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 thedevelopment of a high capacity radio system for a small,miniaturized electronic pill device that can be swallowable orimplantable in human body in order to detect biological signalsor capture images that could eventually be used for diagnosticand therapeutic purposes.Electronic pills, smart capsules or miniaturizedmicrosystems swallowed by human beings oranimals for various biomedical and diagnosticapplications are growing rapidly in the last years.The designed telemetry unit is asynchronous bidirectional communication blockusing continuous phase DQPSK of 115 kHz lowcarrier frequency for inductive data transmissionsuited for human body energy transfer. Thecommunication system can assist the electronicpill to trigger an actuator for drug delivery, torecord temperature, or to measure pH of the body.It consists additionally to a 32bit processor,memory, external peripheries, and detectionfacility. The complete system is designed to fitsmall-size mass medical application with low power consumption, size of7x25mm. The systemis designed, simulated and emulated on FPGA.

I. INTRODUCTION

Recent development in electronic pill technology requiresthe integration of more complex systems on the same platformwhen compared to conventional implantable systems. A small miniaturized electronic pill can reach areas such as smallintestine and deliver real time video images wirelessly to anexternal console. Fig. 1 shows a wireless endoscope (i.e. Electronic pill) for a medical monitoring system. The devicetravels through the digestive system to collect image data andtransfers them to a nearby computer for display with adistance 1 meter or more. A high resolution video basedcapsule 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 bandtransmission and thus have limited number of camera pixels.One of current state-of-the-art technologies for wirelessendoscope 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 channelbandwidth for this band is only 300 kHz. It is difficult toassign enough data rate for the high quality video data at the moment for a real time monitoring. It is quite obvious thatthere is a need for higher-bandwidth data transmission forelectronic pills that could facilitate a better diagnosis.

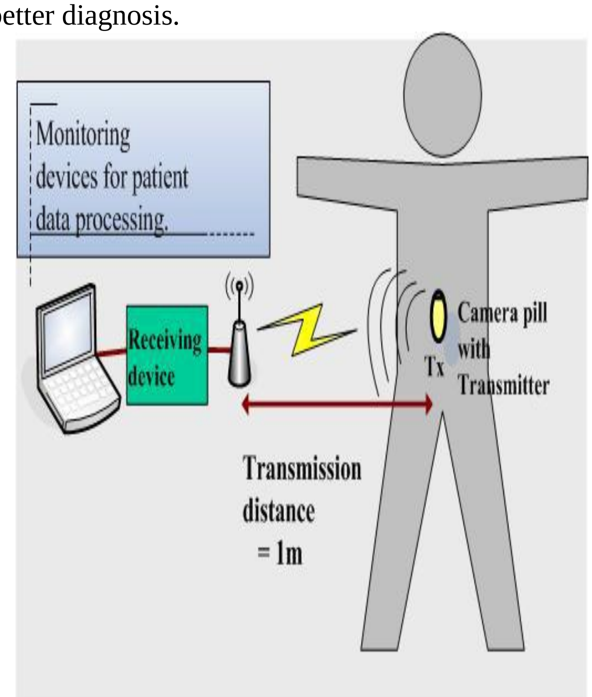

Fig. 1.A wireless endoscope monitoring system

Back to four decades, Mackay invented the first radiotelemetry capsule with one transistor in 1957 and thefirst successful pH sensor capsule was achieved in1972, since then research and developments were carried out enhancing and expanding in this field.

