Article

Active Compact Wearable Body Area Networks for Wireless Communication, Medical and IoT Applications

Albert Sabban ^{1,2}

¹ Department of Electrical Engineering, Kinneret College, Kinneret, 15132, Israel; sabban@netvision.net.il; Tel.: +972-4-8759111; Fax: +972-4-8759111

² Department of Electrical Engineering, ORT Braude College, Karmiel, 2161002, Israel

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Abstract: The development of compact wearable antennas and transceivers for communication, IoT (Internet of Things), and biomedical systems will be presented in this paper. Development of Compact efficient wearable antennas is one of the major challenges in development of wearable communication, IoT, and medical systems. The main goal of wireless body area networks (BANs), WBANs, is to provide continuously medical data to the physician. 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. Microstrip antennas resonant frequency is altered, due to environment conditions, different antenna locations, and different system operation modes. These disadvantages may be solved by using compact active and tunable antennas. A new class of wideband active wearable antennas for medical applications is presented in this paper. Amplifiers may be connected to the wearable antenna feed line to increase the system dynamic range. Small lightweight batteries supply the bias voltage to the active components. An active dual polarized antenna is presented in this paper. The active dual polarized antenna gain is 14 ± 3 dB for frequencies ranging from 380 to 600 MHz. The active transmitting dual polarized antenna output power is around 18 dBm. A voltage-controlled diode, varactor, may be used to control the antenna electrical performance at different environments. For example, an antenna located in patient stomach area has VSWR (Voltage Standing Wave Ratio) better than 2:1 at 434 MHz. However, if the antenna will be placed on the patient back, it may resonate at 420 MHz. By varying the varactor bias voltage, the antenna resonant frequency may be shifted from 420 to 434 MHz. An ultra-wideband passive and active printed slot antenna may be employed in wideband wearable communication systems. The active slot antenna gain is 13 ± 2 dB for frequencies from 800 MHz to 3 GHz.

Keywords: wearable wireless communication systems; wearable antennas; active antennas; wearable body area networks; medical applications; IoT applications

1. Introduction

Wearable systems have several applications in personal communication devices and medical devices, as presented in [1–9]. Printed antennas are frequently used as wearable antennas in BANs and medical systems, see [1–3]. Printed antenna features, such as small volume and low production cost, are crucial in several wireless communication systems. Moreover, printed antennas are compact, flexible, and can be used as wearable antennas. Printed wearable antennas are presented in journals and books, as referred in [10–15]. Investigation of RF transmission near the human body for wearable communication systems is presented in [16–23]. However, small printed antennas suffer from low efficiency [24]. Active antennas for communication systems are presented in journals, as referred

to in [25–31]. Novel active and tunable wearable antennas for BAN applications is presented in this paper. Active wearable antennas may be used in receiving or transmitting communication and medical systems. In transmitting channels, a power amplifier is connected to the antenna. In receiving channels, a low noise amplifier is connected to the receiving antenna. Amplifiers may be connected to the wearable antenna feed line to increase the system dynamic range. The active loop antenna gain is 25 ± 2.5 dB for frequencies ranging from 350 to 580 MHz. The active loop antenna noise figure is 0.7 ± 0.2 dB for frequencies ranging from 400 to 900 MHz. A varactor is used to control the antenna electrical parameters at different locations on the patient body. The antenna resonant frequency may be shifted by 10% by varying the varactor bias voltage. The presented active antennas electrical performance was optimized by using ADS software [32]. There is good agreement between the computed and measured results in all the active antennas and devices presented in this paper.

