

**Review on the Electronic Pill system**

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Abstract—Annually, millions of people in the world suffer GI disease serious enough to require hospitalization. In over one-third of these cases, the cause is never found. Despite standard invasive examination techniques, much of the GI tract's inner workings remain a mystery. Swallowable capsules have been evolving for almost half a century and are now helping uncover GI tract mysteries in diagnostic and therapeutic applications. The electronic pill is one of the most efficient drug delivery system. It uses four sensors , controller , antenna , power source and additional circuitry . This paper deals with the detailed working of batteryless electronic pill , Technical challenges occurring in fabrication of an electronic pill and research data from commercial capsules

I. INTRODUCTION

The electronic pill is a drug delivery device consisting of four sensors. They are Silicon diode (Temperature Sensor) , ion-Sensitive Field-Effect Transistor (Ion concentration Sensor) , Direct contact gold electrode (Conductivity Sensor) , three-Electrode Electrochemical Cell (Sensor used to calculate rate of dissolved oxygen and identify the activity of aerobic bacteria in small and large intestine) . It also consists of a Loop Antenna , Microcontroller , Power circuitry and additional circuitry as per the need of application.

The whole system consists of the electronic pill and external circuitry for wireless power transmission (for wireless electronic pill) and software's used for data processing .An electronic pill may have an inbuilt battery or could also be batteryless using wireless energy transfer .

There are a good number of manufacturers of electronic pills , but Olympus and Given Imaging are the major commercial vendors .There are many technical challenges in the fabrication of the electronic pill such as its size , biocompatibility , interference with medical instruments and power supply.

There has been research conducted on the use of Ultra Wide Bandwidth for communication in the system of electronic pills which has its own advantages and disadvantages which is explained in the latter part of the paper.

II. THEORETICAL ANALYSIS**A. Batteryless Electronic pill**

Currently, the battery, one of the essential components in electronic pills, provides the power source to the active electronic components in the device. Although small miniature rechargeable battery technologies are available, the lifetime they provide may not satisfy the desired operation time for detecting and transmitting enough useful data from inside the body. Current electronic pills have limited operational time as a result of the battery technology used. One way to enhance this operational lifetime is to charge the battery wirelessly. Alternatively, a completely wireless power system could also be used. In batteryless systems, it is necessary to bring the charging transmitter very close to the patient's skin to charge the electronic pill. Unlike conventional implant systems longer- range wireless power transfer is required for electronic pills, which needs to transfer energy efficiently through the 15–20 cm thick skin in order to reach the device inside the body. Wirelessly energizing electronic pills was studied early in the development of the first electronic pills. One of the first electronic pills used an inductive link for wireless power transfer. The cylindrical shaped pill was 0.7 cm in diameter and 2.5 cm in length. A large circularly shaped coil connected to an external source was placed around the body to energize the capsule while inside the body. The batteryless pills in and operate based on passive telemetry. They utilize a resonant circuit whose characteristic frequency is sensed from the outside. This capsule operates in a similar fashion as current reflective RFID technology. Electronics pills with wireless power sources are generally smaller in size than a battery-powered capsule, with the further advantage of the virtually unlimited device life they provide.

Figure 1 shows the block diagram of an electronic pill system. The electronic pill system has four sensors - Silicon diode (Temperature Sensor) , ion-Sensitive Field-Effect Transistor (Ion concentration Sensor) , Direct contact gold electrode (Conductivity Sensor) , three-Electrode Electrochemical Cell (Sensor used to calculate rate of dissolved oxygen and identify the activity of aerobic bacteria in small and large intestine) it takes data from the four sensors and amplifies and filters it .This data is given to the multiplexer for input selection . In addition to the sensors the system also has a camera .The data from the sensors and the camera is given to the microcontroller for processing of data from the

sensors and camera .The controller receives the power from a wireless power source which is attached externally as a belt to the user/patient .The external source consists of wireless links which serves as a medium for the transfer of data from the electronic pill to the computer . The results of processing of data from sensors and camera can be seen and processed on the computer . Technical details of freq. voltage