II. WIRELESS TELEMETRIES USED IN ELETRONIC PILL

There are plenty of publications describing the currenttrend on wireless endoscopes and technologies. One of therecent articles given in [7] gives a good history of capsules from their early development to clinical implementation. Thedesign 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 electronicpill to cover all these names. The early attempts were based on low frequencies and with simple structures [1][6]. The basictransmitter are used namely Hartley and collpitts oscillator topology connected to a sensor has been used to send the signal frominside the body to external devices for tracking physiologicalparameters of inner organs. Despite simplicity, the earlysystems were bulky due to large electronic components and batteries used and were targeting temperature, pH andpressure [8][9].As the electronic device should deeply be placed insidethe body, which makes the wireless communicationinteresting due to its surrounding medium, the recent attemptsin electronic pills have also been limited to low frequencytransmissions (UHF-433 ISM or lower) [10]-[16]. The lowfrequency transmission is easy to design and is foundattractive due to its high efficiency. However a low frequency link requires large electronic components such as capacitorsand inductors, which makes it difficult to realize a completeintegrated 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 thestrong 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	Frequen.	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 X26.7 mmxmm	2X 1.5 V silveroxide	8 mA (24 mW)
(Wang, 2008) [13]	510 X480 pixels	PO1200 CMOS	NA	NA	AM	High (variable)	10x190 mmxmm	3 V, wireless	125 mW
(Kfouri, 2007) [16]	768 X 494 pixels	CCD ICX228AL	UHF	250 kbps	-	NA	20X 100 mmxmm	Li-ion battery	-
(Park, 2002) [13]	510 X492 pixels	OV7910 CMOS	315 MHZ	NA	AM	NA	10 X 7 mmxmm	5 V	NA
Johannesen, 2006) [11]	pH and Temp. Sensory	pH and Temp.	433 MHz	4 kbps	OOK	NA, 1m	12X 36 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	27X 19X 19 mm3	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 designapproaches have been followed by the designers. Fig. 2illustrates different shapes that has been used or can be usedto integrate all the necessary blocks. As shown, each unit canbe designed on a separate board layer and then stacked on topof each other. In a design shown in Fig. 2-(a) antenna can beplaced such that it can easily be inserted on top of thetransmitter layer. The capsule shape is also divided into two regions where antenna can be designed to be placed in upperhalfwhereas the remaining electronic units are packed in thelower-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 caneasily be integrated in a capsule structure shown in Fig. 2.

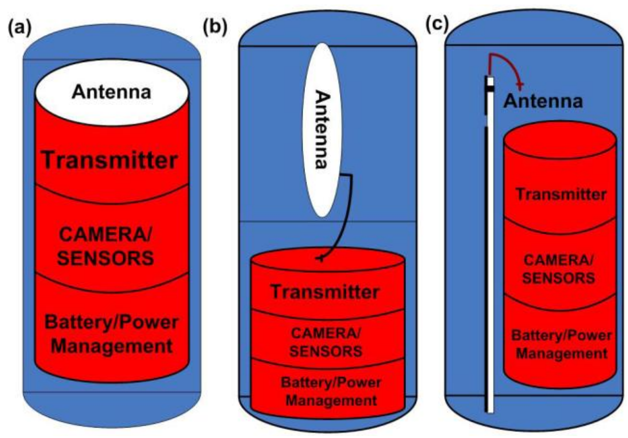

Fig. 2.Different shapes and orientation of possible E-pills

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-directionalcommunication channel from-to the body, trigger anactuator for drug delivery and record temperature orpH 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 beused for precise drug delivery in the human gastrointestinaltract. Real-time energy transfer is necessary for these types of endoscopes to provide mechanical function as they requirelarge power for continuous movement.A recent study [14] demonstrated a prototyping system toachieve 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 thusconsumes low-power. However the actual powerconsumption of a device could only be realistic when allblocks of an electronic pill are integrated together. The device operates at 144 MHz, relatively lower than most of thesystems that are operating at UHF, which necessitates a largerantenna that will increase the physical size. In [15], Park, *etal*. also uses a simple AM (amplitude modulation). It isdesigned with a mixer and an oscillator circuit together withthe CMOS image sensor and a loop antenna to form acapsule-shaped telemetry device. This device uses an externalcontrol unit to control the capsule inside the human body.

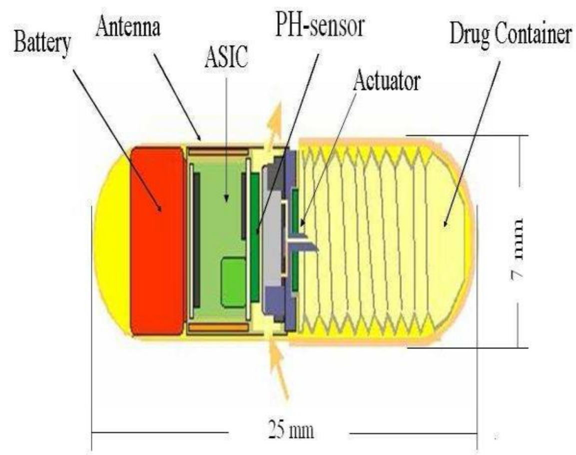

Fig. 3. Concept of drug delivery for a E-pill.