2. Active Wearable Body Area Networks and Antennas

This paper presents active antennas (AAs) for medical, sports, and IoT applications. Active antennas are devices combining antennas with active components. The radiating element is designed to provide the optimal load to the active elements. The integration of the antenna and the active components drastically reduce the system volume, system weight, and complexity of the matching network. In the last decade, active antennas are employed in wireless and in medical communication systems [25–31]. The major applications of active antennas are electronically scanning arrays and phased arrays. Indeed, arrays of active antennas are well suited for mobile communication systems requiring dynamic satellite tracking. The most common approach toward achieving fast-beam scanning is through the integration of monolithic microwave integrated circuit (MMIC) phase shifters, low noise amplifiers, and solid state power amplifiers with the radiating elements. In some cases, hybrid electromechanical arrays, combining mechanical steering with electrical steering shaping, are used. This architecture is often used to reduce the number of active control elements by limiting the electrical scanning in only one plane. This is often the case for mobile terminals, where azimuth scanning is performed by mechanical rotation, and elevation agility is realized by a linear phased array. Developments in RF technologies, such as MIC, MMIC, LTCC, MEMS, and other fabrication processes allowed automated low-cost production process of phased arrays with a high integration level. Phased arrays are much faster for beam switching than mechanically scanned antennas. Early phased array antennas were passive antennas. The front end of the antenna was composed of array elements with phase shifters. With the great progress of GaAs MMIC technology in the last twenty years, solid state device dimensions have been minimized to the size of the array elements, enabling distributed phased array architectures. High-power amplifiers and low noise amplifiers (LNAs) could be placed close to the front end, and connected to each radiating element. This phased array architecture allows significant power efficiency improvement and better receive sensitivity. The only loss before the first LNA is the antenna. The amplifiers may be packaged in transmit (receive) modules with power dividers (combiners), phase shifters, and attenuators. Development of compact wideband active antennas may improve, significantly, the performance of wearable systems. The design and development of compact printed active loop, dipole, and slot antennas is presented in this paper.

3. Active Receiving Wearable Body Area Network with Loop Antenna

Figure 1a presents a basic receiver block diagram with an active antenna. In Figure 1a, the LNA, low noise amplifier, is an integral part of the antenna. A commercial E PHEMT LNA, 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 active antenna configuration is shown in Figure 1b. The receiving active antenna block diagram is presented in Figure 1c. 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 amplifiers. The amplifier specifications are given in Table 1. The amplifier complex S parameters are listed in Table 2. The amplifier noise parameters are listed in Table 2. 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 1d. 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 1e. The active antenna gain is 25 ± 2.5 dB for frequencies from 350 to 580 MHz. The active loop antenna noise figure is 0.7 ± 0.2 dB for frequencies from 400 to 900 MHz. There is a good agreement between computed and measured.

Figure 1. Cont.

Figure 1. Receiving active antenna assembly. (a) Receiver block diagram with active antenna; (b) Active printed loop antenna layout; (c) Receiving active antenna block diagram; (d) Loop antenna S11 parameters on human body; (e) Active loop antenna S21 parameter, gain, on human body.

Table 1. Low noise amplifier (LNA) specification.

Parameter	Specification	Remarks
Frequency range	0.4–3 GHz	
Gain	26 dB @0.4 GHz 18 dB @2 GHz	V _{ds} = 3 V; I _{ds} = 60 mA
N.F	0.4 dB @0.4 GHz 0.5 dB @2 GHz	V _{ds} = 3 V; I _{ds} = 60 mA
P1dB	18.9 dBm @0.4 GHz 19.1 dBm @2 GHz	V _{ds} = 3 V; I _{ds} = 60 mA
OIP3	32.1 dBm @0.4 GHz 33.6 dBm @2 GHz	V _{ds} = 3 V; I _{ds} = 60 mA
Max Input power	17 dBm	
V _{gs}	0.48 V	V _{ds} = 3V; I _{ds} = 60 mA
V _{ds}	3 V	
I _{ds}	60 mA	
Supply voltage	±5 V	
Package	Surface Mount	
Operating Temperature	−40 °C–80 °C	
Storage Temperature	−50 °C–8100 °C	

Table 2. LNA S parameters and noise parameters.

