Low-Power Polling Mode of the Next-Generation IMES2 Implantable Wireless EMG Sensor

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***Abstract*—The IMES1 Implantable MyoElectric Sensor device is currently in human clinical trials led by the Alfred Mann Foundation. The IMES is implanted in a residual limb and is powered wirelessly using a magnetic field. EMG signals resulting from the amputee's voluntary movement are amplified and transmitted wirelessly by the IMES to an external controller which controls movement of an external motorized prosthesis. Development of the IMES technology is on-going, producing the next-generation IMES2. Among various improvements, a new feature of the IMES2 is a low-power polling mode. In this low-power mode, the IMES2 power consumption can be dramatically reduced when the limb is inactive through the use of a polled sampling. With the onset of EMG activity, the IMES2 system can switch to the normal higher sample rate to allow the acquisition of high-fidelity EMG data for prosthesis control.**

I. INTRODUCTION

An IMES system (Fig.1) consists of multiple IMES devices implanted in the musculature of the residual limb. The IMES devices are linked to a Prosthesis Controller through a Telemetry Controller (TC). The IMES devices are powered using a 121kHz magnetic field, that supports forward telemetry commands used to control the acquisition and flow of EMG data. Each IMES reports sampled EMG data in a TDM fashion via an outward high-frequency telemetry link. The received EMG data are interpreted by the TC and processed by a motor controller which drives motors in the prosthesis according to the EMG commands in the user's residual limb. The system architecture will support up to 32 active IMES per limb. The IMES device (Fig.2) consists of a silicon ASIC chip, a ceramic substrate, a power supply filter capacitor, a magnetic core, and a two coil windings (one for 121kHz power and one for the RF reverse telemetry transmission). The assembly is placed in a ceramic tube with hermetically sealed metal endcaps which act as the EMG electrodes.

II. IMES HISTORY

The silicon chip for the first Implantable IMES MyoElectric Sensor was developed by under NIH funding, to Northwestern University, by the Illinois Institute of Technology and Sigenics Inc. [2, 3], and first described in 2003 [4] with a full system description in 2010 [1]. Following translational system development and packaging innovations by the A.E. Mann Foundation (AMF) [5], the IMES1 system is now undergoing human clinical trials at Walter Reed National Military Medical Center (Fig.3), funded and sponsored by AMF. The trial has provided a subject with a trans-radial amputee simultaneous control of 3-degrees-of-freedom in a hand prostheses. (http://clinicaltrials.gov/ct2/show/NCT01901081).

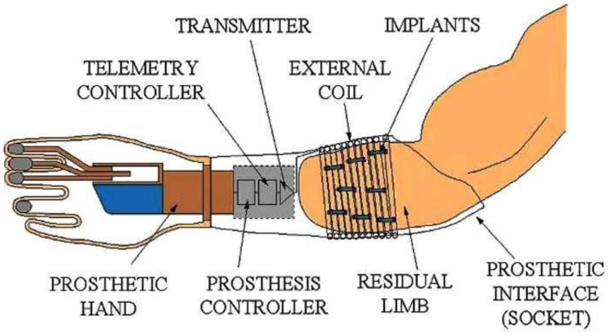

Fig. 1: Overview of the IMES system showing implanted IMES devices, external powering coil, Telemetry and Prosthesis Controllers, and prosthetic hand.

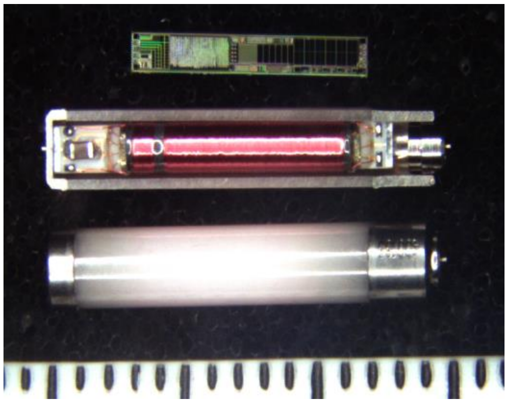

Fig. 2: Photograph of IMES components in three assembly states. Top, IMES silicon chip, Middle sectioned IMES capsule containing IMES subassembly, Bottom, completed IMES implant. Shown next to 1mm scale

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*Research supported by the University of Colorado Denver on NIH Grant 5R01EB001672-08.

