

# New Models for Telemetry System to Measure the Pressure Characteristics of Gastrointestinal Tract

Issa Jaafar<sup>1</sup> and Hayder J Essa<sup>2</sup>

<sup>1</sup>Communication Engineering Technology, Assiniboine Community College, Brandon, Manitoba-Canada

Issajaafari@Assiniboine.net

<sup>2</sup>College of Pharmacy, AL-Mustansiriyah University, Baghdad, Iraq

Hayder.Essa@campus.ie

## Abstract

**The work presented in this paper, introduces different simulation models for a telemetry system used for diagnosing the pressure characteristics of the gastrointestinal tract. Real data recorded by a Manometry device, that detects pressure changes within a sealed cavity, is employed to assess the performance of the proposed system. Three different Pulse Coding Modulation (PCM) and Successive Approximation Register (SAR) analog to digital conversion algorithms are used for the channel coding. The created models were simulated and tested using SIMULINK® software. A behavioral model for FSK transceiver suitable for short- range applications has been developed. The transceiver system performance was tested under different conditions and the output simulation results were presented. The obtained output results from the different models are discussed.**

## 1. Introduction

Recent advances in integrated sensors have made the realization of smart microsystems combining a large mixture of microsensors and signal processing circuitries. A number of telemetry-based medical systems have been developed for different implanted applications [1-5]. **Gastrointestinal motility disorders** are caused when either nerves or muscles in any portion of the digestive tract do not function in a strong coordinated fashion; a person develops symptoms related to motility problems [6]. Manometry is an established procedure used for examination of Gastrointestinal tract abnormalities, whose cause is unknown and whose physiological importance is not clear. Some difficulties are associated with manometry techniques, like the distortion of the normal anatomy induced by the tube and inability to get clear signals from the upper digestive tract. This paper proposed an efficient model for ingestible telemetry micro-scale system that can be used to overcome the manometry limitations and detect pressure changes along the GI tract. The basic motive behind this research is to have a comparative study for different techniques that can be used by the proposed telemetry system and leads to efficient data recovery and power consumption. The paper

explains in details the main tasks and functions that should be implemented by the proposed data acquisition system. A collected real data recorded by a manometry device in Yarmouk hospital (Baghdad) is encoded using one of the PCM or SAR algorithms and converted to digital bit streams. The binary data will be processed by a unit, which simulates the tasks of a microprocessor. At this stage, the two channels data are framed, multiplexed and compressed before it sent to the RF unit. A Frequency Shift Keying (FSK) transmitter and receiver were simulated and tested through different noisy conditions. The effects of indoor multipath fading and inband / outband interference effects were also investigated on the overall performance of the system. At the receiver side, data will be demodulated and inversely decoded to recover the analog signals.

## 2. System Description

The main functions implemented by the proposed system are shown in Fig. 1. In the first stage, the obtained real analog signals are encoded into digital data using one of the PCM or SAR source coding techniques. Assuming multi-channel system, the digital data is compressed, multiplexed and framed in the next stage using a data controller; before it is sent to the RF unit.

At this stage, data is modulated using FSK and sent through a noise channel. At the receiver, signal will be demodulated back using direct conversion scheme. Finally the received data will be deframed, demultiplexed, and decompressed to restore the original analog signals.

### A. Small bowel contractile activity

The small intestine is divided into duodenum (25-30cm), jejunum (100–110cm) and ileum (150-160cm). The contractile activity of the small bowel can be characterized by two main properties [4]:

- (1) The electrical slow waves, which are the oscillations of the membrane potential of smooth muscle cells.
- (2) Coordination of propagation of the contractile activity, which describes the movement of the slow waves along the small bowel.

In Table 1, the general, the general characteristics of the contractile activity waves for a normal case are given.