F-GHz	S11	S11°	S21	S21°	S12	S12°	S22	S22°
0.10	0.986	−17.17	25.43	168.9	0.008	88.22	0.55	−14.38
0.19	−31.76	0.964	24.13	158.9	0.016	74.88	0.54	−22.98
0.279	0.93	−45.77	22.97	149.5	0.021	65.77	0.51	−33.65
0.323	0.92	−53.39	22.45	145.3	0.026	62.38	0.49	−39.2
0.413	0.89	−65.72	20.98	137.27	0.03	57.9	0.46	−49.3
0.50	0.87	−77.1	19.54	130.3	0.034	53.03	0.43	−57.5
0.59	0.83	−87.12	18.08	124.14	0.038	48.18	0.40	−64.12
0.726	0.8	−100.8	16.22	115.7	0.042	42.06	0.36	−74.86
0.816	0.77	−108.8	15.07	110.75	0.044	39.53	0.34	−80.87
1.04	0.74	−126.2	12.74	100.13	0.049	33.69	0.29	−94.96
1.21	0.71	−137.6	11.25	92.91	0.051	30.05	0.26	−104
1.53	0.687	−154.2	9.29	82.06	0.055	26.08	0.22	−119
1.75	0.67	−164.1	8.24	75.31	0.058	23.14	0.20	−128.4
2.02	0.67	−174.6	7.27	67.82	0.06	20.88	0.18	−138.8

Noise Parameters				
F-GHz	N.FMIN	N11X	N11Y	rn
0.5	0.079	0.3284	24.56	0.056
0.7	0.112	0.334	36.08	0.05
0.9	0.144	0.3396	47.4	0.045
1	0.16	0.3424	52.98	0.042
1.9	0.306	0.3682	100.93	0.029
2	0.322	0.3711	106.01	0.029
2.4	0.387	0.3829	125.79	0.029
3	0.484	0.401	153.93	0.036
3.9	0.629	0.429	−167.3	0.059
5	0.808	0.4645	−125.53	0.11
5.8	0.937	0.4912	−99.03	0.162
6	0.969	0.498	−92.92	0.177

4. Active Receiving Wearable Body Area Network with a Dual Polarized Antenna

A compact dual polarized antenna is shown in Figure 2a, and the antenna was presented in [4]. The antenna feed network is printed on a 0.25 mm-thick FR4 dielectric substrate. The radiating element is printed on a second layer, which is a 0.25 mm-thick Kapton substrate. The antenna thickness is 0.005 mm. The antenna size is 50 × 50 mm. A compact dual polarized active receiving radiating element is shown in Figure 2b. The compact dual polarized antenna may be attached to the patient body. The antenna bandwidth is around 12% for VSWR, better than 2:1. The active dual polarized antenna S21 parameter, gain, on human body, is shown in Figure 2c. The active antenna gain is 25 ± 2.5 dB for frequencies ranging from 380 to 680 MHz. The active loop antenna noise figure is 1 ± 0.5 dB for frequencies ranging from 400 to 900 MHz, as shown in Figure 2d.

Figure 2. Cont.

Figure 2. (a) Printed compact dual polarized wearable antenna; (b) Active printed compact dual polarized receiving antenna layout; (c) Active dual polarize antenna S21 parameter, gain, on human body; (d) Active dual polarize receiving antenna noise figure.

5. Active Transmitting Wearable Body Area Network with a Dual Polarized Antenna

Figure 3a presents a basic transmitter block diagram with an active antenna. A printed compact dual polarized transmitting antenna is presented in Figure 3b. The antenna volume is $50 \text{ mm} \times 50 \text{ mm} \times 0.005 \text{ mm}$. In Figure 3b, the high-power amplifier, HPA, is an integral part of the antenna. The HPA, a MMIC GaAs MESFET, is connected to the transmitting antenna. The active transmitting dual polarized antenna layout is shown in Figure 3b. The amplifier pin description is shown in Figure 3b. The transmitting active antenna block diagram is presented in Figure 3c. The radiating element is connected to the HPA via an output HPA matching network. The HPA input matching network connects the amplifier port to the transmitter. The amplifier specifications are given in Table 3. The high-power amplifier complex S parameters are listed in Table 4. The active transmitting dual polarized antenna S11 parameters, computed and measured, is better than 3:1 in the frequency range from 410 to 450 MHz. The active transmitting dual polarized antenna S21 parameter, gain, on human body is presented in Figure 3d. The active dual polarized antenna gain, computed and measured, is $14 \pm 3 \text{ dB}$ for frequencies ranging from 380 to 600 MHz. The active transmitting dual polarized antenna output power is around 18 dBm.

Figure 3. Cont.

