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A 1-MHz, 5-Kb/s Wireless Command Receiver for Electronic Site Selection in Multichannel Neural Biopotential Recording

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Abstract—**This paper reports on a battery-powered telemetric command receiver for electronic site selection in multichannel neural recording applications. The receiver selects seven recording sites from a total of 28 available sites, according to four pre-defined site-selection patterns, via a 1-MHz, 5-Kb/s, amplitude-shift-keyed (ASK) link. The seven selected sites can then be wirelessly monitored via a 100-MHz frequency-modulated (FM) link. The receiver also performs power management to increase battery service lifetime. A bi-directional wireless recording microsystem incorporating this receiver is fabricated on a 4.6 × 4.6-mm^2 chip using the AMI 1.5μm 2P2M n-well CMOS process. Design methodology and architecture of the receiver together with measurement results from its wireless analog front-end are presented.**

I. Introduction

Long-term monitoring of physiological parameters in biological hosts can be of great interest in a variety of applications including ground-based or future space station studies. Figure 1 shows the schematic block diagram of a general-purpose bi-directional wireless multichannel biomicrosystem, which can be targeted at measuring biopotentials, blood pressure, core body temperature, or multi-axis acceleration in small unrestrained rodents or primates. These systems can be either implanted inside the biological host (internal) [1] or carried by the biological host similar to a backpack (external) [2]. Information signals recorded from information sources by a number of different sensors are conditioned, multiplexed, and transmitted to an external information receiver via a wireless link. This external receiver usually consists of a signal receiver, demodulator, demultiplexer, signal conditioner/amplifier, and display/recorder equipment. An on-board telemetric command receiver operating via a second wireless link is also incorporated to activate the microsystem when a measurement sequence is required. The on-board receiver can be employed to add actuation capabilities in addition to sensing by performing different tasks, such as neural tissue stimulation, microdrive actuation for electrode positioning, or recording site selection, via a second wireless link in a bi-directional microsystem.

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We have previously reported on the measured performance characteristics of a battery-powered 8-channel wireless FM IC for neural recording applications [3]. In this paper, we report on the design methodology, architecture, and preliminary measurement results from a fabricated prototype receiver capable of wireless electronic site selection and power management, which is integrated with the aforementioned transmitter circuitry in a single-chip bi-directional wireless microsystem.

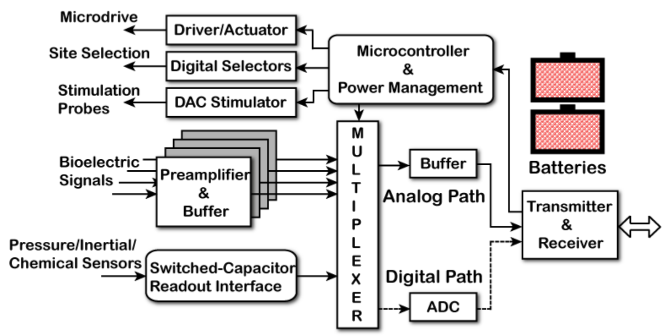

Fig. 1. Block diagram of a general-purpose bi-directional wireless multichannel biomicrosystem.

II. Receiver Architecture

Figure 2 shows the schematic block diagram of a bi-directional wireless microsystem, which incorporates the proposed receiver and is targeted at biological-electronic interfacing in multichannel neural recording applications. The receiver circuitry selects seven recording sites from a total of 28 available sites according to four pre-defined site-selection patterns. The seven selected sites can then be monitored via a second wireless link. Site-selection command bytes are first generated and Manchester-encoded by an external PC-based LabView program according to a pre-defined selection pattern. The command bytes are subsequently encoded onto the amplitude of an RF carrier in the medium frequency range (0.3 to 3MHz) using external electronics system as shown in Fig. 2. An on-chip ASK demodulator recovers the serial data bit-stream from the low-amplitude (in the range of a few millivolts) incoming RF signal, which is further decoded by an on-chip Manchester decoder to retrieve the original command byte and the clock signals.

