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Innovation and Review in, Health Monitoring Systems and Wearable Medical Sensors

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1. Abstract

This paper presents wearable sensors for medical application and medical systems. The sensors and antennas were developed and measured in vicinity of the human body. The electrical characteristics of human body tissues were considered in the design. Healthcare and wearable industry have been in continuous growth in the last decade. There is a continuous increasing demand for wearable personal medical sensors. Wearable technology provides a powerful new tool to medical services, surgical rehabilitation services and medical Internet of Thing, IoT, systems. Wearable Wireless Body Area Networks, WWBANs, can record electrocardiograms, measure body temperature and blood pressure, measure heartbeat rate, arterial blood pressure, electro-dermal activity, sweat, and other healthcare parameters the collected information can be transferred online to the physician or stored in the medical center database. Wearable medical sensors became an important part of individuals' daily lives especially during and after COVID19 pandemic. Wearable medical sensors provide scanning and sensing features that are not offered by cellular phones and laptop computers.

Wearable wireless devices usually have communication capabilities and user may access information in real time. Several wireless technologies are used to handle the data collection and processing by medical monitoring systems. The collected raw data may be fed to a database of a medical Center to analyse rapidly the collected data. This analysis typically results in a response that might alert a physician to contact a patient who is experiencing abnormal symptoms. This paper presents innovation and a short review of health monitoring systems and wearable medical sensors.

2. Introduction

The main goal of monitoring systems and wearable medical sensors is to increase disease prevention. By using more wearable medical sensors and devices a person can handle and be aware of his private health. Online analysis of continuously measured medical data of large number of medical centers patients may result in a better efficient low-cost medical treatment. Wearable devices have several applications in personal wireless communication, medical monitoring systems, IoT devices, RFID, medical and sport sensors as presented in [1-8]. Medical monitoring systems and medical devices were developed in the last twenty years to provide powerful new tools to medical services and to monitor patient health as discussed and presented in books and papers [9-44]. In [9] Vital signs monitoring and patient tracking over a wireless network is presented. In [10] WBAN-based system for health monitoring at home is presented. A biometric method to secure telemedicine systems is presented in [11]. In [30] a wireless body area network with an adaptive thermal-aware protocol is presented. In [31] a secure thermal-energy aware protocol is discussed. Motion and gait sensors are presented in [32-44]. Medical test results of the wearable sensors on the human body were presented in this paper. Measured results of the wearable sensors using a phantom were presented.

3. Review of Wearable Medical Systems Applications

One of the main goals of wearable medical systems is to maximize disease prevention. By using more wearable medical devices a person can handle and be aware of his private health. Sophistically analysis of continuously measured medical data of large number of medical centers patients may result in a better efficient low-cost medical treatment.

Applications of Wearable Medical Sensors and Systems

• Wearable Medical sensors and devices may help to monitor hospital activities

• Wearable sensors and devices may help to operate and monitor home accessories

• Wearable sensors and devices may help to operate and monitor IOT devices

• Wearable sensors and medical devices may assist Asthma patients

• Wearable Medical sensors and devices may assist Diabetes patients

• Wearable Medical sensors and devices may help in solving sleep disorders

• Wearable Medical sensors and devices may assist in solving Obesity problems

• Wearable Medical sensors and devices may assist in solving cardiovascular diseases

• Wearable Medical sensors and devices may assist Epilepsy patient

• Wearable Medical devices may help in treatment of Alzheimer's disease patients

• Wearable Medical sensors and devices may help to gather data for clinical research trials and academic research studies

3.1 Physiological Parameters Measured by Wearable Medical Systems

Several physiological parameters may be measured by using wearable sensors and medical devices. Some of these physiological data is presented in this section.

3.1.1. Measurements of the Patient Blood Pressure and Heartbeat Rate: Blood pressure indicate what is the arterial pressure of the blood circulating in the patient body. Some of the causes of changes in the blood pressure may be stress and overweight. Blood pressure of a healthy person is around 80 by 120. Where the systole is 120 and the diastole is 80. Ten percent changes above or below these values is a matter of concern and should be analyzed. Usually, blood pressure and heartbeat are measured in the same set of measurements. The Blood pressure and heartbeat may be transmitted to the physician and to the medical Center online. The physician may contact the patient for further treatment.

Measurements of heartbeat rate is one of the most important tests taken to examine the health of a patient. A change in the heart rate will change the blood pressure and the amount of blood delivered to the body organs. The heart rate of a healthy person in around 75 times per minutes. Changes in heartbeat may cause several types of cardiovascular diseases. Usually, heart rate is measured by using a stethoscope. However, this is a manual test and is not so accurate. To measure and analyse the heart beat a wearable medical device may be connected to patient chest.

3.1.2. Measurements of Respiration Rate: Measurements of respiration rate indicates if a person breathes normally and if the patient is healthy. Elderly and overweight people have difficulties in breathing normally. Wearable medical devices are used to measure a person respiration rate. A wired medical device used to measure respiration rate may cause uneasiness to the patient and cause an error in measurements of respiration rate. It is better to use a wireless medical device to measure respiration rate. The measured respiration rate may be transmitted to the physician and to the medical Center online. The physician may contact the patient for further treatment.

3.1.3. Wearable sensors Tracking and Monitoring Staff and Patients inside a Medical Centers: Each patient may have a wearable device attached to the body. The wearable device is connected to several sensors and each sensor has its own specific task to perform. For example, one sensor node may be detecting the heart rate and body temperature while another is detecting the blood pressure. Physicians can carry a wearable device, which allows other hospital personnel to locate them within the hospital.

3.1.4. Measurements of the Patient Temperature: The temperature of a healthy person ranges between 35˚C to 37.5˚C. Temperatures below or above this range may indicates that the person is sick. It is important to measure accurately the patient temperature, patient temperature above 40˚C may cause death. The human body temperature may be transmitted to the physician and to the medical Center online. The physician may contact the patient for further treatment.

3.1.5. Measurements of Sweat Rate: Glucose is supplied to the human body usually as a sugar that is a monosaccharide that provide the primary energy source to the human body. When a person does extensive physical activity, glucose come out of the skin as a sweat. A wearable medical device may be used to monitor and measure the sweat rate of a person or an athlete. A wearable medical sensor may be attached to the person clothes in proximity to the skin to monitor and measure the sweat rate. This wearable sensor may be used to measure the sweat PH that may be used to diagnose diseases. Measurements of sweat rate and PH may be used to monitor the physical activity of a person. The water vapor evaporated from the skin is absorbed in the wearable sensor to determine the sweat PH. If the amount of sweat, coming out of the body is too high the body may dehydrate. Dehydration causes tiredness and fatigue.