Figure 3. (a) Transmitter block diagram with active transmitting antenna; (b) Transmitting active compact dual polarized antenna layout; (c) Transmitting active antenna block diagram; (d) Active dual polarized antenna S21 parameter, gain, on human body.

An active transmitting loop antenna layout and block diagram is shown in Figure 4a. The radiating element is connected to the HPA via the HPA output matching network. The HPA input matching network connects the amplifier input port to the transmitter. The amplifier specifications are listed in Table 3. The HPA complex S parameters are listed in Table 4. The active transmitting loop antenna S21

parameters, gain, on a patient, are presented in Figure 4b. The active transmitting loop antenna S11 and S22 parameters on human body are better than 3:1 in the frequency range from 360 to 600 MHz. The active dual polarized antenna gain is 13 ± 3 dB for frequencies from 360 to 600 MHz. The active transmitting dual polarized antenna output power is around 18 dBm. There is a good agreement between computed and measured values.

Table 3. High-power amplifier (HPA) specification.

Parameter	Specification	Remarks
Frequency range	0.4–2.5 GHz	
Gain	15 dB @0.4 GHz 17.8 dB @2 GHz	Vds = 5 V; Ids = 85 mA
N.F	5.5 dB @0.4 GHz 5.5 dB @2 GHz	Vds = 5 V; Ids = 85 mA
P1dB	18.0 dBm @0.4 GHz 18.0 dBm @2 GHz	Vds = 5 V; Ids = 85 mA
OIP3	29 dBm @0.4 GHz 29 dBm @2 GHz	Vds = 5 V; Ids = 85 mA
Max. Input power	10 dBm	
Vgs	0.48 V	Vds = 5 V; Ids = 85 mA
Vds	5 V	
Ids	85 mA	
Supply voltage	± 5 V	
Package	Surface Mount	
Operating Temperature	-40°C – 80°C	
Storage Temperature	-50°C – 100°C	

Table 4. High-power amplifier S parameters.

F-GHz	S11 dB	S11°	S21 dB	S21°	S12 dB	S12°	S22 dB	S22°
0.20	0.065	−38.75	−3.09	−139.2	−47.56	157.63	−1.03	−74.66
0.344	−1.1	−77	11.8	118.7	−37.9	78.4	−7.2	−131.6
0.4	−2.2	−88.5	13.8	85.24	−36.9	52.76	−11	−143.5
0.52	−4.44	−107.5	15.8	30.2	−36.7	14.1	−19.4	−132.5
0.64	−6.4	−122	16.8	−11.4	−37.2	−12.6	−19.2	−100.3
0.712	−7.4	−100.8	17.13	−32.7	−37.5	−25.4	−17.7	−100.6
0.88	−9.2	−144.6	17.72	−77.1	−38.5	−49.4	−15.7	−119.7
1.04	−10.4	−158.6	18.1	−115.1	−39.6	−67.5	−15.3	−144.5
1.24	−11.3	−178.7	18.37	−159.7	−41.3	−86.9	−15.9	−178.7
1.36	−11.8	167.4	18.4	174.4	−42.4	−91.4	−16.5	159.2
1.48	−12.2	151.2	18.4	149	−43.6	−94.9	−17.5	136.8
1.6	−12.8	134.3	18.3	123.3	−44.2	−93.4	−18.9	113.7
1.8	−14.3	101.2	17.9	83	−43	−86.3	−22	69.5
2	−16.5	61.8	17.3	43.5	−40.4	94.6	−27	6.42
2.16	−18.5	22.1	16.8	12.9	−38	−105.5	−27.8	−70.2
2.4	−19.4	−53.9	15.7	−31.8	−36	−128	−22.2	−147.2
2.56	−17.7	99.7	15	−60	−34.6	−145.6	−19.3	−179.4
2.7	−15.7	131	14.3	−84.3	−33.8	−160.3	−17.5	158.1
2.86	−13.7	159	13.5	−111.1	−33	−177.7	−16	134.7
3	−12.2	179.1	12.7	−134.1	−32.4	167.4	15.2	116.3

Figure 4. Cont.

Figure 4. (a) Active transmitting printed loop antenna layout; (b) Active transmitting loop antenna S21 parameter; (c) Tunable folded compact dual polarized antenna; (d) Resonant frequency of a tunable antenna as function of varactor capacitance.

