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간섭이 최소화된 장거리 WSN 시스템을 위한 ESPAR 안테나

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ESPAR Antenna for Long Distance WSN Systems with Minimum Interference

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요 약

최근 UHF(Ultra-High Frequency) 대역 애플리케이션을 사용한 무선 주파수 식별(RFID)은 사물 인터넷(IoT) 시스템에서 필수적이다. 무선 센서 네트워크(WSN)는 사물 인터넷(IoT)의 필수적인 부분이다. 오늘날에는 더 나은 통신을 위해 더 먼 거리, 최소 간섭 및 최적의 신호 대 잡음비(SNR)를 통해 WSN 시스템을 설계하는 것이 매우 중요하다. 본 논문에서는 간섭을 최소화하기 위한 ESPAR(Electronically Steerable Parasitic Array Radiator) 안테나를 설계하고, RFID 태그와 리더기 간의 장거리 통신에서 최적의 SNR 값을 위한 링크 버짓(LB)을 분석하여 WSN 시스템의 아키텍처를 제안한다. MATLAB 시뮬레이션에서. ESPAR 안테나는 이득, 방사 패턴 및 반사 계수를 기반으로 매우 우수한 성능을 보여준다. 제안된 ESPAR 안테나의 최대 이득 값은 7.55 dBi로 얻어지며 WSN 시스템에서 이전에 발표된 논문과 비교하여 장거리 통신이 가능한 모든 방향의 간섭을 성공적으로 처리할 수 있다. 링크 버짓 분석을 통해 제안된 기술은 지상에서 약 20미터, 개방형 환경에서는 50미터 정도를 지원할 수 있다.

Key Words : UHF, RFID Reader, ECG, ESPAR antenna, Link Budget, Range

ABSTRACT

Recently, radio frequency identification (RFID) with ultra-high frequency (UHF) band applications became an essential part in the Internet of Things (IoT) system. Wireless sensor networks (WSNs) are an integral part of the IoT. Nowadays, it is very important to design the WSN system model in longer distance with minimum interference and optimum signal-to-noise ratio (SNR) for better communications link. In this paper, we have proposed the architecture of WSN system by designing electronically steerable parasitic array radiator (ESPAR) antenna for minimum interference. Also, the link budget (LB) for distance depending on different SNR values between the RFID tag and reader are analyzed using MATLAB simulation tools. The ESPAR antenna shows very good performance based on gain, radiation pattern, and reflection coefficient. The maximum value of gain of the proposed ESPAR antenna is obtained as 7.55 dBi which will successfully handle the interference at any directions to be communicated over long distance as compared to the previously published once papers in WSN system. The link budget analysis spectacled that the proposed article in the indoor environment could easily be applied for 20 meter.

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Ⅰ. Introduction

Internet of Things (IoT) is the latest technique in the recent communication systems. They are now ubiquitous and used in many vital applications. The concept of IoT is seen as the next generation of technologies that recognizes the interaction between different types of devices, machines, and objects. WSN can be considered as a key component of the IoT because it could help users (individuals or machines) to communicate within their environment and also interact with the live events. With rapid development of wireless technology in digital electronics, and nano devices which are used in many places of daily life. These are usually organized in the way of low power components, smart sensors, microelectronics, embedded control panels, and capable of computation by distributing information and network communication. These innovative devices are usually used to form WSN to provide sensing services over long distance with better battery life span[1-5].

Applications of RFID systems have greatly facilitated the supply-chain and logistics industry. During the past couple of years, the passive RFID systems operating in the UHF band are especially attractive due to their significant advantages such as long identification range, low cost and small size. A passive tag is typically composed of an antenna and an integrated circuit chip. It acquires power entirely from the impinging electromagnetic fields radiated by an RFID reader. The communication between tag and reader is established by the use of far-field electromagnetic waves. In order to send information back to the reader, the tag modulates the backscattered fields by varying its antenna load[4]. Also, the emerging RFID technology has brought new opportunities for HRV monitoring in a more convenient and accurate approach, as the RFID tag can be regarded as an extremely lightweight sensor and its nature of identification can be used to effectively and easily distinguish different human subjects[3]. Other advantages of the RFID tag include medical telemetry, remote switches, position location and tracking devices, and passive data exchange, to name just a few[6-10].