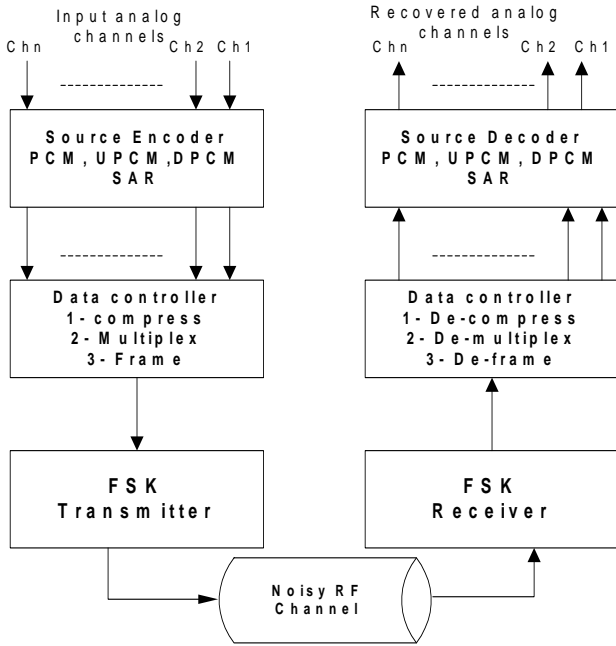


Fig .1. Block diagram of the proposed data acquisition system

Table 1. Contractile activity characteristics for a normal case

Site	Velocity of propagation (cm min <sup>-1</sup> )	Maximum frequency of contractions (per minute)	Duration (minutes)
Duodenum	-----	11.7 ± 0.1	8.7 ± 1.0
Jejunum			
Segment 1	4.3 ± 0.6	11.3 ± 0.1	9.1 ± 0.6
Segment 2	2.8 ± 0.4	10.7 ± 0.1	11.7 ± 0.6
Segment 3	2.0 ± 0.5	10.4 ± 0.2	14.7 ± 1.2
Ileum			
Segment 1	1.3 ± 0.2	9.8 ± 0.2	15.6 ± 1.6
Segment 2	0.9 ± 0.1	9.3 ± 0.2	15.3 ± 1.0
Segment 3	0.6 ± 0.2	8.9 ± 0.2	13.9 ± 1.1
Segment 4	-----	8.5 ± 0.2	13.8 ± 1.5

### B. PCM source coding

PCM technique proved to have a good compression capability for non-stationary signals like audio speech. From Table 1, it is obvious that the contractile signals have different frequency contents at different time periods. The signal behavior is tending to be noisier and rapidly changing if there are motility disorders. In this case PCM becomes a good candidate to digitize such type of signals.

Three different types of 8-bits PCM algorithms have been modeled in this work using SIMULINK®. These are uniform PCM (UPCM), non-uniform PCM (NPCM), and differential PCM (DPCM).

### C. Successive approximation register (SAR)

SAR analog to digital conversion architecture has been implemented since it provides low power consumption as well as a small form factor. An 8-bit behavioral model has been built as shown in Fig. 2.

The model contains the three basic SAR units: sample and hold, comparator, DAC, and logic control to perform the binary search mechanism.

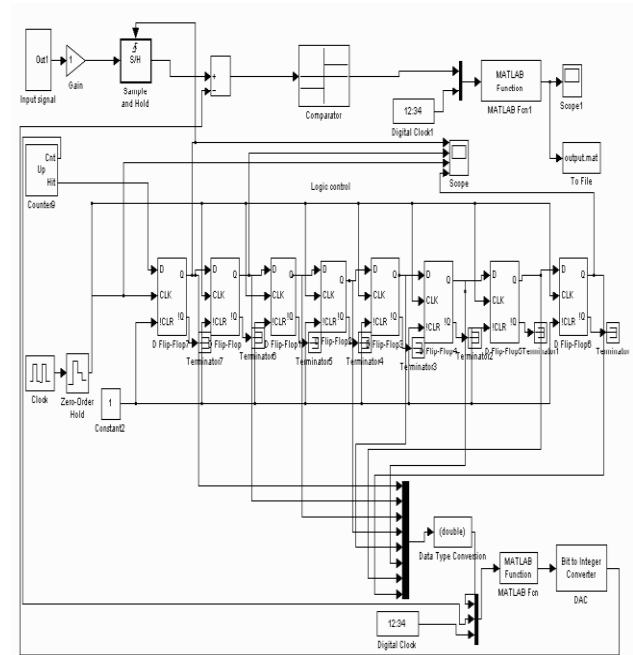


Fig .2. Block diagram of an 8-bit SAR ADC

## 3. Compression Performance

In the data controller, the following functions are achieved:

- The input data bytes are compressed based on sending only the unrepeated frames with their counts.
- Multiplexing the multi-channel input frames.
- Start and end of frame patter generation.
- Introducing channel coding for correcting errors caused by noisy channel transmission. Three different error correcting codes have been investigated, these are:

- A. Binary Cyclic codes BCC (15,5).
- B. Bose-Chaudhuri-Hocquenghem codes BCH (15,5).
- C. Hamming codes (15,11).

