

Analysis and Review of Possible e-pill with Wireless Communication Finding Applications in Biomedical

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ABSTRACT

Getting exact diagnosis, recording or analysis of vital parameters of the stomach, intestine and other internal parts of the human being is the biggest challenge for the advanced medical science and technology. This work will address the challenges to facilitate the development of a high capacity radio system for a small, miniaturized electronic pill device that can be swallowable or implantable in human body in order to detect biological signals or capture images that could eventually be used for diagnostic and therapeutic purposes. Electronic pills, smart capsules or miniaturized microsystems swallowed by human beings or animals for various biomedical and diagnostic applications are growing rapidly in the last years. The designed telemetry unit is asynchronous bidirectional communication block using continuous phase DQPSK of 115 kHz low carrier frequency for inductive data transmission suited for human body energy transfer. The communication system can assist the electronic pill to trigger an actuator for drug delivery, to record temperature, or to measure pH of the body. It consists additionally to a 32bit processor, memory, external peripherals, and detection facility. The complete system is designed to fit small-size mass medical application with low power consumption, size of 7x25mm. The system is designed, simulated and emulated on FPGA.

I. INTRODUCTION

Recent development in electronic pill technology requires the integration of more complex systems on the same platform when compared to conventional implantable systems. A small miniaturized electronic pill can reach areas such as small intestine and deliver real time video images wirelessly to an external console. Fig. 1 shows a wireless endoscope (i.e. Electronic pill) for a medical monitoring system. The device travels through the digestive system to collect image data and transfers them to a nearby computer for display with a distance 1 meter or more. A high resolution video based capsule endoscope produces a large amount of data, which should be delivered over a high capacity wireless link. Since its early development [1]-[3], wireless

endoscope (i.e. electronic pill) designs have been based on narrow band transmission and thus have limited number of camera pixels. One of current state-of-the-art technologies for wireless endoscope device is commercially available by the company "Given Imaging" [4]. The pill uses the Zarlink's RF chip [5] for wireless transmission based on the Medical Implant Communication Service (MICS) band. The allowable channel bandwidth for this band is only 300 kHz. It is difficult to assign enough data rate for the high quality video data at the moment for a real time monitoring. It is quite obvious that there is a need for higher-bandwidth data transmission for electronic pills that could facilitate a better diagnosis.

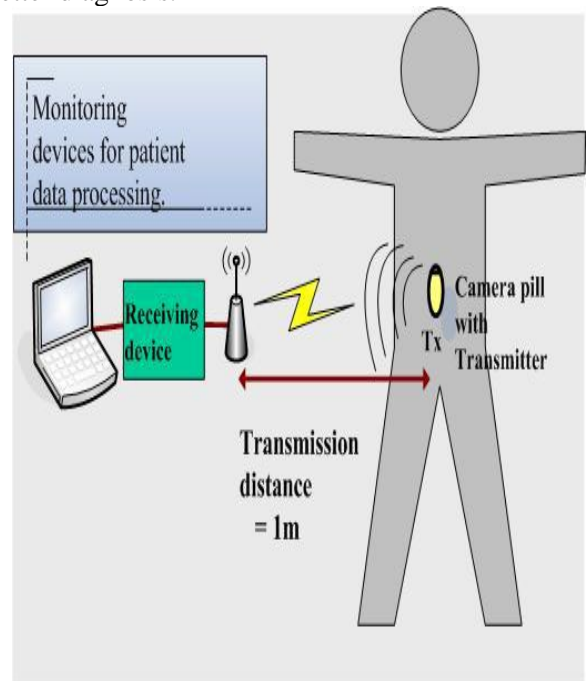


Fig. 1. A wireless endoscope monitoring system

Back to four decades, Mackay invented the first radiotelemetry capsule with one transistor in 1957 and the first successful pH sensor capsule was achieved in 1972, since then research and developments were carried out enhancing and expanding in this field.