In wireless communication systems, the received power is an important parameter since sufficient power is necessary to maintain a given set of data exchange[5]. Radio link budget generally refers to the expression for prediction of received power, and it is a determinant factor for the coverage estimation. We can roughly estimate the coverage range by means of combining radio link budget with other parameters, such as the sensitivity of the receiver and transmitted power of the transceiver[10-16].

Electronically steerable parasitic array radiator (ESPAR) is the technique by which beam steering is achieved without the use of phase shifters. In ESPAR antenna, a driven element is surrounded by closely spaced parasitic elements. This type of antenna used for the design, utilized a loop topology with the network to enable an efficient interface to the Microcontroller.

The work in this paper is divided into several sections. Section II, presents literature review, system configuration is presented in section III. Section IV, design of 13-elements ESPAR antenna to be performed through the system. In section V, we proposed an RFID-based link Budget to perform HRV monitoring on human subjects, which aims to observe the performance of ECG system. Section V, represents the conclusions of the paper.

Ⅱ. Literature Review

An wireless sensor network (WSN) is used for data logging and system management which has different types of sensors and control units. Now, new sensor technology provides the solution of design and adjustment of multiple medical applications. The application contains sensors facilities over distinct without any direct contact. General purpose sensor systems are usually evaluated by observing the performance based on distance, light, heat, humidity, air pressure, speed, acceleration, acoustics, magnetic fields, and accuracy. A terminal (bridge) i.e. reader collects data from standard sensors (tag) and relays them to the visualizer. The exact form of system

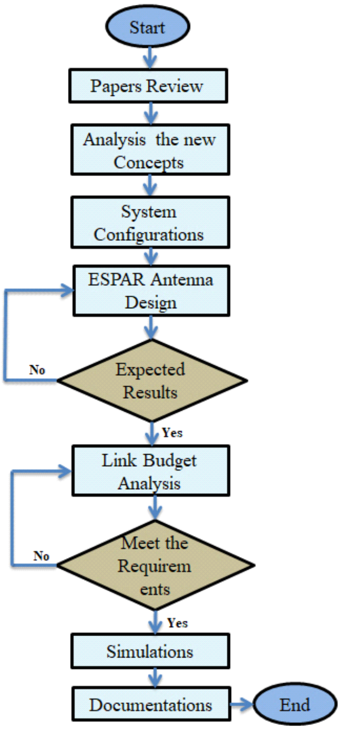


Fig. 1. Demonstration of the ensembles design flow chart.

configuration, receiver antennas, distance, and interference are deployed to create a WSN. For enabling the sensor application using existing technology, the function of broad range is a key issue. In paper[1], UHF RFID based low power (1mW) ECG monitoring system is proposed but its drawback is the minimum distance of only 5 centimeters and didn't talk about the interference management systems. Paper [4] described heart rate variability (HRV) based on RFID tag array by extracting the reflection signal, and discrete wavelet transform (DWT)-based method but the paper didn't consider about the range, interference, and battery life span. In paper [8], presented the minimum power based accelerometer for therapy system using UHF RFID technique with system configurations whenever the paper didn't talk about the range as it's an important factor in WSN communications. The paper [9] proposed human skin based on pH sensor that will work on UHF frequency band (868-960 MHz) over the distance of (1-2) meters. The performance of the ECG signals in WSN system based on the absorption of power and distance between the tag and reader is proposed in [18]. The maximum distance of this paper is 1 to 5 m to be performed. In paper [19], the WSN system is discussed using the technique of sink node and high altitude platform (HAP) in 5G technology. Another paper [20] proposed a system to monitor temperature or humidity for maintaining hospitals and pharmaceutical devices by making node layer and local management layer of WSN system.