3.1.6. Measurements of Human Gait: Human gaits are the various ways in which a human can move. Movements of human limbs are called human Gait. Different gait patterns are characterized by differences in limb movement patterns, overall forces, velocity, kinetic and potential energy cycles, and changes in contact with the ground. Walking, jogging, skipping, and sprinting are defined as natural human gait. Gait analysis is a helpful and fundamental research tool to characterize human locomotion. Wearable sensors may be attached to different parts of the human body to measure and analyze human gait. The movement signal recorded by these sensors can be used to analyze human gait. Temporal characteristics of gait are collected and estimated from wearable accelerometers and pressure sensors inside footwear. In sports, gait analysis based on wearable sensors can be used for sport training and analysis and for the improvement of athlete performance. The ambulatory gait analysis results may determine whether a particular treatment is appropriate for a patient. Motion analysis of human limbs during gait is applied in pre-operative planning for patients with cerebral palsy and can alter medical treatment decisions. Parkinson's disease is characterized by motor difficulties, such as gait difficulty, slowing of movement and limb rigidity. Gait analysis has been verified as one of the most reliable diagnostic signs of this disease. For patients with neurological problems, such as Parkinson's disease and stroke, the ambulatory gait analysis is an important tool in their recovery process and can provide low-cost and convenient rehabilitation monitoring. Fall is a major threat to health and independence among elderly people. Gait analysis using wearable devices was used to analyse and predict fall among elderly patients. Gait analysis based on wearable devices may be applied in healthcare monitoring, such as in the detection of gait abnormalities, the assessment of recovery, fall risk estimation, and in sport training. In healthcare centers, gait information is used to detect walking behaviour abnormalities that may predict health problems or the progression of neurodegenerative diseases.

4. Monitoring Systems and Wireless Body Area Networks (WBANs)

The main goal of WBANs is to provide continuously biofeedback data. WBANs can measure body temperature and blood pressure, record electrocardiograms, measure heartbeat rate, arterial blood pressure, electro-dermal activity, and other healthcare parameters in an efficient way. For example, accelerometers can be used to sense heartbeat rate, movement, or even muscular activity. Body area networks (BAN) includes the applications and communication devices using wearable and implantable wireless networks. WBANs continuously provide biofeedback data about the patient health. WBAN offers freedom of movement to patients and users. The patient can move freely in the medical center and even leave the medical center. A sensor network that senses health parameters is called a body sensor network (BSN). A wireless body-area network (WBAN) is a special purpose wireless-sensor network that incorporates different networks and wireless devices to enable remote monitoring in various environments.

Wireless monitoring of physiological signals of large number of patients is needed in order to deploy a complete WSN in healthcare centers. Human health monitoring is emerging as a significant application of embedded sensor networks. A WBAN can monitor vital signs, providing real-time feedback to allow many patient diagnostics procedures using continuous monitoring of chronic conditions, or progress of recovery from an illness. Recent technological advances in wireless networking promise a new generation of wireless sensor networks suitable for human body wearable network systems. An application of WBANs in medical centers where conditions of large number of patients are constantly being monitored as presented in Fig. 1 to Fig.3. Figure 1 presents a monitoring systems and Wearable Body Area Network, WBAN. Several sensors, such heart rate, gait, and sweat sensors, are placed on a patient body. Figure 2 presents a medical emergency center and hospital monitoring systems and Wearable Body Area Network, WBAN, with several wearable sensors.

Data acquisition in WBAN sensors and devices may be point-to-point or multipoint-to-point, depending on the specific application. Detection of an athlete's physical and health condition requires point-to-point information sharing through various wearable sensors. Human body monitoring of vital signs will require to route data from several wearable sensors, multipoint- to-point, to a specific node, which in turn can relay the information wirelessly to a computer or to a medical center database. Data may be transferred in online mode or stored in a computer for analysis when needed. Human body monitoring applications require online data transfer. Monitoring an athlete's physiological data may be collected offline and stored for processing and analysis purposes.

A typical wireless body area network consists of number of compact low-power sensing devices, control unit and wireless transceivers. The power supply for these components should be compact, lightweight, and long-lasting as well. Moreover, energy harvesting devices may be used to charge the battery. WBANs consists of several compact low volume devices. To improve the efficiency of WBAN it is important to minimize the number of nodes in the network. Adding more devices and path redundancy for solving node failure and network problems is not recommended in WBAN networks. WBANs receive and transmit a large amount of data continuously. Data processing must be hierarchical and efficient to deal with asymmetry of several resources, to maintain system efficiency and to ensure the availability of data. WBANs in a medical center consist of wearable and implantable sensors nodes that can sense biological information from the patients and transmit it over a short distance wirelessly to a control wearable device or a device placed in an accessible location. In WBAN networks the sensor electronics must be miniaturized, low-power and detect medical signals such as pulse rate, electrocardiograms, pressure, electroencephalography, and temperature. The gathered data from the control devices are transferred to remote computing devices in a wireless body-area network for diagnostic and therapeutic purposes by including other wireless devices for long-range transmission.

A wireless control unit is used to collect data from sensors through wires and transmit it to a remote station for monitoring.

Figure 3 presents IoT wireless wearable body area network (WBAN) and a hospital health monitoring system architecture.

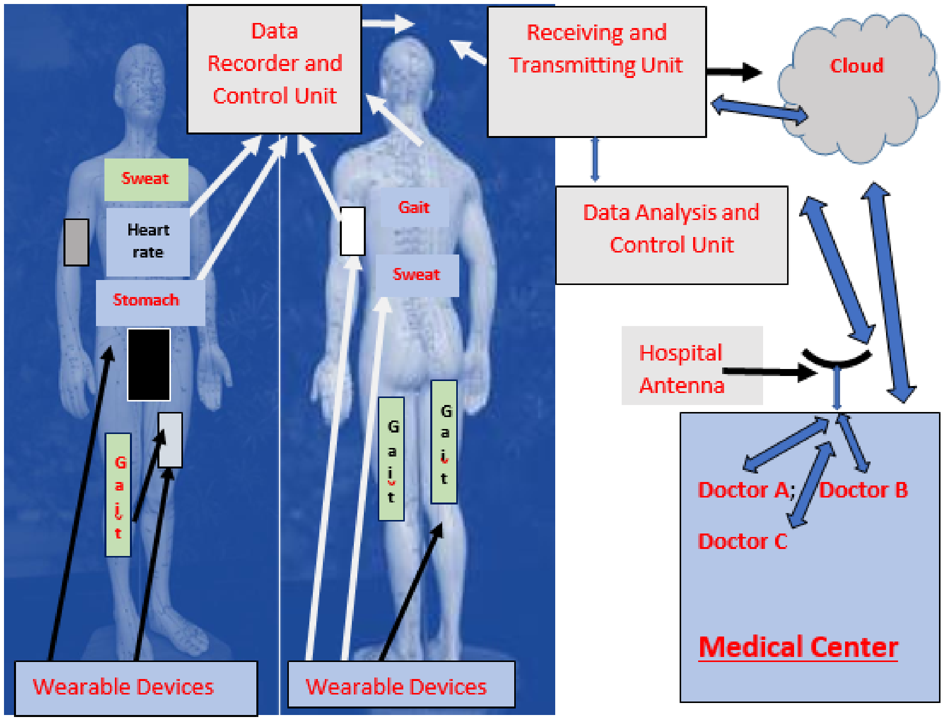


Figure 1: Monitoring systems and Wearable Body Area Network, WBAN.