II. WIRELESS TELEMETRIES USED IN ELECTRONIC PILL

There are plenty of publications describing the current trend on wireless endoscopes and technologies. One of the recent articles given in [7] gives a good history of capsules from their early development to clinical implementation. The design of wireless capsules started around 1950s. Since then, they have been called as endoradiosondes, capsule, smartpill, electronic pill, wireless capsule, wireless endoscopy, videocapsule and so forth. Herein we will use the term electronic pill to cover all these names. The early attempts were based on low frequencies and with simple structures [1][6]. The basic transmitter used namely Hartley and Colpitts oscillator topology connected to a sensor has been used to send the signal from inside the body to external devices for tracking physiological parameters of inner organs. Despite simplicity, the early systems were bulky due to large electronic components and batteries used and were targeting temperature, pH and pressure [8][9]. As the electronic device should deeply be placed inside the body, which makes the wireless communication interesting due to its surrounding medium, the recent attempts in electronic pills have also been limited to low frequency transmissions (UHF-433 ISM or lower) [10]-[16]. The low frequency transmission is easy to design and is found attractive due to its high efficiency. However a low frequency link requires large electronic components such as capacitors and inductors, which makes it difficult to realize a complete integrated system.

From Table I, it seems that in current attempts the transmission frequency has been limited to around UHF frequencies. Although the advances in high frequency and high bandwidth communication technologies for wireless systems have been significant in the commercial domain, these technologies are not directly transferable to biomedical implant or ingested systems due to the differing power, size, and safety related radiation requirements. As an example, in [17] an implant prototyped with a ZigBee compliance –one of the low-power, less complex and small size commercially available wireless standard occupies an area of 26X14X7 mm³ without being integrated with other required blocks of an electronic pill. The existing advanced wireless systems such as ZigBee (IEEE 802.15.4), WLANs, and Bluetooth (IEEE 802.15.1) operate at 2.4 GHz ISM band and suffer from the strong interference from each other when located in the same environment [18]. Thus an electronic pill should probably have a different transmission band for an interference free wireless system. The existing wireless

modules contain complex multi-access communication protocols such as OFDMA that increase the power consumption and size of the wireless chip. Unless these chips are miniaturized to levels that can be inserted into a capsule size of 11mmX30 mm, the telemetry used will still be based on simple communication modulations like ASK, OOK, FSK, AM.

Table I. Recent facts and outcomes of the research carried out across the world on E-pill

| Reference | Image Resolution | Image sensor | Frequency | Data Rate | Modulation | Trans. Power | Physical Dimension | Power Supply | Current Power |
|-------------------------|-------------------------|-----------------|-----------|-----------|------------|-----------------|--------------------------|------------------------|------------------|
| (Thone, 2009) [14] | 640 X 480 pixels | MT9V013 (VGA) | 144 MHz | 2 Mbps | FSK | -18 dBm | Not finalized | 3 V coin cell | NA (2 mW for Tx) |
| (Chen, 2009) [10] | 307, 200 pixels | VGA 0-2 fps | 433 MHz | 267 kbps | FSK | NA | 11.3 X 26.7 mm | 2X 1.5 V silver oxide | 8 mA (24 mW) |
| (Wang, 2008) [13] | 510 X 480 pixels | PO1200 CMOS | NA | NA | AM | High (variable) | 10x190 mm | 3 V, wireless | 125 mW |
| (Kfourri, 2007) [16] | 768 X 494 pixels | CCD ICX228 AL | UHF | 250 kbps | - | NA | 20X100 mm | Lithium battery | - |
| (Park, 2002) [13] | 510 X 492 pixels | OV7910 CMOS | 315 MHz | NA | AM | NA | 10 X 7 mm | 5 V | NA |
| Johannesson, 2006) [11] | pH and Temp. Sensory | pH and Temp. p. | 433 MHz | 4 kbps | OOK | NA, 1m | 12X36 mm, 8g | 2X1.5 V SR48 Ag2O | 15.5 mW |
| Valdastri, 2004) [12] | Multi-channel | Sensors | 433 MHz | 13 kbps | ASK | 5.6 mW 5 m | 27X19X19 mm ³ | 3-V coin cell (CR1025) | - |
| Mackay, 1957) [1] | pH, temp., oxygen level | Sensors | 100 kHz | - | FM | - | - | - | - |