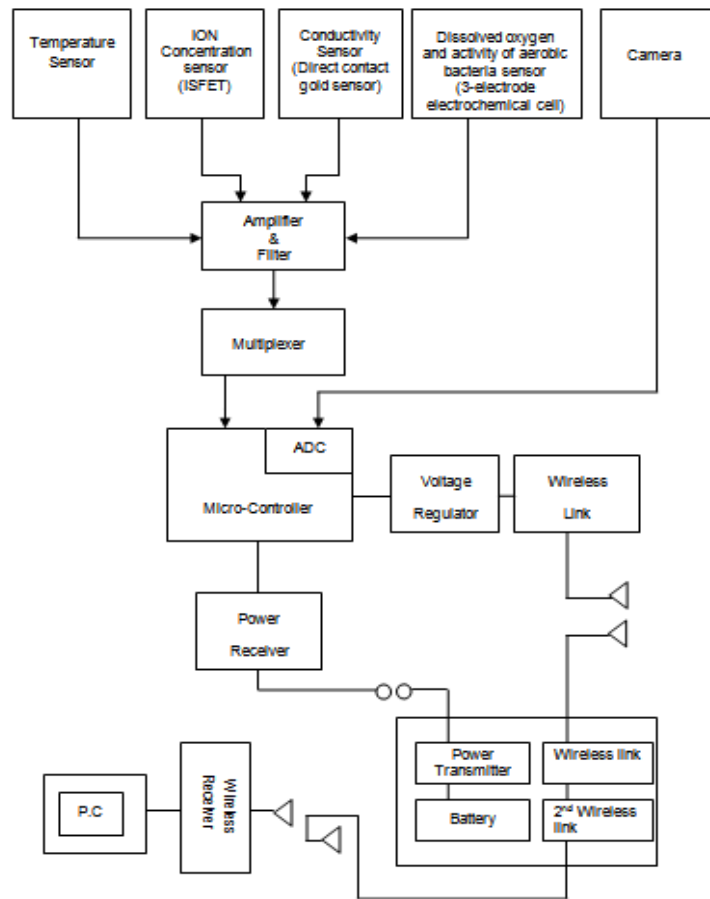


Figure 1. Block diagram of electronic Pill system .

B. Hardware Design transmitter

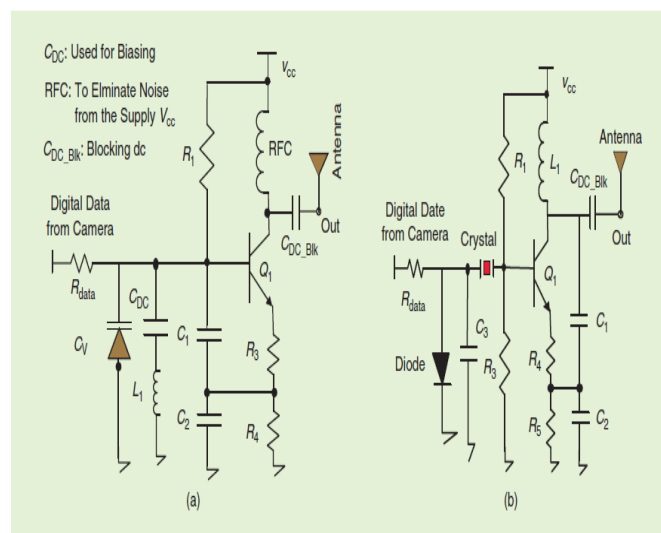


Figure 2. E-pill transmitters based on RF Colpitts oscillator: (a) a common collector Colpitts oscillator and (b) a common base Colpitts oscillator with crystal.

The earliest electronic pills and even more recent ones use a transmitter circuit. With respect to figure 2 the operation frequency of these transmitters is established by the frequency selection filter consisting of $L1$, $C1$, and $C2$ as

$$\omega_0 = 1 / \sqrt{[(L1 \ C1 \ C2) / (C1 + C2)]} \quad (1)$$

To measure pressure inside the body with early electronic pills, a diaphragm was used to move an iron core inside the oscillation coil ($L1$). As the induction changes, the amount of the frequency change was dependent on the pressure change. In the case of video imaging in modern electronic pills, digital data converted from image signals are applied to the input, as shown in. The transmitter uses a varactor (variable capacitor; C_v) to generate FSK or FM modulated signals for wireless transmission of medical data or images. The value of the variable capacitor C_v changes with respect to the amplitude of the input signal, which could be image data from a camera, or a physiological signal such as temperature or pH level in electronic pill applications. In a real implementation, the values of inductors and capacitors will have tolerance variations that will result in potential offsets in the transmission frequency, making it difficult to recover the transmitted signal at the receiving site. One way to overcome this issue is to use a crystal to maintain the oscillator frequency at the desired transmission frequency.