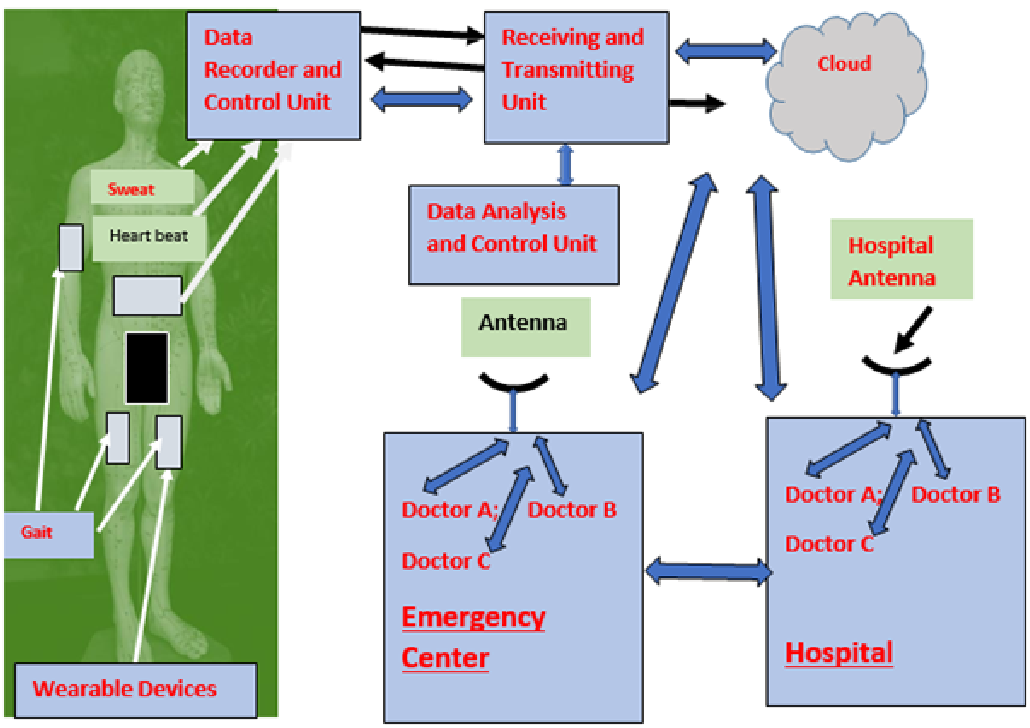


Figure 2: Medical centers Monitoring Systems and Wearable Body Area Network, WBAN.

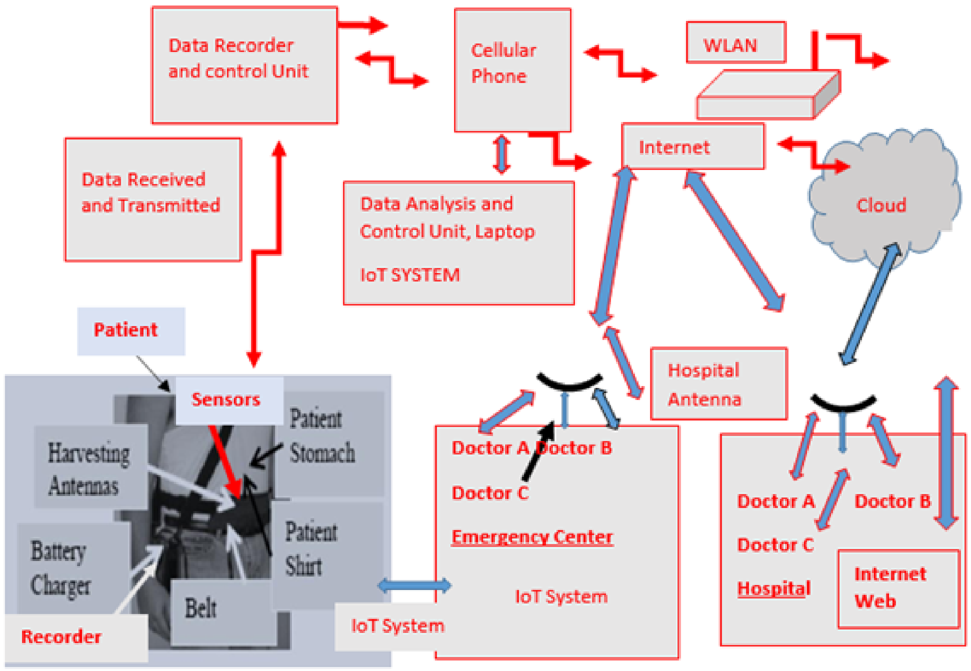


Figure 3: IoT wireless wearable body area network (WBAN) and health monitoring system architecture.