III. PHYSICAL IMPLEMENTATION AND POSSIBILITIES OF E-PILL

Since miniaturization is important, different design approaches have been followed by the designers. Fig. 2 illustrates different shapes that has been used or can be used to integrate all the necessary blocks. As shown, each unit can be designed on a separate board layer and then stacked on top of each other. In a design shown in Fig. 2-(a) antenna can be placed such that it can easily be inserted on top of the transmitter layer. The capsule shape is also divided into two regions where antenna can be designed to be placed in upper half whereas the remaining electronic units are packed in the lower-half. Placing electronic units on one side of antenna is another possibility (Fig. 2-(c)). Commercially available minicameras can easily be integrated with electronic pills [19]. Small miniature rechargeable battery technologies are also being developed [20] with a dimension around 5 mm and can easily be integrated in a capsule structure shown in Fig. 2.

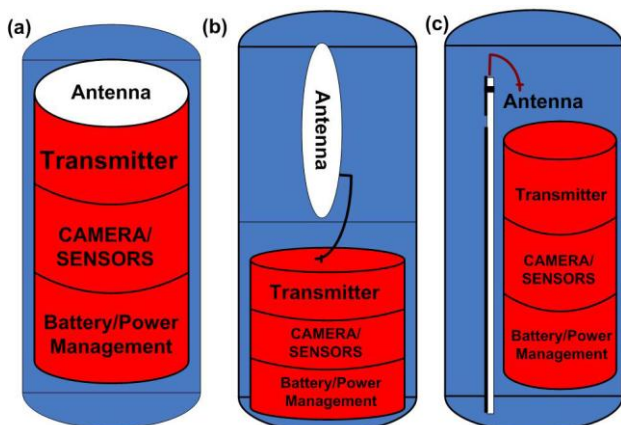


Fig. 2. Different shapes and orientation of possible E-pills

Now the concept of drug delivery can also be implemented in the possible conceptualized E-pill. Figure 3 shows the concept of the electronic pill. It is designed to establish bi-directional communication channel from-to the body, trigger an actuator for drug delivery and record temperature or pH value via temp sensor or chemical sensor.

Another type of capsule is the robotic endoscope [13] which additionally has features such as locomotion and the energy transmission using electromagnetic coupling. Although the device size is quite large comparing to other proposed systems, it is probably because of these additional functionalities. Similar to smart pill, such a

device can be used for precise drug delivery in the human gastrointestinal tract. Real-time energy transfer is necessary for these types of endoscopes to provide mechanical function as they require large power for continuous movement. A recent study [14] demonstrated a prototyping system to achieve high data rate (2 Mbps) for higher image resolution. It can enable an image resolution up to 15-20 fps (frame per second) using compression technique like JPEG. It uses a simple Colpitts oscillator. The transmitter itself thus consumes low-power. However the actual power consumption of a device could only be realistic when all blocks of an electronic pill are integrated together. The device operates at 144 MHz, relatively lower than most of the systems that are operating at UHF, which necessitates a larger antenna that will increase the physical size. In [15], Park, *et al.* also uses a simple AM (amplitude modulation). It is designed with a mixer and an oscillator circuit together with the CMOS image sensor and a loop antenna to form a capsule-shaped telemetry device. This device uses an external control unit to control the capsule inside the human body.