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Fig. 3: Testing the Arm SSgt. James Sides, left, talks with Dr. Paul Pasquina, principal investigator on a new implantable device that can control a prosthetic limb with an amputee's own muscle. Courtesy Uniformed Services University

[http://www.popsci.com/article/technology/video-marine-prosthetic-hand-controlled-his-own-muscles?src=SOC&dom=tw]

III. THE NEXT-GENERATION IMES – IMES2

As part of the continuing IMES work under the present NIH BRP grant, revisions to the original system architecture and electronic design of the IMES have been made to improve the performance and flexibility of the system. A new IMES2 silicon ASIC has resulted from this enhancement effort. The enhancements present in the IMES2 ASIC are listed below, and further described in [7].

- A low-power polling mode for power reduction
- Telemetry Controller is backward-compatible with the earlier IMES system, and both IMES1 and IMES2 devices can operate in the same limb
- Improved EMG amplifier performance
- 10bit (IMES2) vs. 8bit (IMES) ADC
- Reverse telemetry data rate increased to 424kbps
- Forward and reverse telemetry CRC error detection
- Continuous diagnostic monitoring of the IMES2 internal voltage and current levels
- On-Chip Temperature Sensor
- On-Chip Moisture Sensor (for package fault detection)

Here, we describe the test results of the new low-power polling mode.

IV. LOW-POWER POLLING MODE

A significant challenge in the design of any electronic prosthetic system is minimizing the weight and size while maximizing the battery life of the wearable prosthesis. When combined within a single limb, the multiple IMES in the original IMES system operate at a programmable, yet constant sample rate and all IMES require a constant “high power” to operate continuously at a high sample rate.

An IMES2 system can sense when the prosthesis control has been inactive for a predefined period of time by observing an absence of EMG activity. It can then change from the normal high sample rate to a much lower sample rate. If EMG activity is again detected using the lower sample rate data, the system can restore the high sample rate to enable the agile control of the prosthesis (see section VIII for details of our testing).

To save power in the “polling mode,” the IMES2 devices are designed to consume very little power in the time interval between low sample rate samples. For this reason, the TC can reduce the intensity of the magnetic field in the time interval between low sample rate samples, thereby saving considerable power - as illustrated in Figure 4.

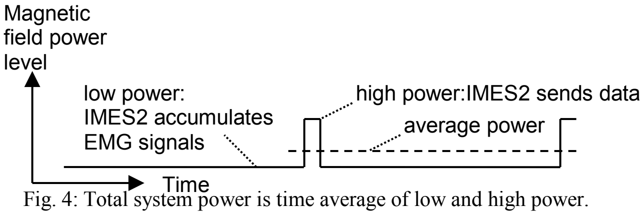

Fig. 4: Total system power is time average of low and high power.

In polling mode, the IMES2, shuts down unnecessary circuit modules between high power states. During the low power time interval it only amplifies EMG and maintains clock synchronization so it can predict when high power will again be available to do an ADC conversion and send its outward data telemetry. All IMES2 devices in a system also remain synchronized and maintain the memory of their individual device settings, during the low-power state.

After the predetermined low-power interval of monitoring EMG activity, the TC will increase the magnetic power for just long enough to allow the implanted IMES2 devices to convert and send their EMG samples, and then the system immediately reverts to low power until the next high power interval.

The polling sampling rate is programmable from 1.4sps to 375sps, and the command to change the IMES2 devices from low power to high-fidelity mode takes only 1mS. This allows the system to dynamically trade off sampling rate for power consumption. The penalty for a lower sample rate is a longer prosthesis response time to restore continues EMG control, but since this tradeoff may be made dynamically, controller algorithms can be developed to reduce the impact on the user.