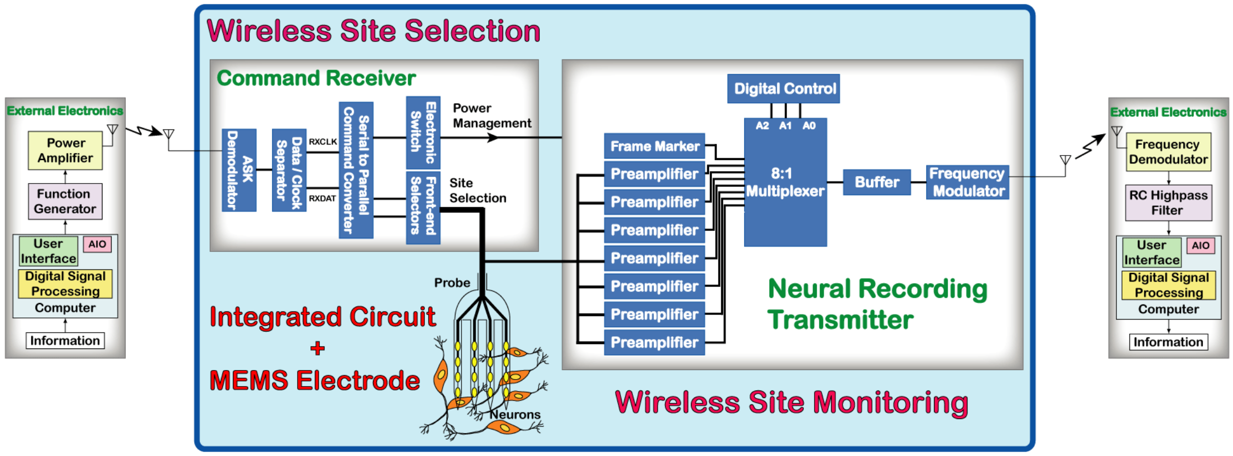

Fig. 2. Block diagram of a battery-powered bi-directional wireless µsystem for multichannel neural recording, incorporating the proposed receiver.

A monolithic digital controller then converts the received serial command byte into parallel data, checks it for possible single-bit errors, and then executes it. The seven selected sites are subsequently routed to an 8-channel integrated recording transmitter (7 data channels + 1 synchronization channel) that features on-chip ac amplification, dc baseline stabilization, clock generation, time-division multiplexing, and wireless FM transmission of µV- and mV-range input biopotentials in the VHF frequency band of 94 to 98MHz [3]. The microsystem uses two miniature batteries (±1.5V) for operation. The on-chip receiver circuitry also performs power management in order to increase the battery service lifetime. With the reception of each site-selection command byte during the programming phase of the microsystem operation, if no single-bit error has occurred during the wireless transmission and if the received command contains the correct identification (ID) code, then the receiver actuates an electronic switch to connect the batteries to the recording transmitter block and routes the seven selected sites to the transmitter input lines for simultaneous monitoring during the recording phase of operation.

A. *Command Byte Structure*

Figure 3 shows the structure of the site-selection command byte. A synchronizing "high" bit designates the start of each byte, and is used by the monolithic digital controller block to indicate the reception of all the eight bits of one site-selection command. The next three bits, $ID_{0\text{-}2}$, indicate a unique code that identifies the command byte to the on-chip receiver. If the received ID code is different from the one that is internally programmed for the chip (010 in this work) the receiver circuitry will discard the data. This feature is incorporated to decrease the probability of false-triggering the system from other unrelated transmitters that might be operating nearby. The next bit, M_d, indicates the operation mode of the microsystem. A received "high" bit will connect the batteries to the multichannel neural recording transmitter, and one of the four site-selection patterns will be selected according to the two site-selection bits, $A_{0\text{-}1}$. A received "low" bit will disconnect the batteries to shut down the transmitter. The status of the two site-selection bits will be unimportant in this mode. An additional bit to generate even parity is added to each command byte to allow for single-bit error detection. Parity-check circuitry in the receiver will check the parity of each received command, and will discard the data if an odd parity is detected.

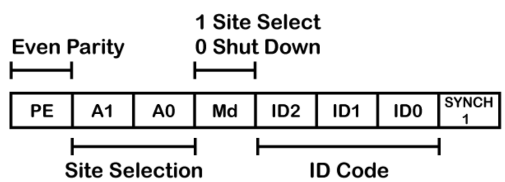

Fig. 3. Command byte structure for recording site selection.

B. *ASK Demodulator*

Since the proposed biotelemetry microsystem is battery-operated, the downlink does not carry any power information and, therefore, the peak-to-peak amplitude of the incoming RF carrier is expected to be in the range of only a few millivolts, which is not large enough to turn on/off the diodes in a conventional voltage-based bridge rectifier. Figure 4 depicts the architecture of the ASK demodulator employed in this work, which is based on a low-power, compact, *current-based* rectifier suitable to rectify very-low-amplitude input signals [4]. The incoming 1-MHz ASK carrier is preamplified by ~10dB. The amplified carrier is then half-wave-rectified and lowpass-filtered to obtain a baseband slow-varying signal that follows the amplitude variations of the ASK signal. The baseband signal is further amplified by ~40dB and bandpass-filtered to remove the 1-MHz carrier feedthrough noise. It is then dc-level-shifted and squared up by an analog comparator with pre-defined hysteresis. The comparator output is the digital Manchester-encoded data (MED) extracted from the amplitude of the ASK signal. The level shifter, realized via passive external highpass filtering (220-pF capacitor and 2-MΩ resistor), ensures that the demodulator will remain insensitive to any slow, long-term voltage variations in the carrier envelope, and that it will only respond to the depth and speed of the envelope modulation.