Outputs a serial bit stream of 2.5Kbps bit rate to the FSK transmitter.

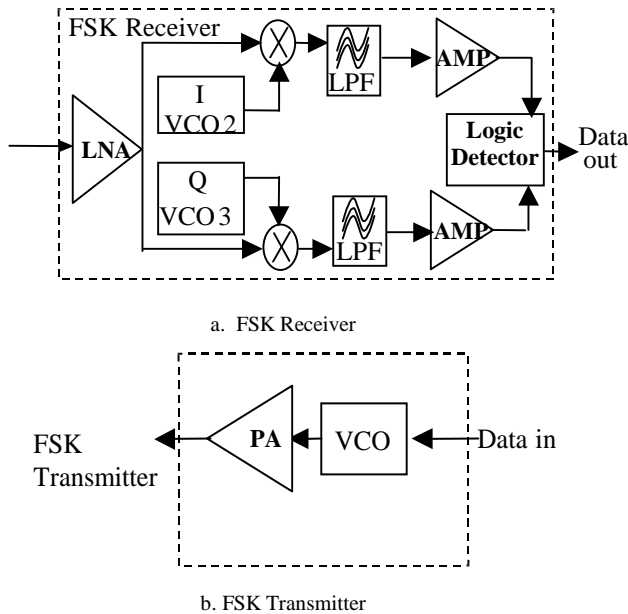
The performance of the data compression was assessed in terms of the number of repeated, not repeated frames and percentage compression ratio. In Table 2, the results are given for the 4 source encoding methods applied on two input channels for a time period of 50 seconds. The sampling rate of the contractile signals was selected to be 1msec, which is suitable for the expected highest frequencies of the signals.

**Table 2.** Date Compression performance

Source encoding method	Frames sent	Frames not sent	Compression ratio %
UPCM	8500	4000	68
NPCM	9135	3365	73.08
DPCM	7156	5335	57.32
SAR	2658	9842	78.736

#### 4. FSK Transmitter/Receiver

A simple FSK modulator/demodulator is modeled based on direct conversion type as it offers more advantages than the heterodyne counterpart. Fig 3 shows the block diagram of such model type



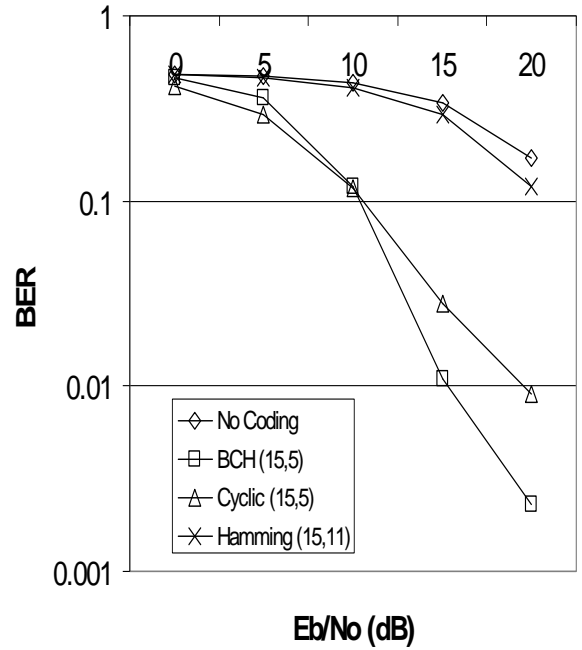
**Fig .3.** Architecture of the simulated direct conversion FSK transmitter/receiver

##### A. Channel encoding and BER estimates

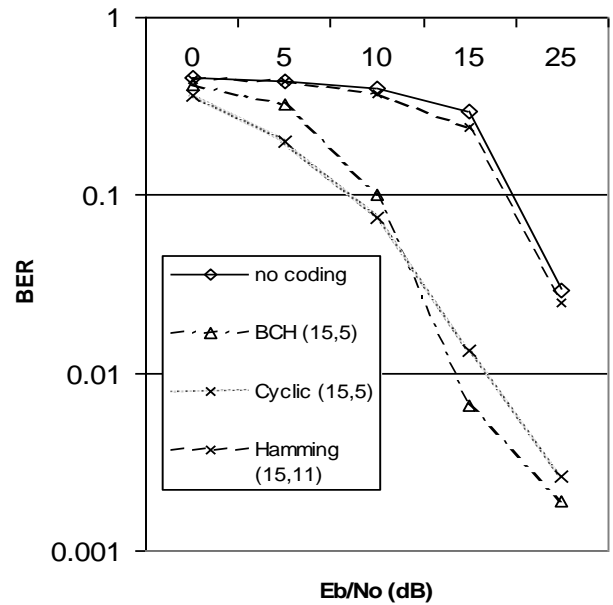
The bit error rate (BER) estimate is used to evaluate the performance of the transceiver under different conditions. Channel encoding is one of the procedures used to improve the BER level. In Figures 4 and 5, the three different channel coding schemes have been implemented with both UPCM and SAR. It has been found that similar BER behavior was obtained for both NPCM and DPCM obtained for both NPCM and DPCM.

