# A CUSTOM-DESIGNED CHIP TO CONTROL AN IMPLANTABLE STIMULATOR AND TELEMETRY SYSTEM FOR CONTROL OF PARALYZED MUSCLES

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## SUMMARY

A custom-designed chip has been developed for the control of paralyzed muscles. The system is capable of fulfilling the stimulus and telemetry needs of advanced FNS applications requiring multiple channels of stimulation and multiple channels for sensor or biopotential sensing. An inductive RF link provides power to the implant device as well as a two-way transcutaneous communication. An application specific integrated circuit (ASIC) decodes the commands and provides functional control within the implant, and modular circuitry provides specific implant functions. The ASIC chip provides up to 32 independent channels of stimulation, with independent control of stimulus pulse duration, pulse amplitude, inter-phase delay, recharge phase duration, and pulse interval. It can also control up to 8 independent back-telemetry analog channels, with independent control of sampling rate and pulse powering parameters (amplitude and duration). The mixed analog digital chip has been fabricated in a 1.2 µm N-well CMOS technology.

## STATE OF THE ART

Over the past twenty years, clinical researchers have been intensively using functional neuromuscular stimulation (FNS) for control of paralyzed muscles. The experience demonstrate the feasibility and the success of the intervention in individuals with spinal cord injury, and other central nervous system injuries. FNS systems can be accepted by the user when the basic motor function can be restored, and the maintenance is minimized. Such requirements necessitate an implantable system. The first generation of the implant at Case Western Reserve University used eight channels of stimulation /1/. The implant was under supervision of an external control unit and was operated by an external joint angle position /2/. This system provides hand grasp for individuals with C5 and C6 level spinal cord injury.

## MATERIAL AND METHODS

Advanced FNS application requires an increased number of stimulation channels, and multiple sensory and bio-potentials channels. The implant should provide back telemetry capabilities to control the device or to diagnose the system status.

Extend capabilities of the system require a complex digital/analog circuitry. An application specific integrated circuit (ASIC) can provide minimal size and reasonable power consumption needed for an implantable stimulator-telemeter.

## RESULTS

An application specific integrated circuit (ASIC) has been developed to control implantable stimulator-telemeters. This mixed analog-digital ASIC combines all command decoding, control and current regulators that are used by the stimulus output stages and the transducer powering circuitry.

The design constraints of the ASIC include physical size, circuitry complexity, number of I/O pads, and cost. These factors have led to implementing the command-control system in direct and expanded mode. Direct mode requires no additional circuitry. Expand mode need an external address decoding. **Figure 1** shows a simplified block diagram of the chip.