5. Development of Compact Wideband Wearable Sensors for Medical Applications

Development of Compact efficient wearable antennas are one of the major challenges in development of wearable communication, IoT, and medical systems. Body area network (BAN) antennas should be flexible, lightweight, compact, and have low production cost. However, low efficiency is the major disadvantage of small, printed antennas. Wearable antennas can receive or transmit electromagnetic energy from inside the human body or from outside the human body. Design and development of wearable antennas should consider the effects of the human body on the electrical parameters of the antenna. If the radiator is inside the human body and the wearable antenna is placed near or on the body there is a strong interaction between the body tissues and the antenna. However. If the radiated power is from outside the body and a ground plane separate between the body and the radiating element of the wearable antenna, for example microstrip antennas, there is a small interaction between the body tissues and the antenna. In several medical applications loop antenna is used. The loop antenna is referred to as the dual of the dipole antenna. A small dipole, compared to wavelength, has magnetic current flowing (as opposed to electric current as in a half wave dipole), the fields would resemble that of a small loop. The directivity of a loop antenna with circumference of 0.5λ long is around 1dBi. Loop antennas have low radiation resistance and high reactance. It is difficult to match the antenna to a transmitter. Loop Antennas are most often used as receive antennas, where impedance mismatch loss can be accepted. Small loop antenna is used in medical devices as field strength probes, in pagers and in wireless measurements. A BALUN transformer is connected the loop feed lines. BALUN transformer is a transformer from a balance transmission line to unbalance transmission line. The transformer may be used to match the loop antenna to the communication system. Photo of Loop antennas is shown in Figure 4. The loop antenna may be inserted to a sleeve a shown in Figure 4. The sleeve electrical properties were chosen to match the loop antenna to human body. The sleeve also provide protection from the environment to the antenna. Loop antennas behave better in vicinity of the human body than dipole antennas. The reason is that the electric near fields, $r< \lambda/ 2\pi$ is the distant of the field point to the radiating element, in dipole antenna are very strong. For r<<1, the dominant component of the field varies as $1/r^3$ and decay rapidly. In this case the waves are standing waves and the energy oscillate in the antenna near zone and are not radiated to the open space. The real part of the pointing vector equal to zero. Near the body the electric fields decays rapidly. However, the magnetic fields are not affected near the body. The magnetic fields are strong in the near field of the loop antenna. These magnetic fields give rise to the loop antenna radiation. The loop antenna radiation near the human body is stronger than the dipole radiation near the human body.

Several loop antennas are used as "wearable antennas". The loop antenna may be tuned by adding a capacitor or a varactor, as presented in Figure 5, and inserted inside a wearable belt. The loop antennas were printed on FR4 substrate with with 4.5 dielectric constant and 0.5mm thickness. The loop diameter is 45mm. The loop antenna VSWR, from 410MHz to 500MHz, without the tuning capacitor was 4:1 and is better than 2:1 at this frequency range with a tuning capacitor. Computed S11 of the loop Antenna with a tuning capacitor is presented in Fig. 6. The printed loop antenna radiation pattern at 435MHz on human body is shown Figure 7a, the loop antenna 3D radiation pattern is shown Figure 7a. The loop antenna gain is around 1.5dBi. The antenna with a tuning capacitor is shown in Figure 5. The antenna sensors shown in Figure 4 and 5 were inserted inside a belt that was worn on the patient shirt to receive the information transmitted from a capsule that the patient swallowed. All the sensors developed and presented in this were designed by using electromagnetic software [45]. There was good agreement between computed and measured results. The Capsule endoscopy parts and structure are presented in Figure 8. The antenna capsule transmits the data and photos taken by the capsule camera. The transmitted data is received by the wearable sensors and routed by coaxial transmission to a recorder.

the organs in the body that food and liquids travel through, as shown in Fig. 9. When food leaves the stomach, it enters the small intestine that is connected to the large intestine. The intestines are responsible for breaking food down, absorbing its nutrients and solidifying the waste. The small intestine is the longest part of the gastrointestinal (GI) tract. The camera takes thousands of pictures that are sent to a recorder worn on a belt around the waist. The physician analyzes the test result in his office. The physician uses analysis software and can decide if the patient is healthy or not. Patients wearing wearable sensors and recorders during endoscopy test are shown in Figure 10. These tests were taken to select the best sensor structure and location on the body. Typical results of this tests are presented in Figure 11a and 11b. The electrical characteristics of the wearable sensors are measured by using a phantom. The phantom is a fiberglass cylinder with 1.5m height and 0.4m diameter as shown in Figure 12. The thickness of the cylinder surface is around 2.5mm.

The phantom contains a mix of water, sugar, and salt. The relative concentration of water, sugar and salt determines the electrical characteristics of the phantom environment. A mixture of 55% water 44% sugar and 1% salt presents the electrical characteristics of stomach tissues. The phantom may be used to measure electromagnetic radiation from inside or outside the phantom. The phantom contains a plastic rod with 5mm thickness. The position of the plastic rod inside the phantom may be adjusted. The plastic rode may be rotated. A small transmitting antenna may be attached to the plastic rod at different height positions.

The antenna may be rotated in the x-y plane.

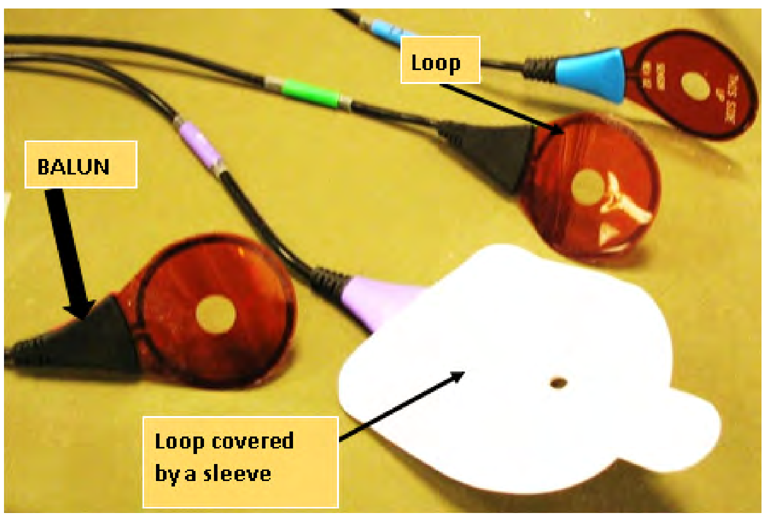


Figure 4: Fabricated Loop antennas with and without a sleeve

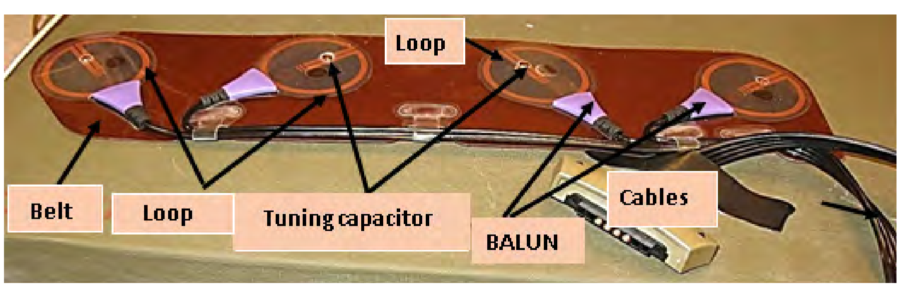


Figure 5: Fabricated Loop antenna array inside a belt.