Table II summarizes the commercially available electronicpill technologies that are already been used in clinicalenvironments. 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 toassign enough data rate for the high quality image and videodata at the moment for a real time data transfer andmonitoring.

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	Micron, CMOS	402-405 & 433 (Zarlink)	800 kbps (FSK)	Battery	11X26 mmxmm, <4 gr	14 images per second, or 2,600 color images
EndoCapsule	Olympus Optical	CCD camera, 1920 X 1080	--	--	Battery	11X26 mmxmm	2 images per second
Norika	RF System Lab	CCD Image sensor	--	--	Wireless Power	9X 23 mmxmm	NA
SmartPill	Smartpill Corp.	acidity (pH), press., temp.	--	--	Battery	13X26 mmxmm	Only sensor discrete data

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 tosimplification 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 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.

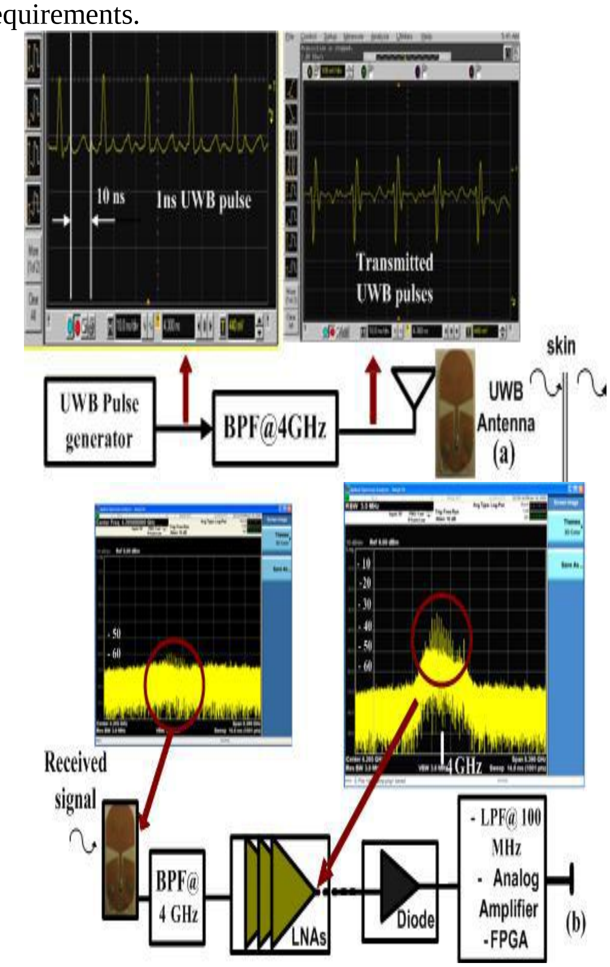

Fig. 3.A ultra wideband (UWB) wireless telemetry prototype and measurement results,(a) transmitter with 1 ns UWB pulse, and (b) receiver with spectrums.

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 onlyincreases the battery life but also reduces the physical size. Using a high gain antenna at the receiver we couldreduce the tissue effect by 20 dB and more [23]. The 50 MHz data stream is obtained at the FPGA after the demodulationprocess. 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 forelectronic pill technology in order to visually examine thedigestive tract wirelessly with better and detailed images.

Techniques and methodologies have been presented in thispaper for the use of wideband technology in a miniaturizedelectronic pill to provide a high capacity wireless channel. A prototyping system including UWB transmitter/receiver andantennas has been developed to investigate the feasibility of ahigh data rata transmission for the electronic pill technology. Integration of antenna with the UWB transmitter electronicshas been considered in a capsule shaped structure. Althoughit is known that tissue imposes strong attenuation at higher frequencies, we have shown there are some advantages to useDue to the high data rate capacity (e.g. 100 Mbps), awideband electronic pill can transmit raw video data withoutany compressing, resulting low-power, less delay in real-timeand increased picture resolution. With a high definitioncamera such as 2 megapixels, UWB telemetry can send up to10 frame per second (fps). We believe that the wideband pill systems for medical professionals to analyze real-time videoand image data wirelessly as a less invasive method.

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