##### B. Adjacent channel interference ACI effect

This is a phenomenon whereby channels that are beside one another in the frequency domain may have some spectral overlap, causing impairment and interference. A continuous-time baseband model for a binary FSK data transmission system is illustrated in Fig.6.



**Fig .4.** BER performance using UPCM and channel encoding



**Fig .5.** BER performance using SAR and channel encoding

Generally the two generated FSK tones can be described using the following equation:

$$x(t) = A(t) \cos((w_s \pm w_c)t) \quad (1)$$

The composed signal  $s(t)$  can be expressed as:

$$s(t) = \sum_{\substack{p=-p \\ p \neq 0}}^p e^{j(2\pi p B_c t + \phi_p)} x_p(t - \tau_p) \quad (2)$$

Where  $p$  is the adjacent channel,  $B_c$ ,  $\phi_p$  and  $\tau_p$  are the channel spacing in Hz, phase shift and delay, respectively, of the  $p^{th}$  adjacent channel. The transmitted signal propagates through a linear channel having impulse response  $c(t)$ . After receive filtering with  $h(t)$ , the received ACI term can be written as:

$$z(t) = s(t) * c(t) * h(t) \quad (3)$$

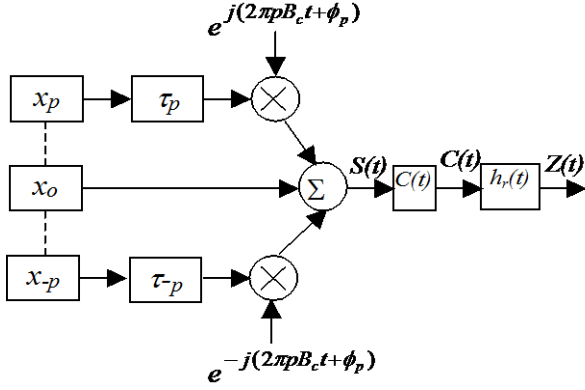


Fig .6. ACI system model

The ACI is effective when considering system working beside other wireless data acquisition units. This problem became major when the transmission frequencies of these channels are so closed to each other with different power ratios. The adjacent channel power ratio (ACPR) is defined as the ratio of the average power in the adjacent frequency channel (or offset) to the average power in the transmitted-frequency channel. The ACPR can be estimated by the following equation:

$$ACPR = 10 \log_{10} \left( \frac{A_2^2}{A_1^2} \right) \quad (4)$$

Where  $A_1$  and  $A_2$  are the voltage signal levels of both the transmission and the adjacent channels. Table 3 presents the ACPR against the BER for different guard bands (GB). The carrier frequency = 1MHz, frequency shift =  $\pm 100$ KHz and output transmitted power = -85dBm.

Table 3. BER Performance for different GB's

ACPR	BER		
	GB=20KHz	GB=40KHz	GB=50KHz
5	0.5	0.07	0
6	0.5	0.2	0
7	0.5	0.45	0.333
8	0.5	0.5	0.484
9	0.5	0.5	0.5

## 5. Decoder Performance

At this stage, the received bit stream will be inversely processed to recover the original signal. A model has been

developed and tested for source encoding technique. The effect of the channel encoding on the overall channel performance has also been investigated.

The output signal to noise ratio parameter is used to assess the quality of the reconstructed data. Fig.7 shows reconstructed contractile signals (motility disorder case) using the four source encoding techniques tested under noisy channel conditions. It is clear that NPCM has good reconstruction ability. Both UPCM and SAR show a comparable performance, while a bad tracking was obtained with DPCM sample of recovered contractile signals (normal case) are presented in Fig 8 using both UPCM and SAR coding.