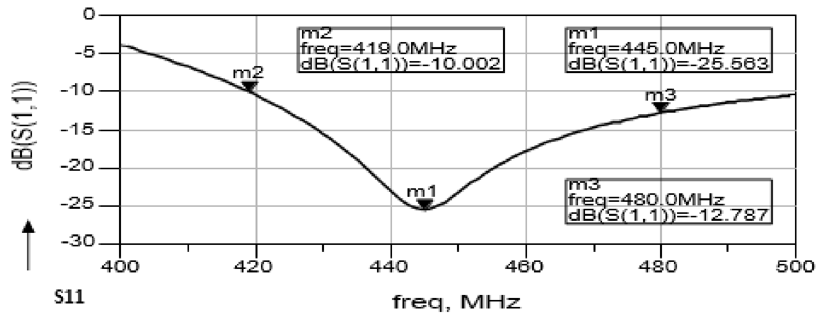


Figure 6: Computed S11 of Loop Antenna with a tuning capacitor.

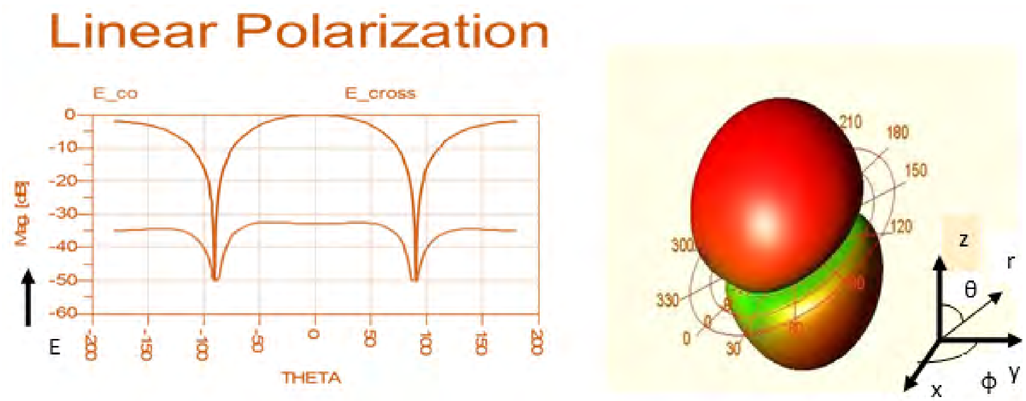


Figure 7: a. Radiation pattern of Loop Antenna on human body. b. 3D Radiation pattern

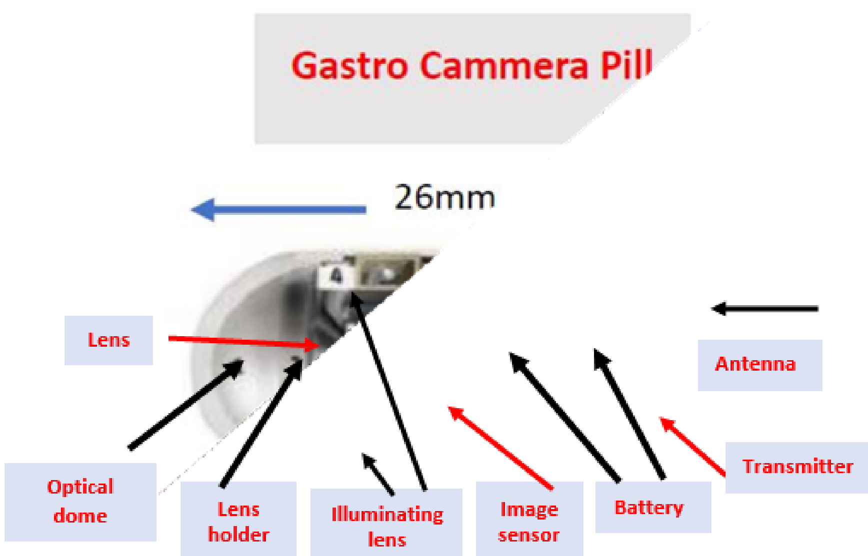


Figure 8: Capsule endoscopy parts and structure

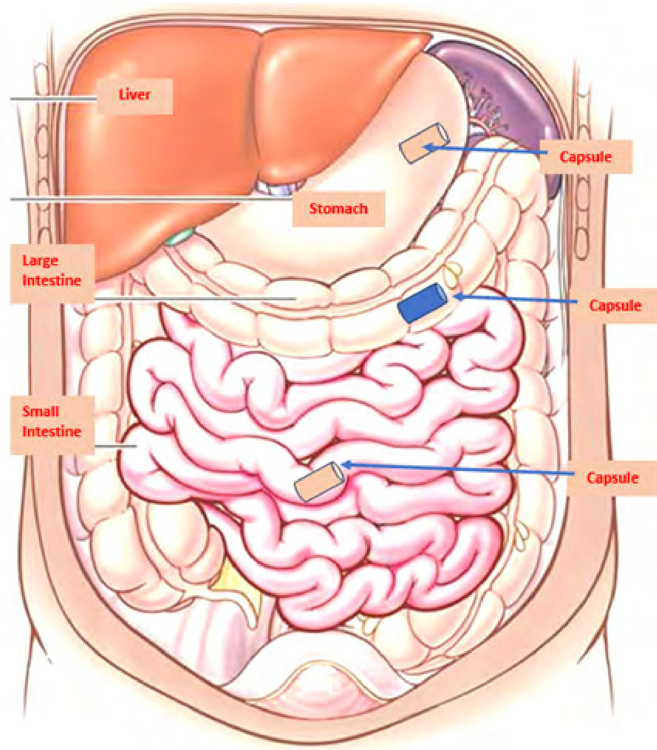


Figure 9: Digestive track of the endoscopy capsule.

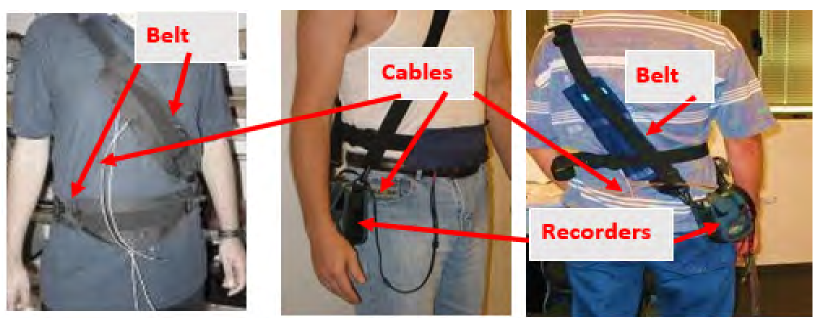
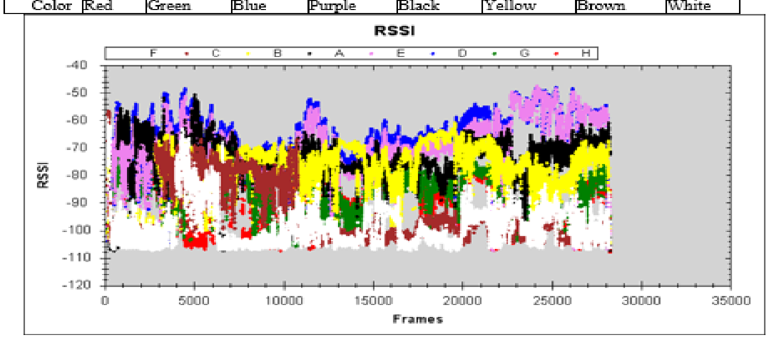
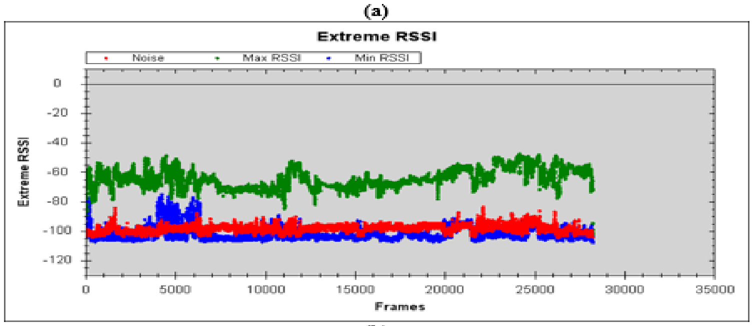