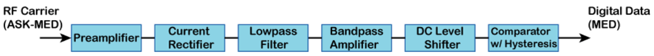

Fig. 4. Block diagram of the ASK demodulator employed for data extraction.

C. Current Rectifier

The current rectifier is a precision CMOS half-wave rectifying transconductor stage based on a cascode current subtractor, as shown in Fig. 5 [4]. The biasing voltage, V_b, is chosen so that M_c and M_d always operate in the saturation region. If the input current I_1 is less than I_2, the PMOS transistor M_b cuts off, and the output current decreases to about zero. The simulated power consumption is ~55μW from 3V and the dc output offset current is ~103nA.

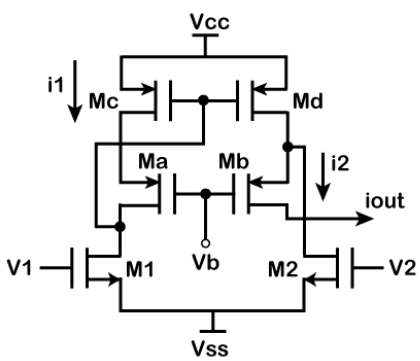

Fig. 5. Circuit schematic of the current-based half-wave rectifier.

D. Data/Clock Separator (DCS)

In order to synchronize the time bases of the external command transmitter and the on-chip receiver for data recovery, Manchester encoding technique is employed to combine the clock and data signals at the transmitter side before sending to the microsystem. This coding technique offers strong timing information to readily recover the clock signal by providing a high-to-low or low-to-high transition for every "1" or "0" in the serial command byte, respectively. It also removes the dc residual of the encoded data, regardless of the message sequence, by providing positive and negative polarities for each data bit at the expense of doubled transmission bandwidth and error rate.

A mixed-signal asynchronous DCS block, as shown in Fig. 6, separates the clock and data signals from the incoming MED [5]. The capacitor in the delay cell is applied externally for a data rate of 5Kb/s. If a bit-center transition is detected by the transition detector block, the MED is sampled after a delay of ~0.75T where T is the clock period. Therefore, as long as the timing jitter in the MED is less than ~0.25T, the clock and data signals can be reliably recovered. After sampling the MED, the transition detector is reset, and a new transition can then be detected. The active-low global reset line (RST) is generated by an on-chip power-on-reset (POR) circuitry.

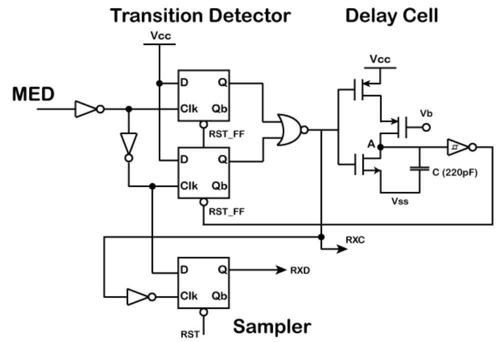

Fig. 6. Block diagram of the asynchronous data/clock separator (DCS).

E. Digital Controller

The monolithic digital controller consists of an 8-bit serial-to-parallel data converter, a 3-bit digital comparator, and an 8-bit parity checker circuit block. After recovering the clock and data signals, the command bits are loaded into an 8-bit serial shift register with each cycle of the recovered clock. Once the eight bits are fully loaded, the shift register latches the entire received command into an 8-bit parallel register for storage. A digital comparator then checks whether the received command contains the correct ID code, and an 8-bit parity checker verifies whether a single-bit error has occurred in the received command or not. If no problem is observed, the two site-selection bits, A_0 and A_1, are routed to the control lines for an array of front-end multiplexers to select the seven recording sites. The received mode bit, M_d, is also inverted and applied to an electronic switch that connects the batteries to the recording transmitter.

III. Measurement Results

The 28-channel command receiver was integrated with an 8-channel biopotential recording transmitter within a bi-directional biotelemetry chip fabricated using the AMI 1.5μm 2P2M n-well CMOS process. The chip measured 4.6 × 4.6mm^2. A microphotograph of the fabricated chip is shown in Fig. 7. Measurement results from the wireless analog front-end are reported in this section. Testing of the full receiver architecture is currently underway. To test the ASK demodulator, a 1-MHz ASK signal was wirelessly coupled to the chip at the secondary terminal of a wideband isolation transformer. The carrier amplitude was modulated by a 5-kHz square waveform and switched between the two levels of 33mV and 12mV for a modulation depth of ~46%, as shown in the top trace of Fig. 8. The second trace shows the measured baseband signal that tracks the amplitude variations of the ASK input signal after rectification and lowpass filtering. The third trace depicts the baseband signal after bandpass filtering and further amplification.