6. Tunable Wearable Body Area Network

Small printed tunable antennas are crucial in the development of Wearable BAN, WBAN, systems. Tunable antennas consist of a radiating element and of a voltage-controlled diode, varactor. Varactor diodes are used in voltage-controlled oscillators, VCOs. Varactor diodes are semiconductor devices that are used in many microwave systems where a voltage-controlled variable capacitance is required. Varactor diodes function as a voltage-controlled variable capacitance. The radiating element may be a microstrip patch antenna, dipole, or loop antenna. The antenna resonant frequency may be adjusted by using a voltage-controlled diode to tune variations in the antenna resonant frequency at different environments. The varactor capacitance is given in Equation (1). The circuit frequency, f_r , may be calculated by using Equation (2).

$$C = \frac{A\epsilon}{d}, \quad (1)$$

where C —capacitance, A —plate area, and d —diode thickness.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

Varactors are voltage-controlled diodes used to tune microwave devices. Low frequency varactors are manufactured on silicon substrates. High frequency varactors are manufactured on gallium arsenide substrate. Gallium arsenide diodes have higher Q values, in comparison to silicon diodes. Hyper-abrupt voltage-controlled diodes have nearly linear frequency variation as a function of the applied bias voltage. Abrupt varactors have inverse fourth root frequency variation as a function of the applied controlled voltage. For example, a varactor with 20 pF capacitance may tune a small wearable loop antenna to 433 MHz.

A folded printed tunable antenna is presented in Figure 4c. The antenna volume is 70 mm × 50 mm × 0.016 mm. The folded dipole has a horizontal polarization. The folded slot antenna is vertically polarized. The combined tunable antenna has dual orthogonal polarizations. The antenna is printed on two dielectric substrates. The antenna feed network is printed on a RO3035 substrate that is 0.8 mm thick. The folded antenna is printed on a substrate with 2.2 dielectric constant that is 0.8 mm thick. The location and size of the coupling stubs, shown in Figure 4c, are optimized to achieve the best antenna VSWR. The antenna electrical performance was optimized by using ADS software [32]. The antenna resonant frequency may be tuned by connecting the small tuning bars located along the feed line to the antenna feed line. Varactors are connected to the antenna feed lines, as shown in Figure 4c, to tune the antenna resonant frequency. The varactor control voltage may be

varied automatically to tune the antenna center frequency at different locations on the patient body. The antenna bandwidth is better than 10% for VSWR better than 2:1. The printed tunable antenna beam width is around 100° . The tunable antenna resonant frequency as a function of the varactor capacitance for capacitances up to 2.5 pF is presented in Figure 4d. The antenna resonant frequency varies around $\pm 5\%$ for capacitances up to 2.5 pF. The antenna gain may vary between 1 to 3 dB as a function of the antenna environment. Photos of small printed tunable antennas for WBAN applications are shown in Figure 5a. Figure 5b presents a photo of small dual polarized tunable antenna with a varactor connected to the antenna feed line. The varactor bias voltage was varied from 0 to 9 V. Figure 5c presents measured S_{11} as function of varactor bias voltage. The antenna resonant frequency was shifted by 5% for bias voltage between 7 and 9 V. A voltage-controlled varactor may be used also to tune the loop antenna resonant frequency at different antenna locations on the body. We may conclude that varactors may be used to compensate variations in the antenna resonant frequency at different locations on the human body.

(a)

(b)

Figure 5. Cont.

(c)

(d)

Figure 5. (a) Tunable wearable antennas for medical applications; (b) Photo of tunable compact wearable antenna with a varactor; (c) Measured S_{11} of a tunable antenna as function of varactor bias voltage; (d) Active and tunable wearable antenna.