Figure 10: Patients wearing wearable sensors and recorder during endoscopy test

Cable	1	2	3	4	5	6	7	8
Label	H	G	D	E	A	B	C	F
Color	Red	Green	Blue	Purple	Black	Yellow	Brown	White



(a)



(b)

Figure 11: Endoscopy test recorded results a. Signal received by each sensor. b. Maximum signal value, green, Noise value, red, Minimum signal value, blue.

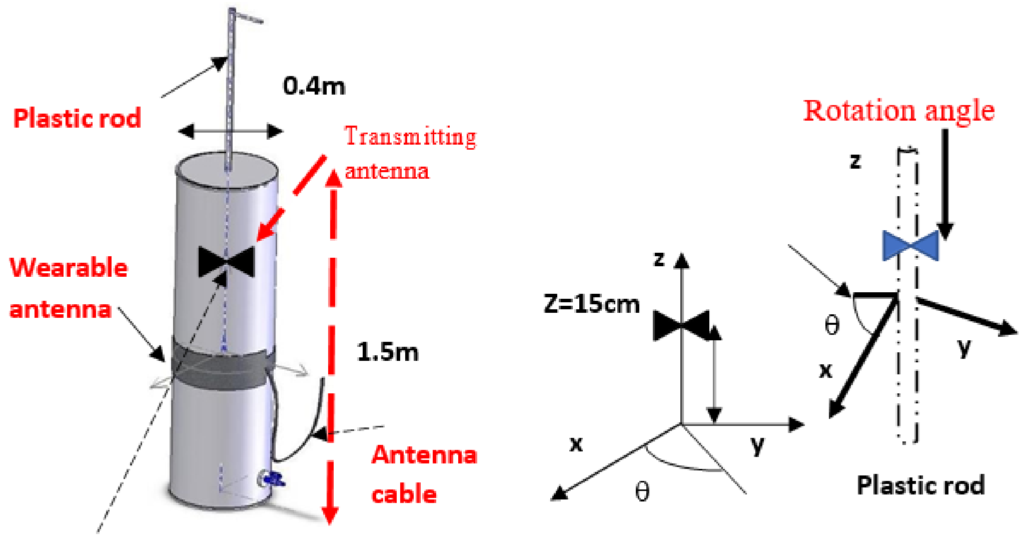


Figure 12: Measurement of wearable sensors using a Phantom with a rotated rod.

5.1. Phantom Test Procedure and Process

Test Procedure and Process is described below. The test checks two parameters of the antennas array:

- Signal reception levels

- Immunity to noise

5.2. Measured Antennas

1. The test checked the following antenna arrays:

2. Four sensor antenna arrays in a belt, antenna in orientations of +45°, +45°, +45°, -45°, presented in Fig. 13.

3. Sensor belt with four loop antennas in orientations of +45°, +45°, +45°, -45°

4. Sensor belt with four antennae in orientations of +45°, -45°, +45°, -45°

5. Thin belt with four sensor Array in orientations of +45°, -45°, +45°, -45°

6. Four loop antenna arrays in a sleeve

5.3. Test Process

- Place the antenna array on the phantom and connect to the recorder.

- Place the transmitter in the phantom in the following coordinates, 5 minutes for each location:

- Z values: from -15cm to +15cm in 15cm increments, zero being the level of the antennas center

- X values: from -5cm to -20cm in 15cm increments, zero being the container's wall where the antennas are attached.

- ɵ values: from 0° to 270° in 90° increments, 0° being perpendicular to the middle of the antennas set.

5.4. Immunity to noise

- Place the transmitter outside the phantom in the following coordinates, 5 minutes per each location:

- Z values: from -40cm to +40cm in 10cm increments, 0 represent the antennas center

- X values: 100cm from container's wall

- ɵ values: from 0° to 270° in 90° increments, 0° being perpendicular to the middle of the antennas set

The average best result was with case 5, four loop antenna array in a sleeve. The measured results of this case are summarized in Table 1. However, in some location and rotation angles in case 1 better results were achieved.

The receiving channel is part of the recorder and consists of receiving wearable antennas, RF head and a signal processing unit. The receiving channel main specifications are listed in Table 2. Block diagram of the receiving channel is shown in Figure 14. The receiving channel consists of an uplink channel at 434MHz and a downlink at 13.56MHz. The uplink channel consists of a LNA with 21dB gain and 1dB noise figure, switching matrix with 2dB losses, low noise amplifier and filter. The downlink channel consists of a transmitting antenna, antenna matching network and differential amplifier. The downlink channel transmits commands to the medical system. Receiving channel gain and noise figure budget is shown in Figure 11.3. The receiving channel, with the LNA noise figure, is around 1.2dB with 49dB gain. The dynamic range and the electrical performance of wearable systems and sensors may be improved by employing active sensors.

Figure 13: Sensor Belt with four Antennas in orientations of +45°, +45°, +45°, -45°, case 1.