The electronic pill system presented uses this technique for the transmitter. When the input signal is one, the diode conducts and $C3$ is short circuited. When the input signal is zero, the diode does not conduct. This binary switching either keeps capacitor $C3$ in the circuit or shorts $C3$ out, modifying the output frequency according to the bit pattern. As a result, two different frequencies will be generated for bit 0 and bit 1, forming an FSK modulated signal. The receiver circuits for the transmitters given in are easily constructed from the radios available in commercial domain. As it is outside the body, the size and power consumption of the receiver is not critical. When a number of similar types of electronic pill systems are used in the same environment, these simple transmitters face the problem of interference and packet collisions and, therefore, lack the multiuser (i.e., multiaccess) capability. The packet collisions occur when more than one user transmits information at the same time; as a result, the required information from each user may be lost. In order to distinguish signals from two electronic pills given to two patients located in the same room, each telemetry should use a pseudo noise (PN) code for identification so that the receiving device can identify the individual electronic pill.

C. Technical challenges

The foremost challenge is miniaturization to obtain an ingestible device. The availability of small-scale devices can place severe constraints on a design, and the interconnection between them must be optimized.

The next vital challenge is to reduce power consumption. In battery-powered devices, the battery itself is likely the largest system component. Also, inductive links can handle only low levels of energy. Therefore, designers must minimize both supply voltage and current consumption while using high-efficiency topologies to achieve the required system performance.

Another challenge involves communication. In particular, the generated wireless signal must not interfere with standard hospital equipment but still be sufficiently robust to overcome external interferences.

The last challenge concerns encapsulating the circuitry in appropriate biocompatible materials to protect the patient from potentially harmful substances and to protect the device from the GI's hostile environment. The encapsulation of contactless sensors (image, temperature, and so on) is relatively simple compared to the packaging of chemical sensors that need direct access to the GI fluids.

D. Research in Commercial Capsules

The commercial vendors of the electronic pill have brought out some new advancements in the technology of the electronic pill. They are classified into four main categories such as i) temperature measurement, ii) imaging techniques, iii) Multisensor systems and iv) drug delivery systems. They are explained in details in the following section.

i) Temperature measurement

Ingestible Thermometer pill developed by NASA was tested on Astronauts working in a hostile space environment with temperatures varying from 120°C to -150°C . The device contained a single-cell nickel cadmium battery that was wirelessly recharged before its use, giving a long shelf life. The frequency of the transmitted near-field signal was directly proportional to the temperature to a good of sensor resolution of approximately 0.1°C .

ii) Imaging techniques

Capsule endoscopy emerged through the '80s and '90s and has become a realistic alternative to standard wired endoscopy. Capsule endoscopes couple one or more imaging devices with a lighting source to capture images of the GI tract, including the small intestine. For the patient, such capsules offer a convenient examination with minimal

preparation and immediate recovery. The main vendors are Olympus and Given Imaging . Olympus received one of the first major patents in 1981. The proposed device applied strong magnetic fields outside the body to control the capsule's displacement and orientation in the stomach, to turn the light on, and to trigger the shutter opening. It initially contained no intelligence or processing capability, and the capsule had to be opened to retrieve the images. The design has evolved to miniaturize the capsule and improve image quality. The latest capsule boasts excellent image quality, brightness adjustment, real-time video viewing, and the ability to activate and deactivate the capsule.

Given Imaging has developed two distinct capsules: PillCam ESO for the esophagus and PillCam SB for the small bowel .



Figure 3. PillCam: (a) the capsule's relative size, and PillCam-produced images of (b) a healthy small intestine and (c) an esophagus. (images courtesy of Given Imaging)

Both capsules measure 11 mm in diameter and 26 mm in length. RF data transmission at 433.10 MHz to an external antenna network enables the transfer of two to eight frames per second. The device, powered by silver oxide batteries, can provide over five hours of continuous video recording.