The improvement in SNR against BER is provided in Fig. 9 using Cyclic coding scheme since it has proved previously to have a good BER performance.

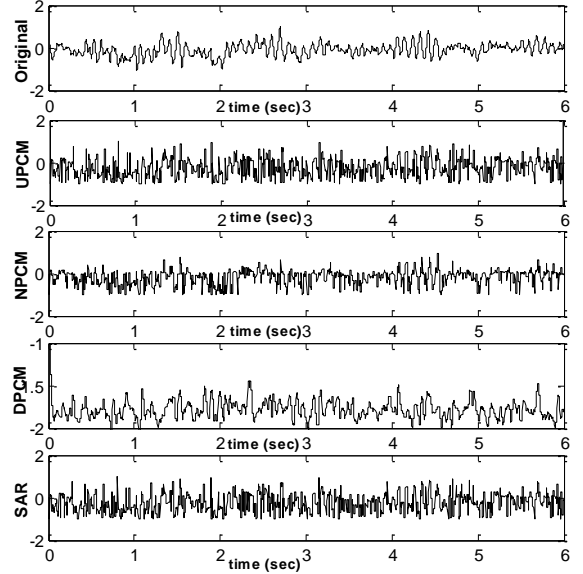


Fig .7. Contractile signals (motility disorder case) reconstructed at  $E_b/N_0=20$ dB

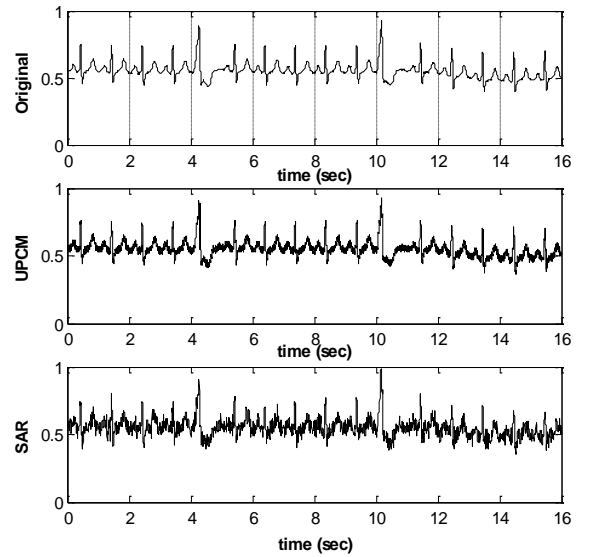
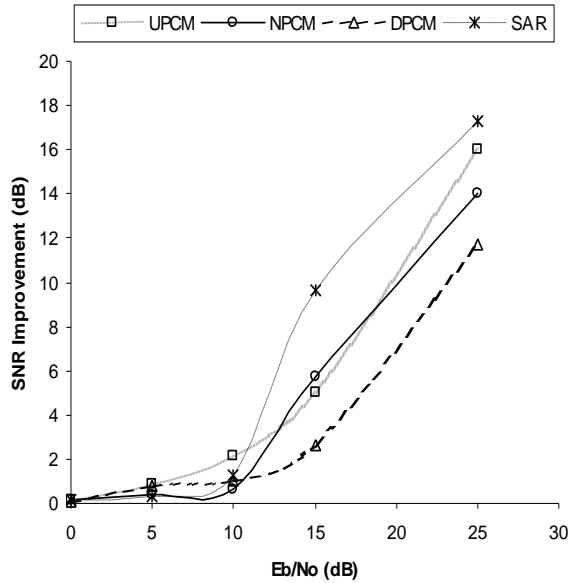


Fig .8. Contractile signals (normal case) reconstructed at  $E_b/N_0=20$ dB using both UPCM and SAR



**Fig .9.** Improved SNR using PCM and SAR coding techniques

## 6. Conclusions

In this paper, the modeling and simulation of an efficient data acquisition of telemetry system suited for measuring the Gastrointestinal contractile signals have been developed. Both source and channel coding effects have been investigated on the system performance.

Three different PCM algorithms have been applied based on the nature of the GI contractile activity signals. SAR data conversion algorithm has been implemented as well and compared to other PCM techniques.

From the presented results, a high compression could be obtained using the SAR which is desired for low power usage. The effect of ACI on the BER estimates has been considered. It was found that reducing the GB's between the adjacent channels enhances the channel transmission. It has been noticed that UPCM and SAR are good candidates for the desired system in combination with channel coding.

## 7. References

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