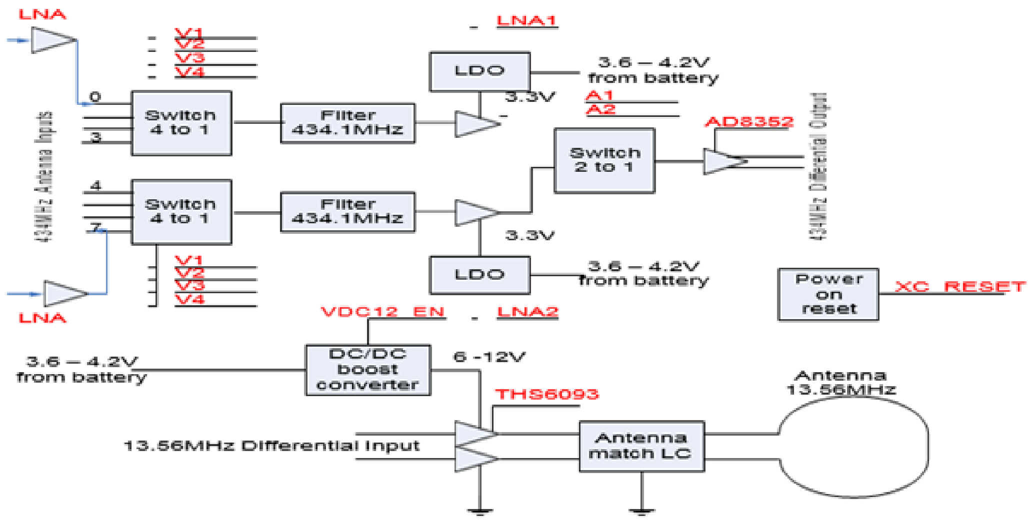


Figure 14: Receiving channel Block Diagram with LNA

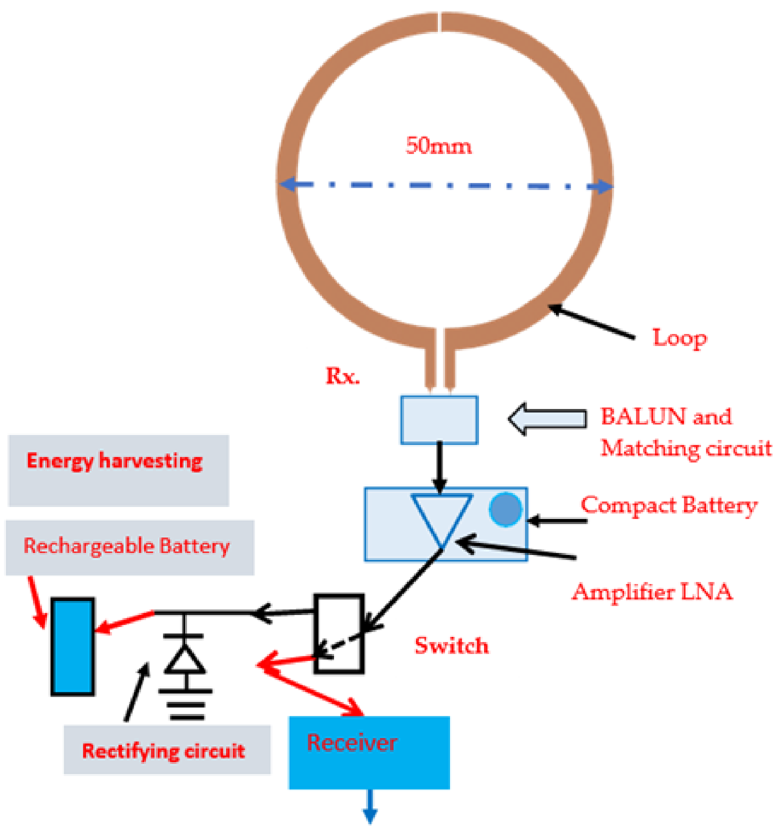


Figure 15: Green active loop antenna sensor with energy harvesting unit

Table 1: Measurements of Antenna case 5

Antenna1(X cm, Z cm)	Angle θ			
Z=0cm	0º	90º	180º	270º
Signal level(dB) X=-5, Z=0	-67	-52	-58	-60
Signal level(dB) X=-20, Z=0	-68	-70	-77	-78
Z=15cm				
Signal level(dB) X=-5, Z=15	-90	-86	-92	-90
Signal level(dB) X=-20, Z=15	-84	-86	-90	-86
Z= -15cm				
Signal level(dB) X=-5, Z=-15	-85	-90	-85	-92
Signal level(dB) X=-20, Z=-15	-90	-85	-75	-78
Noise test	Angle θ			
Z=0cm	0º	90º	180º	270º
Signal level(dB)	-70	70	-70	-70
Noise level(dB)	-90	-90	-90	-90
Z=40cm				
Signal level(dB)	-72	-72	-72	-72
Noise level(dB)	-90	-90	-90	-90
Z=-40cm				
Signal level(dB)	-73	-73	-73	-73
Noise level(dB)	-90	-90	-90	-90

Table 2: Receiving channel main specifications and measured results

Parameter	Specification	Measured results
Frequency range Up link	430- 440MHz	430- 440MHz
Return Loss(dB)	-9	-10
Group Delay	Maximum 50nsec for 12MHz BW	Maximum 50nsec for 12MHz BW
Input power	-30dBm to -60dBm	-30dBm to -60dBm
SNR	>20dB	>20dB
current consumption(mA)	50	45-55
Dimensions(cm)	12x12x5	12x12x5
Frequency range Down link	13.56MHz	13.56MHz
Received power Down link	-8dBm +/- 1dB	-8dBm +/- 1dB
current consumption(mA)	100-110	100-110

6. Green Active Receiving Wearable Sensor with Energy Harvesting Unit

Figure 15 presents a green active antenna sensor for medical applications with energy harvesting unit. The LNA, low noise amplifier, is an integral part of the antenna. A Minicircuits, E PHEMT LNA TAV541, low noise amplifier, is connected to the printed loop antenna. The loop antenna is etched on an FR4 substrate with a thickness of 0.005 mm. The loop antenna diameter is 50 mm. The radiating element is connected to the LNA via an input matching network. An output matching network connects the amplifier output port to the receiver. A compact DC bias network supplies the required voltages to the amplifier. The amplifier specifications are given in Table 1. The amplifier complex S parameters and noise parameters are listed in Mini-Circuits data sheet. The amplifier gain is around 25 dB at 100 MHz and decreases to 8 dB at 2 GHz. The loop antenna S11 parameter on a human body is presented in Figure 16. A textile sleeve covers the loop antenna to match the loop to the antenna environment. The radiating loop antenna and the textile sleeve are attached to the patient body. The antenna bandwidth, computed and measured, is around 20% for VSWR better than 3:1. The active loop antenna S21 parameters, gain, on human body, are shown in Figure 17. The active antenna gain is 25 ± 2.5 dB for frequencies from 350 to 580MHz. The active loop antenna noise figure is 0.7 ± 0.2 dB for frequencies from 400 to 900MHz. There is a good agreement between computed and measured results.