7. Medical Applications for Tunable Wearable Body Area Network

Three to four active compact antennas or active loop antennas may be assembled in a belt and attached to the patient stomach or back, as shown in Figure 5d. The bias voltage to the active elements is supplied by a compact recorder battery. The RF and DC cables from each radiator are connected to a recorder. The recorder consists of a switching matrix, low noise amplifier, filters, and a signal processing unit. The antennas receive signals that are transmitted from sensors that are located on the patient body. During the medical test, the signals are transferred to the signal processing unit. During the system operation, the varactors bias voltage may be varied automatically to tune the medical device to the desired system frequency. Active and tunable antennas may be placed on the patient body in several locations to improve the level of the received signal. The proposed active antennas may be placed on the human body, as shown in Figure 6a. The patient in Figure 6b is wearing a wearable antenna that are placed inside a belt. The antennas belt may be attached to the patient stomach or back.

Figure 6. Cont.

Figure 6. (a) Medical system with printed wearable antennas; (b) Patient with printed wearable antenna; (c) IoT wearable body area network (WBAN) health monitoring system; (d) IoT wireless wearable body area network (WBAN) health monitoring system.

8. Wireless Body Area Networks (WBANs) and Wearable (WBANs)

A wearable body area network (WBAN) health monitoring system is presented in Figure 6c. A typical wireless body area network consists of several compact low-power sensing devices, a control unit, and wireless transceivers, as shown in Figure 6c. The power supply for these components should be compact, lightweight, and long-lasting as well. The recorded and monitoring data may be stored and analyzed by employing cloud storage and cloud computing services. Moreover, IoT technology may be used to transmit and receive from person to medical centers, and from medical stuff to patient. Wireless communication systems offer a wide range of benefits to medical centers, patients, physicians, and sport centers, through continuous measuring and monitoring medical information, early detection of abnormal conditions, supervised rehabilitation, and potential discovery of knowledge through data analysis of the collected information. Wearable health monitoring systems, as shown in Figure 6c, allow the person to closely follow changes in important health parameters, and provide feedback for maintaining optimal health status at every location in the world. The main goal of WBANs is to continuously provide biofeedback data. WBANs can record electrocardiograms, measure body temperature and blood pressure, 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 (BANs) include the applications and communication devices using wearable and implantable wireless networks. 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.

In medical centers, where conditions of a large number of patients are constantly being monitored, a WBAN system may be extremely needed. A wireless wearable body area network (WBAN) health monitoring system is presented in Figure 6d.

Wireless monitoring of physiological signals of a large number of patients is needed in order to deploy a complete WSN in hospitals. Human health monitoring is emerging as a crucial application of the 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. The progress in wireless networking technology promises a new class of wireless sensor networks suitable for WBAN systems.

Data acquisition in WBAN devices can be point-to-point or multipoint-to-point, depending on specific applications. Detection of an athlete's health condition would require point-to-point data sharing across various on-body sensors. Human body monitoring of vital signs will require routing data from several wearable sensors, multipoint-to-point, to a sink node, which, in turn, can relay the information wirelessly to an out-of-body computer. Data may be transferred in real-time mode or non-real-time. Human body monitoring applications requires real-time data transfer. Monitoring an athlete's physiological data can be collected offline, for processing and analysis purposes, by physicians.

A typical wireless body area network consists of a few 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. WBANs consists of compact devices with low volume and fewer opportunities for redundancy. 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 cannot be a practical option in WBAN systems. WBANs receive and transmit a large amount of data constantly. Data processing must be hierarchical and efficient. WBANs in a medical area consist of wearable and implantable sensor nodes that can sense biological information from the human body, and transmit it over a short distance wirelessly, to a control device worn on the patient body. The sensor electronics must be miniaturized, low-power, and detect medical signals such as pulse rate, electroencephalography, electrocardiograms, pressure, and temperature. The gathered data from the control devices are then transmitted to remote destinations in a wireless body area network for diagnostic and therapeutic purposes, by including other wireless networks for long-range transmission. If the Wireless WBAN, WWBAN, is part of the telemedicine system, the medical system can alert medical personnel when life-threatening events occur. In addition, patients may benefit from continuous long-term monitoring as a part of a diagnostic procedure. Patients and physician may achieve optimal maintenance of a chronic condition, and can monitor the recovery period after the acute event or surgical procedure. The collected medical data may be a good indicator of cardiac recovery of patients after a heart surgery. Many people are using WBAN devices, such as wearable heart rate monitors, respiration rate monitor, and pedometers, for medical reasons or as part of a fitness regime. WBAN may be attached to cotton shirts to measure respiratory activity, electrocardiograms, electromyograms, and body posture. The recorded data and patient data may be stored and analyzed by employing cloud storage and cloud computing services.