V. MAGNETIC FIELD GENERATOR POWER CURVE

The magnetic field which powers the IMES2 devices is generated by large currents flowing in a low-loss coil wrapped around the residual limb containing the IMES2 devices. A Class-E power converter is currently used to efficiently generate these high (approximately 1.5 Amperes rms) coil currents [6]. Even with efficient power conversion, losses in the coil and nearby metallic objects are significant. In a typical hand prosthesis, the motors take several Amperes of peak current, but their duty cycle is low compared to the always-on EMG-sensing aspect of the IMES system. From clinician’s experience, a standard-of-care 2-site myo controller, combined with hand and wrist limb, uses a 12V, 780mAh battery that typically lasts for 12-18 hours. The average power consumption is approximately 0.8 Watts. In an IMES system, the magnetic field generator alone consumes approximately 2 Watts continuously. Seventy percent of the limb battery capacity would therefore required to service the IMES. Even a moderate savings in magnetic field power would result in a significant increase in battery life.

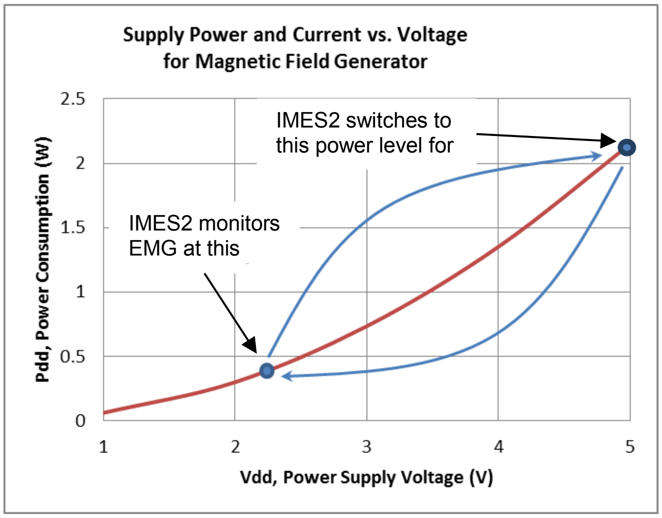

Fig. 5: Magnetic field generator power curve

Figure 5 shows the Power-Voltage curve for our magnetic field generator consisting of a Class E power converter and associated coil. In an IMES2 polling system, the generator would be programmed to operate at the low power (~0.4W) level for many (50 to 100) data frame periods while it autonomously monitors EMG activity. When it is time to poll the IMES2, the magnetic field power is increased to the high power (~2W) and all of the implanted IMES2 devices send their data samples in one data frame period. Figures 6 and 7 show the polling occurring every 50th frame.

In Figures 6 and 7 below, the polling interval is set for 300mS between samples. In a typical system, the polling rate might be increased to 100mS for faster prosthesis response time, as shown in Figures 9-11. For these faster settings, the magnetic generator power consumption is 2.15W in high sample rate mode and 0.48W when the magnetic field is at its low intensity. Using this 7mS/100mS duty cycle, the average power is about 0.6W, a power reduction of 72% from the high sample rate level.

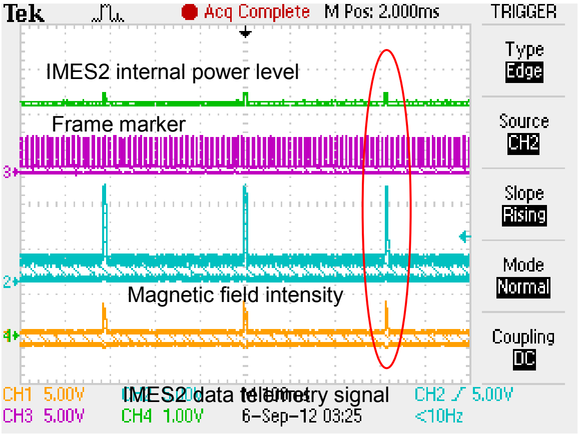

Fig. 6: IMES2 devices send data once every 50th frame in this example. The red circled area is expanded in Figure 7.