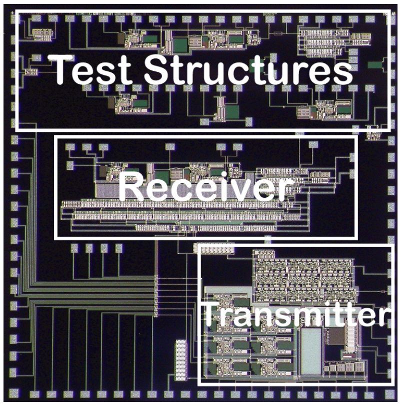

Fig. 7. Microphotograph of the 4.6 × 4.6-mm^2 bi-directional biotelemetry chip fabricated using the AMI 1.5μm 2P2M n-well CMOS process.

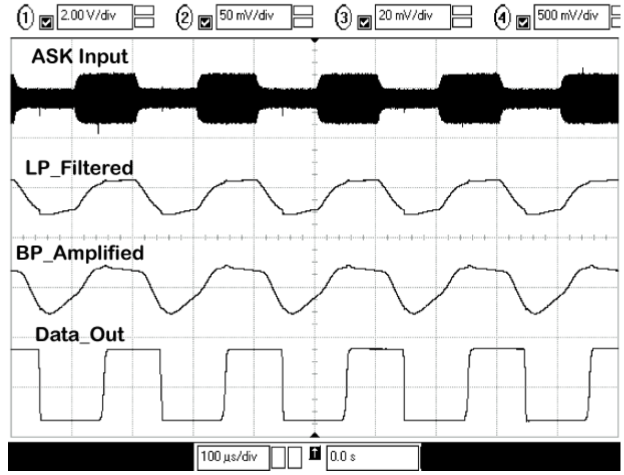

Fig. 8. Measured waveforms of the ASK demodulator (modulating data is a 5-kHz square waveform).

Finally, the fourth trace shows the measured data extracted from the ASK signal amplitude (i.e. the 5-kHz square waveform in this measurement).

The top trace in Fig. 9 depicts the Manchester-encoded command byte corresponding to one of the four site-selection patterns, generated by the external electronics system, which modulated the amplitude of a 1-MHz carrier as shown in the middle trace. Carrier amplitude switched between the two levels of 17.5mV and 6.5mV with a data rate of 5Kb/s. The digital data (Data_Out) was again successfully extracted from the input signal amplitude after wireless reception. The ASK demodulator remained functional at elevated data rates as well up to 20Kb/s. Table I tabulates the receiver performance characteristics.

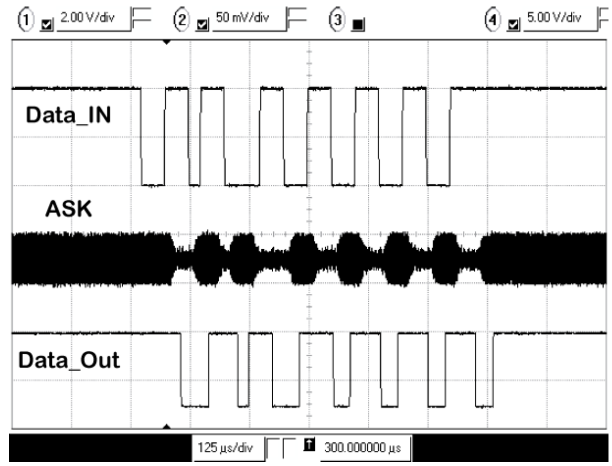

Fig. 9. Measured waveforms of the ASK demodulator (modulating data is the MED for one site-selection pattern with a data rate of 5Kb/s).

TABLE 1
SUMMARY OF RECEIVER PERFORMANCE CHARACTERISTICS

Functionality	Site Selection Power Management
Number of Site-Selection Patterns	4
Total Number of Sites	28
Number of Selected Sites	7
Modulation Scheme	ASK
Carrier Frequency	1MHz
Coding Scheme	Manchester
Data Rate	5Kb/s
Command Length	8 Bits
Input Amplitude (typical)	5-15mV
Input Modulation Depth (typical)	24-50%
Power Supply	±1.5V
Power Consumption ASK Demodulator DCS Block + Digital Controller	 ~354μW ~70μW
Effective # of External Comp.	2
Technology	AMI 1.5μm 2P2M n-well CMOS
Area	2.77mm^2

The receiver was designed to select seven recording sites from a total of 28 available sites via a 1-MHz, 5-Kb/s ASK link. It supported four different site-selection patterns, and also performed power management for increased battery service lifetime.

IV. CONCLUSION

In this paper, the system architecture of a telemetric command receiver integrated with a multichannel neural recording transmitter within a single-chip bi-directional biotelemetry microsystem was presented.

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