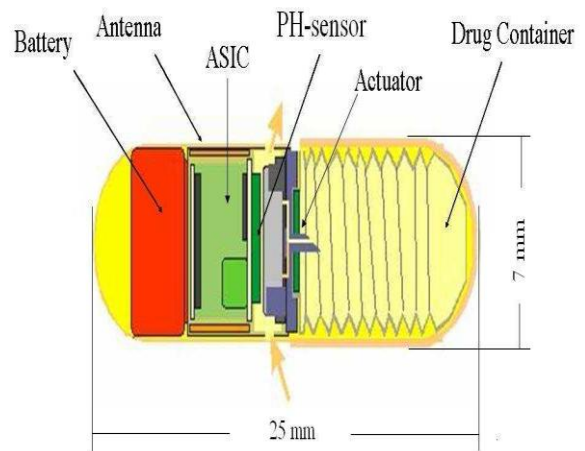


Fig. 3. Concept of drug delivery for a E-pill.

Table II summarizes the commercially available electronic pill technologies that are already been used in clinical environments. Current wireless endoscope device by “Given Imaging” is used to diagnose disorders such as Crohn’s disease, Celiac disease, benign and cancerous tumors, ulcerative colitis, gastrointestinal reflux disease (GERD), and Barrett’s esophagus [4]. The pill uses the Zarlink’s RF chip for wireless transmission [5]. The chip uses the MICS band that allows channels with only 300 kHz. It is thus difficult to assign enough data rate for the high quality image and video data at the moment for a real time data transfer and monitoring.

Table 2. Comparison of different available hardware models from different companies.

| Model | Company | Camera (Sensor) | Freq. (MHz) | Data Rate | Power Source | Physical Dimension | Image rate and resolution |
|--------------|------------------|-------------------------------|-------------------------|----------------|----------------|---------------------|--|
| PillCam (SB) | Given Imaging | Micro n, CMOS | 402-405 & 433 (Zarlink) | 800 kbps (FSK) | Battery | 11X26 mmxm m, <4 gr | 14 images per second , or 2,600 color images |
| EndoCap sule | Olymp us Optical | CCD camera, 1920 X 1080 | -- | -- | Batter y | 11X26 mmxm m | 2 images per second |
| Norika | RF System Lab | CCD Image sensor | -- | -- | Wireless Power | 9X 23 mmxm m | NA |
| SmartPill | Smartpill Corp. | acidit y (pH), press. , temp. | -- | -- | Batter y | 13X26 mmxm m | Only sensor discret e data |

inside a plastic container. Prior to each measurement, jacket of aluminum foil covered the outersurface of the container to minimize outside coupling pathsbetween the antennas.First measurement was taken inside the empty containerand the second with a meat sample inside. Measured S21using the VNA is shown in Fig. 5. Coupling between antennasin the same laboratory environment and instrument calibrationtransmission feasible for electronic pills, we propose to usehigher transmitted signal levels at the transmitter. The UWBSignal power is arranged such that when the signal is radiated through the skin, the power level should meet the FCC mask.Considering the strong attenuation through the body tissue, thetransmitter power level will be adjusted from -20 dBm to 20 dBm in our system, without violating safety requirements.

The receiver can easily be designed for a high data rate asit is built from off-the-shelf high performance RF componentsby using high performance RF ICs (i.e. Amplifiers, Mixers) and high speed Field Programmable Gate Arrays (FPGA).There are different receiver architectures that can easily beconstructed. Usually a mixer is used to down convert the high frequencies to low frequencies. Herein a diode is used due tosimplication in the successive blocks. The received UWBSignal is passed through a BPF, whose center frequency is 4 GHz, to eliminate possible interference from the frequenciesof WLAN standards (for example 2.4 GHz and 5 GHz). Thesignal is then amplified by the Low Noise Amplifier (LNA). A diode and a Low Pass Filter (LPF) down converts the UWBSignal and the baseband data is finally recovered by theFGPA. At the receiver end, the main component is the diode detector. When small input signals below -20dBm are appliedto the diode, it translates the high frequency components totheir equivalent low frequency counterparts due to itsnonlinear characteristic.