9. Active T Shape Slot Antennas for Ultra-Wideband IoT and 5G Communication Systems

A wideband active wearable receiving T shape slot antenna is shown in Figure 7a. The radiating element is designed to provide the optimal load to the active elements. The antenna electrical parameters were calculated, and tuned, by using Computer Aided Design, CAD, tools. The size of the slot antenna shown in Figure 7 is 116 mm × 70 mm. The radiating element is connected to the LNA via an input matching network. An output matching network connects the amplifier port to the receiver. A DC bias network supplies the required voltages to the amplifiers. The amplifier specifications are given in Table 1. The amplifier complex S parameters and noise parameters are listed in Table 2. Active slot antenna S11 parameters are shown in Figure 7b. The antenna bandwidth is around 40% for VSWR better than 2:1. S11 parameters of the T shape wearable slot, on human body, attached to a 1 mm shirt with 2.2 dielectric constant, are presented in Figure 7c. The active slot antenna S21 parameters, gain, are presented in Figure 7d. The active computed and measured antenna gain is 18 ± 2.5 dB for frequencies from 200 to 580 MHz. The active antenna gain is 12.5 ± 2.5 dB for

frequencies from 1 to 3 GHz. The active slot antenna noise figure is 0.5 ± 0.3 dB for frequencies from 300 MHz to 3.2 GHz, as presented in Figure 7e.

Figure 7. Cont.

Figure 7. (a) A wideband active receiving wearable slot antenna; (b) Active T shape slot antenna S11 parameter; (c) S11 of the T shape wearable slot attached to a 1 mm shirt with $\epsilon_r = 2.2$ on human body; (d) Active T shape slot antenna S21 parameter; (e) Active slot antenna noise figure.

A comparison and summary of electrical parameters of the wearable antennas presented in this paper is given in Table 5.

Table 5. Comparison and summary of electrical parameters of wearable antennas.

Antenna	Frequency (GHz)	VSWR	Gain (dB)	Noise Figure (dB)
Loop	0.45	4:1	0	–
Active receiving loop	0.35–0.58	2:1	25 ± 2.5	0.7 ± 0.2
Active Rx. dual polarized antenna	0.38–0.68	2:1	25 ± 2.5	1 ± 0.5
Active Tr. dual polarized antenna	0.38–0.6	3:1	14 ± 3	–
Active transmitting loop antenna	0.36–0.6	3:1	13 ± 3	–
T shape slot	1–3	2:1	3	–
Active Rx. T slot	0.2–0.58	3:1	18 ± 2.5	0.5 ± 0.3
	1–3	2:1	12.5 ± 2.5	

10. Conclusion

Active wearable BANs may be used in receiving or transmitting channels. In transmitting channels, a power amplifier is connected to the antenna. In receiving channels, a low noise amplifier is connected to the receiving antenna.

Ultra-wideband passive and active printed slot antenna may be employed in wideband wearable IoT and 5G communication systems. The active slot antenna gain and noise figure are summarized in Table 5.

The antennas presented in this paper are low-cost wideband passive and active antennas for receiving and transmitting wearable IoT and 5G communication systems for medical application.

Wearable technology provides a powerful new tool to medical and surgical rehabilitation services. Wearable body area network, WBAN, is emerging as an important option for medical centers and patients. Wearable technology provides a convenient platform that may quantify the long-term context and physiological response of individuals. Wearable technology will support the development of individualized treatment systems with real-time feedback to help promote patients' 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. At present, commercialized wearable sensors have been adopted in various applications of gait analysis.

The active transmitting loop antenna and dual polarized antenna output power is around 18 dBm. A comparison and summary of electrical parameters of the wearable antennas, presented in this paper, is given in Table 5.

This paper presents wideband active and tunable printed antennas with high efficiency for commercial and medical applications. The compact tunable antenna bandwidth is around 13% for a reflection coefficient lower than -9.5 dB. The tunable antennas gain is around 2 dBi. A voltage-controlled diode is used to tune the wearable antenna resonant frequency at different positions on the patient body.

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