Given Imaging provides a complete analysis system including the pill, a data recorder, a docking station, and Rapid, a software package for displaying and analyzing images and generating full medical reports. The company is developing a third capsule, PillCam Colon, for the colon and large intestine. It will also soon release the recently FDA approved second generation of SB and ESO capsules. Full FDA approval has given the company an advantage over its competitors; as a result, PillCam is available in almost every developed country.

The RF System Lab has been developing the Norika3 system since 1998. Unlike PillCam, which uses CMOS (complementary metal-oxide semiconductor) image sensors, this device uses a CCD (charge-coupled device) image sensor. This results in superior image quality but with much greater power consumption due to the intense digital signal processing involved. To tackle the power requirement, the capsule transmits raw sensor data, while the processing, which consumes over 90 percent of the power, occurs outside the body. The capsule, 9 mm in diameter and 23 mm long, is the smallest endoscopy capsule. It has four illumination LEDs with different light wavelengths. Three-dimensional coils within the capsule allow optimum power recovery from the inductive link. The system consists of the capsule; a vest with power transmission coils; a joystick-like device to control the capsule and a PC system for signal processing , image display, and data storage.

The second-generation capsule Sayaka, introduced in December 2005, operates on the same principle but has the lens on its lateral surface instead of its end. The imaging device is rotated within the capsule by steps of 7.5 degrees and provides approximately 30 frames per second, giving overall higher resolution.

iii) MultiSensor systems

The SmartPill Corporation has integrated temperature, pressure, and pH sensors into a single capsule, the Smart-Pill pH. The company promotes the device as a complement to endoscopy with the potential to replace gastric-emptying scintigraphy. The SmartPill GI Monitoring System includes the capsule, a wireless data receiver, a receiver docking station, and MotiliGI software.

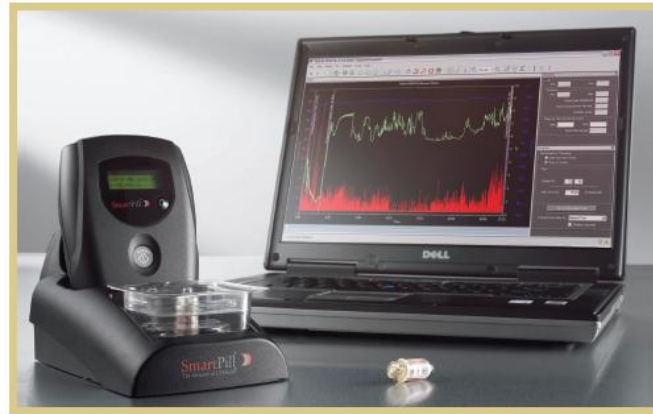


Figure 4. The SmartPill GI Monitoring System includes the SmartPill pH.p, a receiver, a docking station, and a PC user interface.

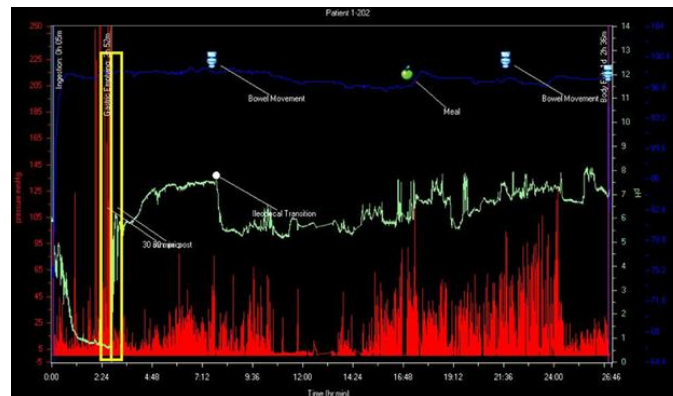


Figure 5. Output of the MotiliGI software.