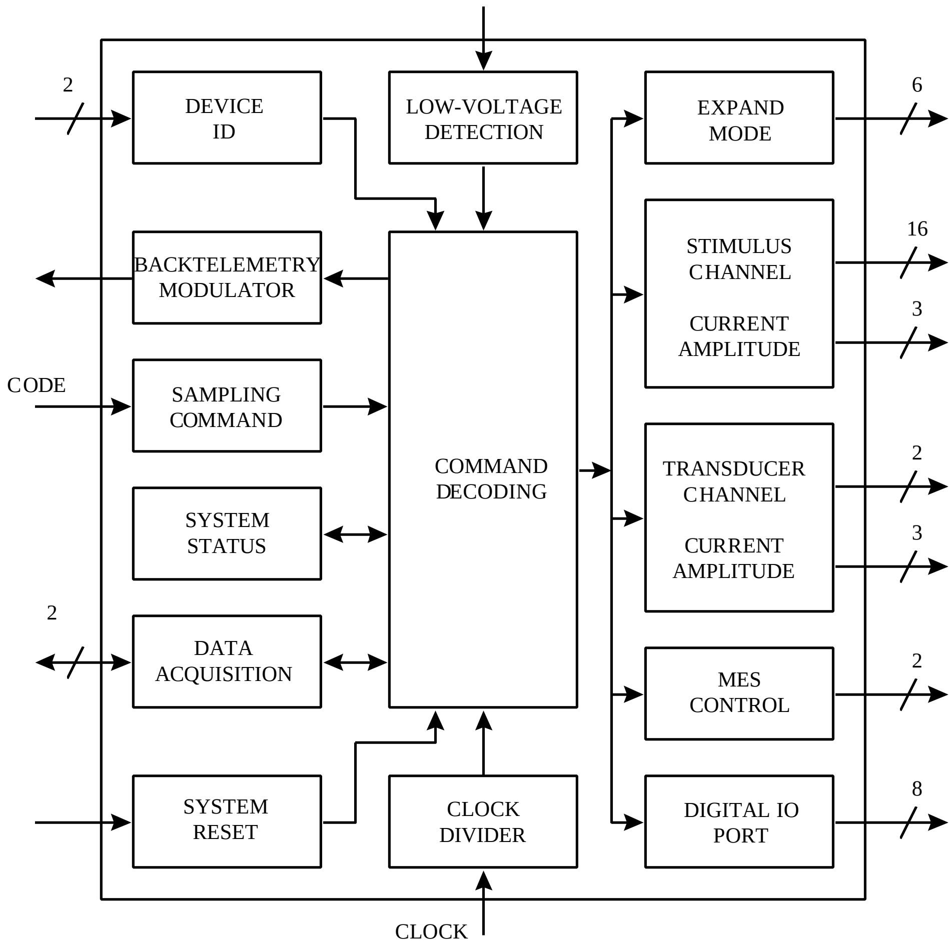


**Figure 1.** Simplified block diagram of the chip

In the direct mode, the ASIC can control sixteen channels of stimulation with independent control of stimulus pulse interval, pulse duration, pulse amplitude, inter-phase delay, and recharge phase duration, two myoelectric signal (MES) processing channels and two transducers.

In the expanded mode, the chip provides up to 32 independent channels of stimulation. Up to eight independent telemetry channels for acquiring data from the implant device itself, such as error conditions and power supply status are provided.

Up to four uniquely addressable devices can be used under coordinated control of a single external controller (Device ID).

The ASIC control two forms of MES signal: processed MES and unprocessed MES. There are up to eight independent telemetry channels for processed MES. Each channel has control of sampling rate, processing control such as gain, filtering, integration duration, and stimulus artifact blanking. Stimulus artifact blanking is active across all implant devices being controlled. In this way, acquisition of MES data can be coordinated with stimulus output from other device present.

The ASIC has a 14-bit command structure **(Figure 2a)**. The command includes one start bit, device identification field ID1-0, interface parameters field C7-0, parity bit, and stop bit. Received asynchronous commands are decoded and functions are executed using a 1 MHz master system clock. The control command is decoded by using two time windows generated by the ASIC logic**(Figure 2b)**. The binary pulse burst is decoded within the coding window and enables the appropriate system functions and addressing. The duration window decodes the duration pulses and outputs these pulse duration and timing signals to the enabled channels and control logic in proper sequence. **Figure 2** shows a command structure of the chip.

During the command decoding, any errors encountered are latched into the system status register, and can be read (telemeter) by the external control system with a subsequent system command. A supply voltage is monitored by the ASIC through external voltage limiting circuitry.