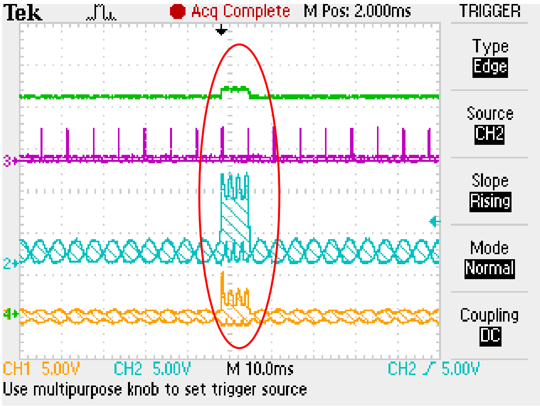

Fig. 7: The magnetic field power is increased only long enough to send one frame of data (one sample from each of up to 32 IMES2 devices in a system). The red circled area is expanded from Figure 6.

VI. ENVELOPE DETECTION PROVIDES EMG HISTORY

The IMES2 can either monitor "raw" instantaneous EMG signals amplified at its electrodes, or these signals can be amplified, rectified and integrated to produce an envelope of the EMG signal, sometimes called "integrated EMG".

Although the IMES2 system can be programmed to send raw samples in the polling mode, integrated EMG will probably be used to trigger the switch to high sample rate mode. Several significant EMG events may occur during the low power interval, and a single instantaneous sample sent during the high power interval would not reflect any prior EMG activity. In the IMES2 low-power mode, the EMG amplifier and envelope detector always remain active. If EMG activity occurs between low power samples, it is "remembered" by the envelope detector, and this residual signal is converted by the ADC during the polling period and can be detected by the Telemetry controller to alert the system that significant EMG activity has occurred between polling intervals. Operation of the EMG envelope detector is shown in Figure 8.

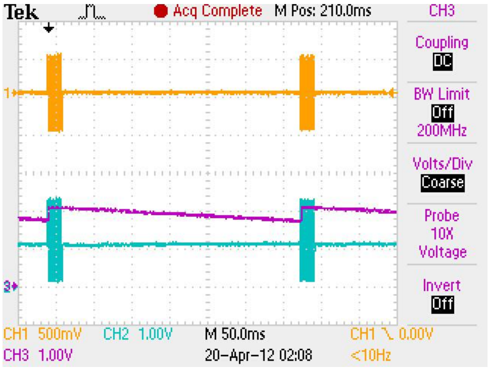

Fig. 8: EMG envelope detector operation. The decay time is programmable to implement a long memory between polling intervals.

VII. AUTOMATIC MODE SWITCHING

As shown in Figure 9, the TC was programmed to first place the IMES2 in low-power polling mode. Asynchronously, a simulated EMG signal was applied to the IMES2 ASIC. The Telemetry Controller detected the presence of a significant EMG envelope, and switched the

IMES2 mode to telemeter high sample rate data. Although not shown, the Telemetry Controller could switch the IMES2 back into the low-power polling mode after a period of no EMG activity.

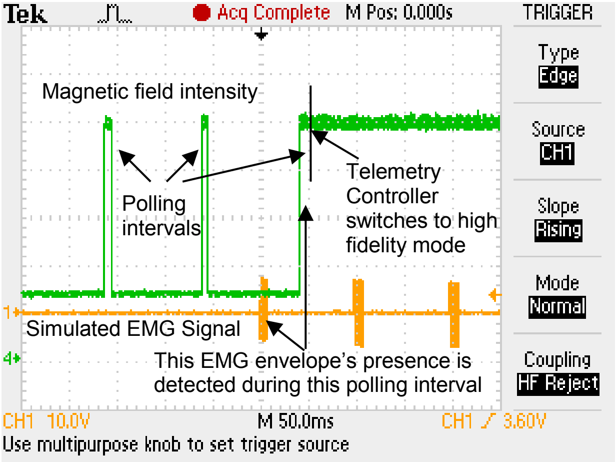

Fig. 9: The Telemetry Controller successfully detects the presence of a first simulated EMG signal pulse occurring between polling intervals. Upon detection, the Telemetry Controller switches the IMES2 device into the high-rate sampling mode for high-fidelity acquisition of the raw EMG signal.