Measurement results, shown in Fig.3(b) are spectrum plots at the outputs of the receive antennaand the low-noise amplifiers.UWB prototype is capable of supporting a low-powerUWB communication, which will be ultimately used to forman in-body-to-air link, without violating FCC regulations.Antennas were placed

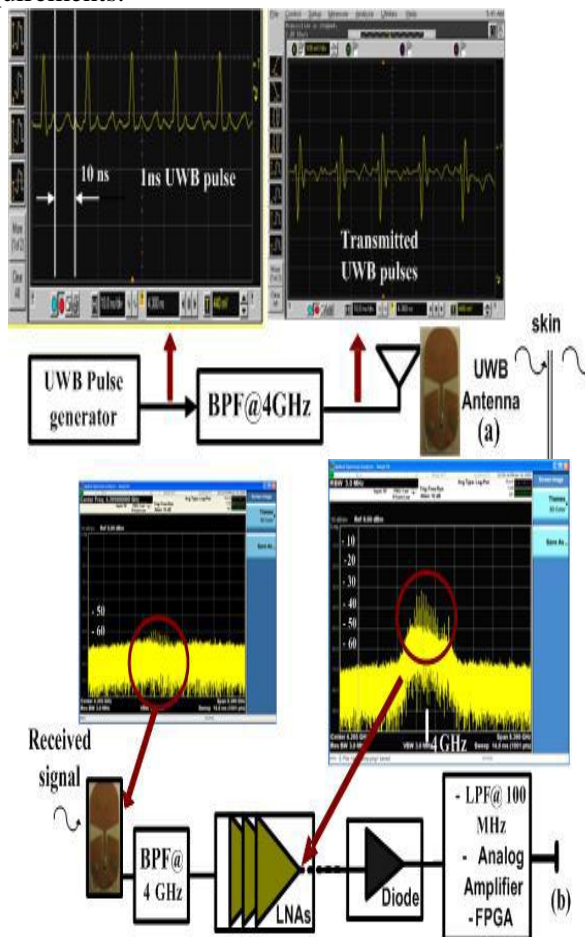


Fig. 3.A ultra wideband (UWB) wireless telemetry prototype and measurement results,(a) transmitter with 1 ns UWB pulse, and (b) receiver with spectrums.

Receiver circuits implement power hungry analog blockslike LNA and mixers at the front-ends. Using only a UWBtransmitter, analog blocks of commerical transceivers areavoided in our electronic pill approach,

which not only increases the battery life but also reduces the physical size. Using a high gain antenna at the receiver we could reduce the tissue effect by 20 dB and more [23]. The 50 MHz data stream is obtained at the FPGA after the demodulation process. The time domain signals before and after the FPGA. The recovered signal is a 50 Mbps pulse obtained from UWB pulses with width of 1ns.

IV. CONCLUSION

A high capacity radio system is currently necessary for electronic pill technology in order to visually examine the digestive tract wirelessly with better and detailed images.

Techniques and methodologies have been presented in this paper for the use of wideband technology in a miniaturized electronic pill to provide a high capacity wireless channel. A prototyping system including UWB transmitter/receiver and antennas has been developed to investigate the feasibility of a high data rate transmission for the electronic pill technology. Integration of antenna with the UWB transmitter electronics has been considered in a capsule shaped structure. Although it is known that tissue imposes strong attenuation at higher frequencies, we have shown there are some advantages to use. Due to the high data rate capacity (e.g. 100 Mbps), a wideband electronic pill can transmit raw video data without any compressing, resulting low-power, less delay in real-time and increased picture resolution. With a high definition camera such as 2 megapixels, UWB telemetry can send up to 10 frame per second (fps). We believe that the wideband pill systems for medical professionals to analyze real-time video and image data wirelessly as a less invasive method.

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