A powerful magnet activates an internal latching switch that provides a connection between the electronics and the battery. Once the capsule is activated, it begins working and transmits data to the mobile-phone-sized receiver (worn on the patient's belt). The receiver, in turn, transfers the data wirelessly to a PC in real time. The SmartPill, which has a 13-mm diameter and is 26 mm long, measures temperature to an accuracy of $\pm 0.5^\circ\text{C}$, pressure resolution to ± 3.6 mm HG, and pH to ± 0.28 . It uses the sensor data in addition to real and elapsed time measurements to provide gastric emptying time, combined small and large intestine transit time, contraction patterns, and a motility index. To optimize the device's performance, the pill samples at a high rate for the first 24 hours and then at a decreased rate as the pill approaches the end of its journey. MotiliGI can plot the acquired data against time, providing invaluable information in the diagnosis of motility disorders such as gastroparesis (slowed passing of solids from the stomach). The pill underwent extensive clinical trials and consequently received FDA approval in July 2006.

iv) Drug delivery systems

Another interesting area of swallowable capsule technology is in-vivo drug delivery or, conversely, sample extraction. Pharmaceutical Profiles is researching drug absorption using the patented Enteron capsule developed by Phaeton Research. The capsule is 32 mm long and 11 mm in diameter

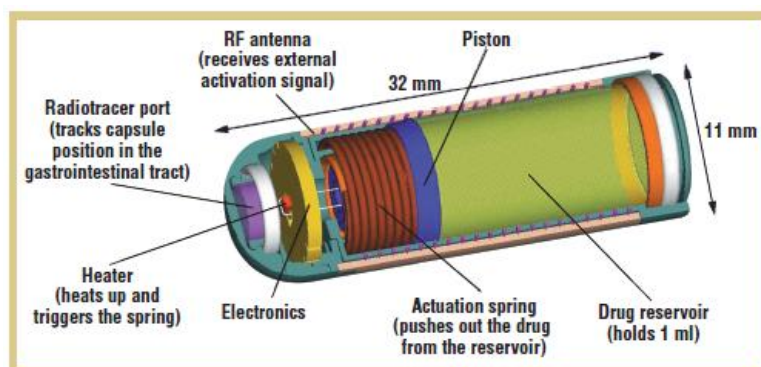


Figure 6. The Enteron drug delivery Piston capsule.

It can hold up to 1 ml of liquid or powder, which it can expel at a target site in the body. The capsule contains a small amount of gamma-emitting tracer, allowing precise tracking in real time using an external gamma camera. When the capsule reaches the target area, an external electromagnetic field actuates the capsule's piston, ejecting the payload. The shell then passes harmlessly out of the body.

IV. CONCLUSION

Integrated biomedical technology might well be the key to the first major scientific revolution of the 21st century, comparable to the semiconductor revolution of the late 20th century. Advances in areas such as nanotechnology, microrobotics, micro power generation, and materials science will present more interesting and exciting opportunities for capsule research projects to exploit. As capsule hardware evolves so too will computing and communication capabilities. Full integration of multiple capsules with implants of other kinds and external diagnostic equipment will move swallowable-capsule technology toward body sensor networks for pervasive patient monitoring. In the years to come, capsules will become smaller and perform more complex diagnostic and therapeutic functions in the human body.

V. FUTURE SCOPE

Future pill systems should be developed that incorporate the following significant design requirements:

- *Multiaccess communication techniques* should be developed to allow the operation of multiple pill devices, as well as monitoring a group of patients within the same environment.
- *Small size antennas*. One challenge observed in the literature for implanted/injected antenna design is the variation of the antenna resonant frequency due the layers of skin, as well as in-body environment conditions. One approach to tackling this is to design the antenna for broadband matching, of which any shift in the 10 dB return loss bandwidth of the antenna is still within the operating frequency of the radio system.
- *The external unit*: This unit should also be miniaturized so that it can be easily wearable by patients.
- *Biodegradable batteries* : Biodegradable power source such as sodium can be used so as to cause no harm to the host organism .

REFERENCES

- [1] Mehmet R. Yuce, Tharaka Dissanayake, Ho Chee Keong, "Wireless Telemetry for Electronic Pill Technology" School of Electrical Engineering and Computer Science, The University of Newcastle, pp. 4-5.
- [2] Mehmet R. Yuce and Tharaka Dissanayake, "Easy-To-Swallow wireless telemetry", pp.3-11.
- [3] Colm Mc Caffrey, Olivier Chevalerias, Cian O'Mathuna, Karen Twomey "Swallowable capsule technology", pp. 1-5.