As shown in Figure 15 the energy harvesting unit is connected to the active loop antenna and consists of a rectifying circuit, and a rechargeable battery. The energy harvesting unit and the antenna provide a self-powered sensor. The rectifier diode converts RF energy, AC energy, to direct current (DC energy). Usually, two types of diode rectifiers are used a half wave or a full wave rectifier, [46-47]. A Half wave rectifier is presented in Figure 18a. The half-wave rectifier converts only the positive voltage half cycle. It allows to harvest only one half of the RF waveform and the efficiency of this rectifier is 40.6%.

A full wave bridge rectifier is presented in Figure 18b. The bridge rectifier consists of four diodes. During the positive half cycle voltage, terminal A will be positive and terminal B will be negative. Diodes D1 and D2 will become forward biased and D3 and D4 will be reversed biased. The full wave rectifier efficiency is 81.2%. Energy harvesting units can be connected to the sensors presented in this paper to provide green renewable energy and can eliminate the usage of power cords and the need to replace batteries frequently.

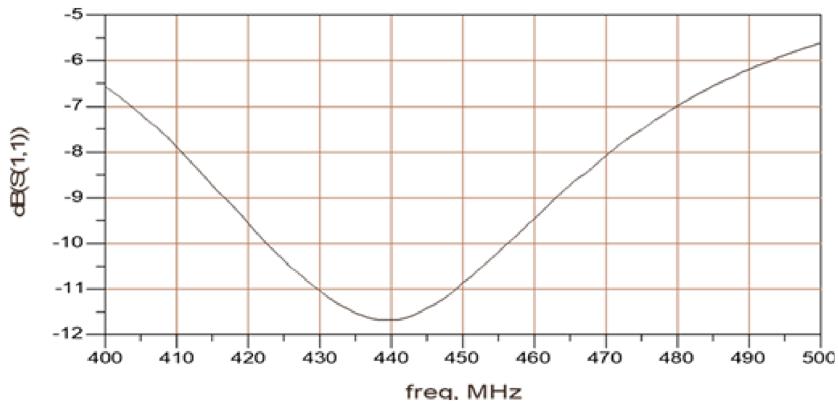


Figure 16: Active Loop antenna sensor, S11 parameters on human body

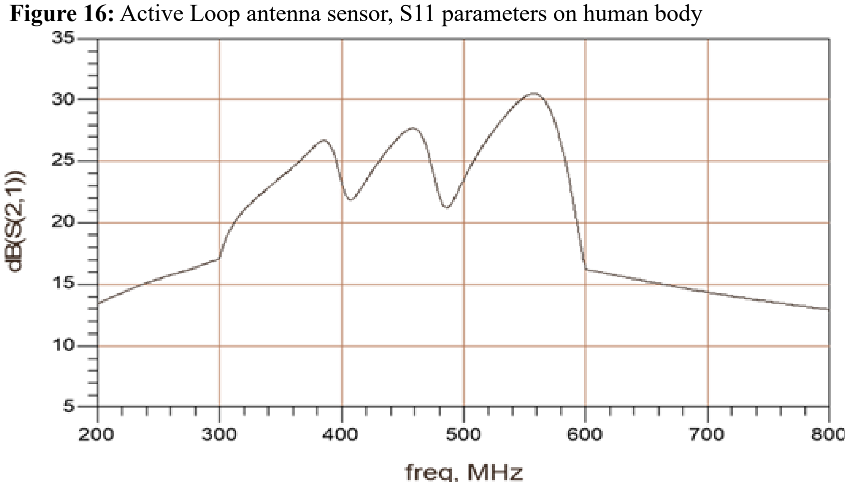


Figure 17: Active Loop antenna sensor, gain, S21 parameters

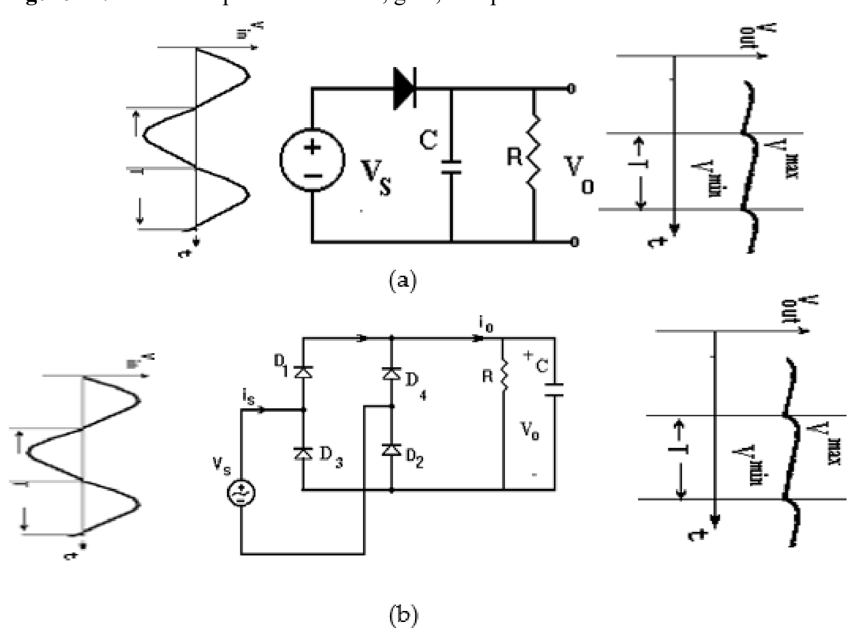


Figure 18: a. Half wave rectifier b. Diode bridge full wave rectifier

7. Conclusions

This paper presented wearable sensors for medical application and medical systems. The sensors and antennas were developed and measured in vicinity of the human body. The electrical characteristics of human body tissues were considered in the design. Wearable sensors provide a powerful new tool for medical and surgical rehabilitation services.

Wearable Body Area Network, WBAN, is emerging as an important option for hospitals, medical centers, and patients. Wearable Area Body Network, BAN, provides a convenient platform that may quantify the long-term context and physiological response of individuals. Wearable BAN systems will support the development of individualized treatment systems with online feedback to help promote and treat patient health. Wearable medical systems and sensors can measure body temperature, heartbeat, blood pressure, sweat rate, perform gait analysis and other physiological parameters of the person wearing the medical device. Gait analysis is a useful tool both in clinical practice and biomechanical research. Gait analysis using wearable sensors provides quantitative and repeatable results over extended time periods with low cost and good portability, showing better prospects and making great progress in recent years. Up to date, commercialized wearable sensors have been adopted in various applications of medical systems, IoT devices, and gait analysis.

Medical test results of the wearable sensors on the human body were presented in this paper. Measured results of the wearable sensors using a phantom were presented.

Energy harvesting units may be connected to the sensors presented in this paper to provide green renewable energy and may eliminate the usage of power cords and the need to replace batteries frequently.

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