Fig. 7), the impedance can initially be as high as 20 to 30 megohms for dry skin. Upon the fast application of a high voltage, that is, a large dV/dt, the skin impedance breaks down to a conducting value of 20,000 to 30,000 ohms. For the stimulus circuitry, it was necessary to adopt a design that was efficient and miniature, yet provided the requisite high-energy output to elicit a painful shock. A flyback transformer approach was chosen with the circuit shown in Fig. 8. A cross-coupled gate oscillator drives the gate of a MOSFET in the flyback transformer (T) primary circuit. The power for this system is derived from a 9 volt alkaline battery. However, by driving the MOSFET at 80 kilohertz, the capacitor in the transformer's secondary circuit is charged up to very high open-circuit voltages (1000 volts). This circuit maintains 150 volts across a 20,000 ohm load. The cross-coupled gate oscillator is switched by an 80 hertz square wave for 100 or 200 msec, yielding a train of 8 or 16 stimulus pulses delivered at 80 hertz. This stimulus delivery frequency is matched to the inherent frequency response of cutaneous pain receptors that is limited by the nerve cell refractory periods. The electrode design limits the propagation of current to the local area of skin contact.

There is an event-counter register in the gate array that records the number of injurious-behavior events

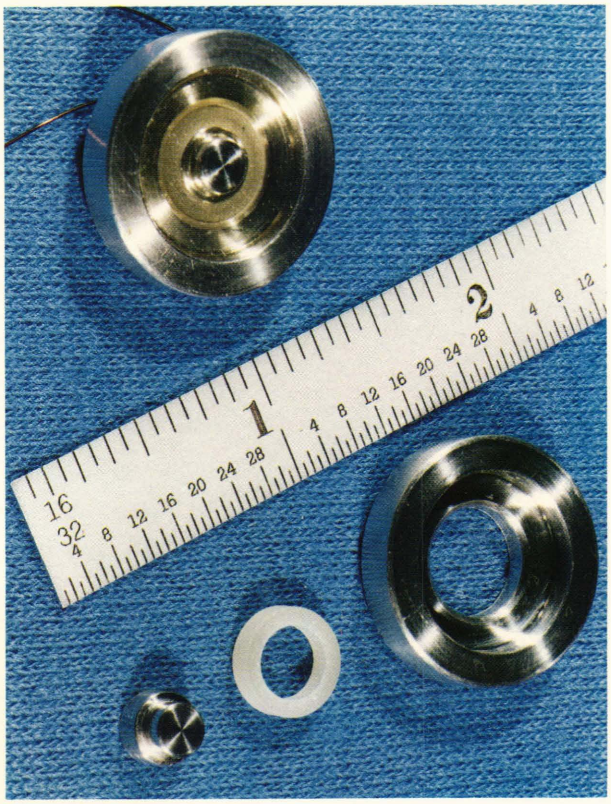

Figure 7—The SIBIS stimulus electrode consists of an inner button electrode, an insulator, and a ring electrode. This design limits current propagation to a small area of the skin.

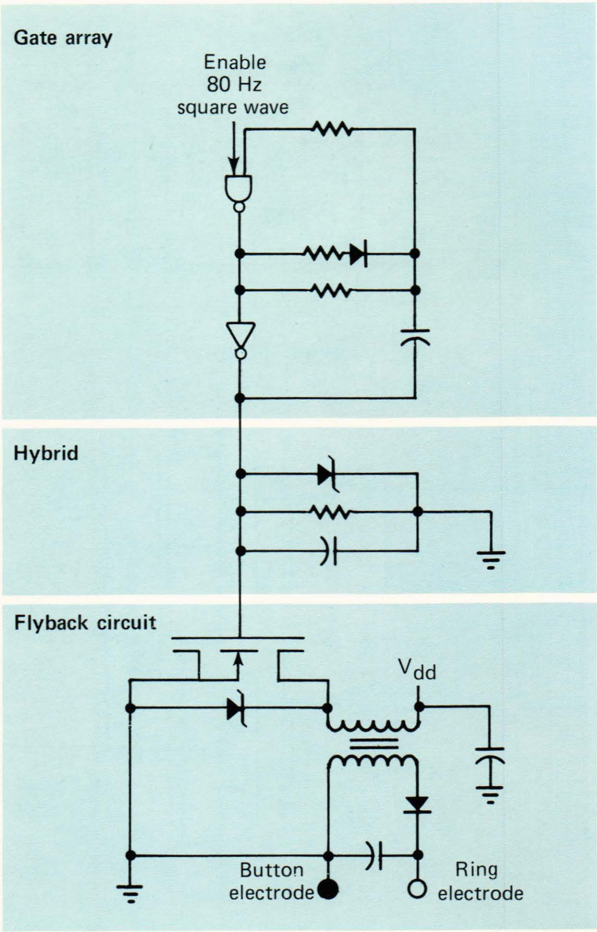

Figure 8—The output shock circuit of the stimulus module consists of a flyback power converter driven by an astable oscillator located on the gate array.

that have occurred. Data from this register are read out on a display unit that is then reset to zero (see Fig. 1). This data logging provision is important for the clinical evaluation of SIBIS as well as for the ongoing monitoring of a patient's progress.

SIBIS is an extracorporeal device designed to inhibit self-injurious behavior. It will provide an efficient, sophisticated therapy that will help patients directly by allowing them to suppress injurious behavior and to engage in learning and social activities. SIBIS will offer better therapy for thousands of patients who have an economically and emotionally costly affliction.

REFERENCES

[1] T. R. Linscheid, "Estimate of the Prevalence of the Self-Injurious Behavior Headbanging in the U.S. Population" (unpublished) (1983).

[2] O. I. Lovaas and J. O. Simmons, "Manipulation of Self-Destruction in Three Retarded Children," *J. Appl. Behav. Anal.* **2**, 143-157 (1969).

[3] J. Carr, "The Severely Retarded Autistic Child," in *Early Childhood Autism* (2nd ed.), Pergamon Press, pp. 253-258 (1976).

ACKNOWLEDGMENTS — The author would like to acknowledge funding and support for SIBIS from the following organizations: American Foundation for Autistic Children, APL Development Fund, C. R. Bard Corp., Oxford Medilog, Inc., and the Public Welfare Foundation. The important contributions of R. E. Fischell, K. Fowler, W. R. Powell, J. P. Reilly, and H. B. Riblet are also acknowledged.