VIII. AUTOMATIC MODE SWITCHING USING A RECORDED EMG SIGNAL

In a fine-wire experiment, EMG signals were previously recorded with commercial equipment at the Rehabilition Institute of Chicago. A recorded Pronator Teres signal was used to drive an IMES2 device on the bench. The switch from polling mode to high-fidelity is shown in the Figures 10 and 11, below.

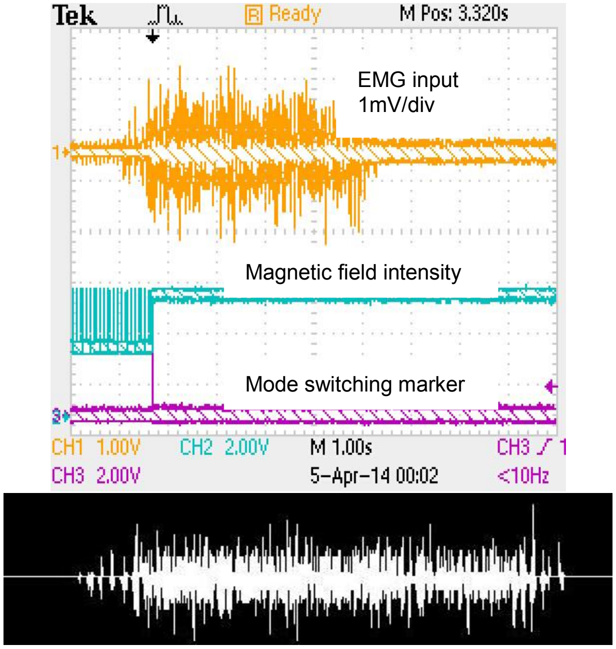

Fig. 10: An actual EMG triggering the transition from polling to high-fidelity sampling mode. The top oscilloscope plot shows the EMG signal and the magnetic field intensity. The bottom plot is a screen capture of the high sample rate telemetered EMG data.

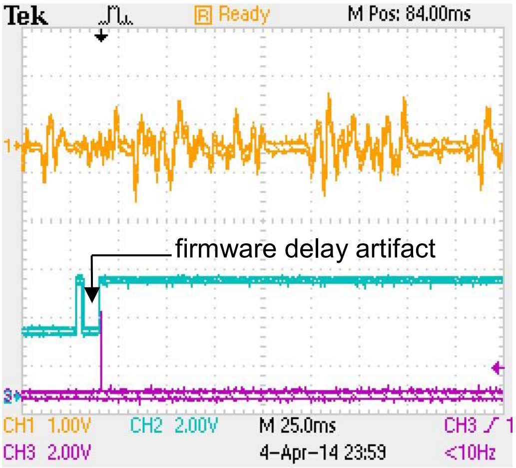

Fig. 11: Same as Figure 11, but zoomed-in to show the beginning of the EMG activity.

Note that the gap shown between the polling period and the switch to high power mode is a correctable artifact of our Telemetry Controller thresholding firmware, and can be reduced to nanoseconds. The EMG activity was captured and reported during the polling pulse.

IX. CONCLUSION

The polling-mode of the IMES2 ASIC is one solution to reducing the operating power of the IMES system. The IMES2 can maintain its synchronization and analog signal processing capability at a much lower power level than the original IMES device. This allows the Telemetry Controller to implement a polling scheme, resulting in a significant system power reduction (4x to 10x) as compared to a fixed sample rate system.

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