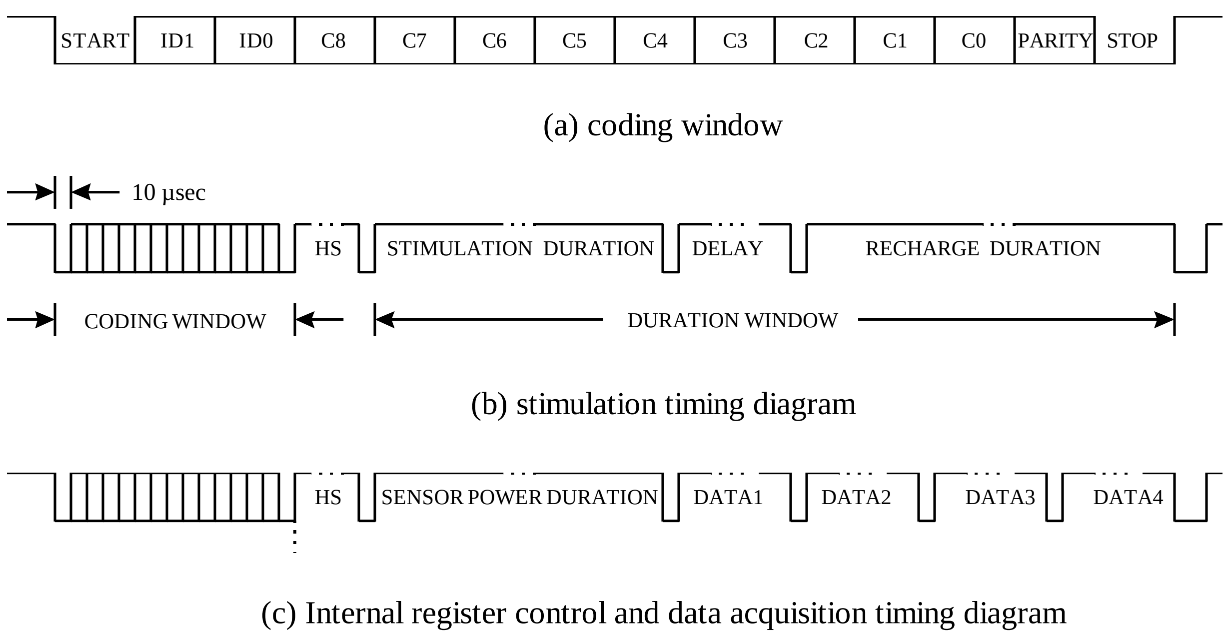


**Figure 2.** command structure

The choice of ASIC technology was based on the trade-off among electrical characteristics, power consumption, standard circuit element availability, development time, and production cost. The standard-cell technology CMOS 1.2 µm n-well was chosen. Integrated circuit layout software was used to design, simulate, and layout the ASIC.

Additional specialized gates, cells, input protection were custom designed and added to the library. The analog part of the circuit is full custom. This part contains the current regulators used to regulate the stimulus pulse current and the remote transducer current pulse. The current regulation is accomplished by using cascade type current mirrors. A low level reference current is set up on first side and this is mirrored into multiple devices wired in parallel. A total of eight mirrors are implemented for stimulus pulse and transducer power pulse. The level of each current regulator is fixed by a single external resistor. The analog and digital part of the circuit were simulated based on the semiconductor foundry electrical specifications. **Figure 3** shows a photograph of the chip.

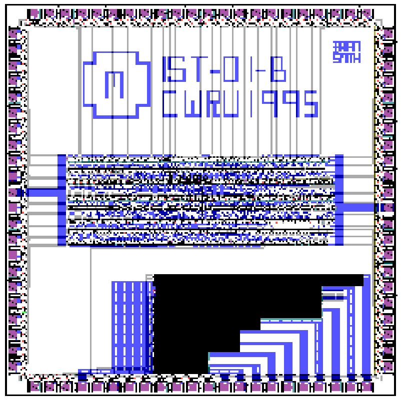


**Figure 3.** photograph of the chip, CMOS 1.2 um, 4.5 mm x 4.5 mm

## DISCUSSION

The ASIC is a modular system which can generate a wide range of functions. By selecting those functional blocks specified by a clinical application, an implantable device can be design having only the capabilities needed for a particular group of patient. This minimizes physical size, power consumption, fabrication effort, and cost for the development of the implant. The ASIC has been successfully developed, fabricated, and tested for an implantable stimulator and telemetry system.

## REFERENCES

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