Ⅲ. System Design

Fig.2 shows an UHF RFID communication diagram for ECG monitoring. EM4325 made by EM microelectronics can be used to enable UHF RFID communication, because in the past it has been used to download higher data transmission[7,8] and has been found to have a reliable measurement of data rate[3]. The EM4325 can be selected to access the RAM program via the SPI cable. Most companies have UHF memory entry RFID chips as a standard model. By changing the transmission of power mode the EM4325 can easily work[2,6-8], among them two power points can be used for the transmission, one depends on the power used by the reader and the other in processing which uses little energy from outside battery[2,3]. The ESPAR antenna used for the design is proposed to be integrated with the EM4325. Based on the design process, there will be enough. This designed system allows enough space near the antenna to provide the best possible

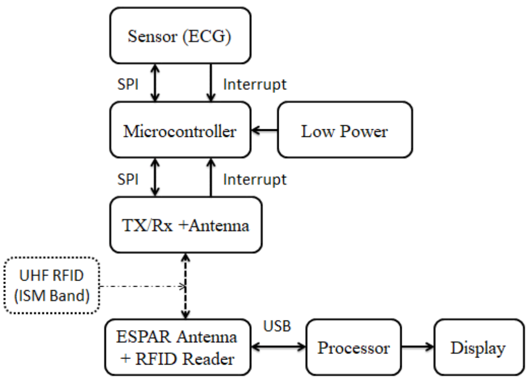
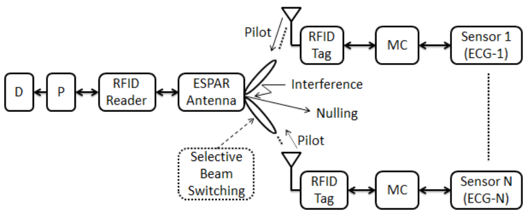


Fig. 2. System block diagram.

performance. At the external side of heart means at top of the chest, the MAX30001 microchip can be chosen due to its high performance and small size to obtain the ECG signal. This break needs a small outer surface that makes it compact so that it can be compatible with special radios[2,3,5]. The TI CC2640R2 BLE microcontroller module can be designed as the very level energy consumer. For the device to function properly, power management is very important, so it uses a small lithium polymer battery (120 mAh), using the charging and regulating process. In the charging time MCP7381T-2ACI IC microchip is applied, which allows external power to be used between the charging station and the charging system to charge up (recharge) the attached battery. This system uses the ADP1710 standard which controls voltages about the amplitude of 2V. Fig. 3 comprises that the system configuration by showing interference.



D=Display, P=Processor, MC=Microcontroller.

Fig. 3. Proposed system configurations.

Ⅳ. Espar Antenna Design

An electronically steerable parasitic array radiator (ESPAR) antenna consists of one active element (fed element or radiator) and the others are the parasitic elements (or parasitic radiators) with variable reactance[21]. The proposed ESPAR antenna is designed using the CST studio simulator. The active monopole (#0) placed in the center of the metal ground plane surrounded by 12- parasitic elements (#1- #12) printed on Rogers RO4725-JXR dielectric substrate. Its thickness, h = 0.787 mm and exhibits a relative permittivity of = 2.55, for this the proposed antenna could be implemented inexpensively. To design low-profile ESPAR

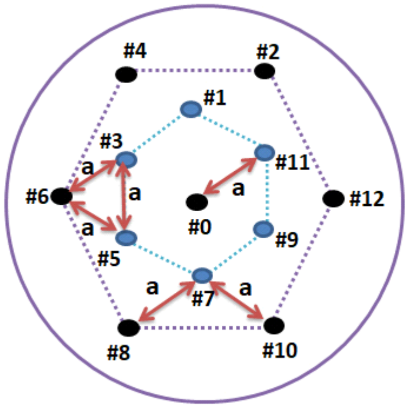
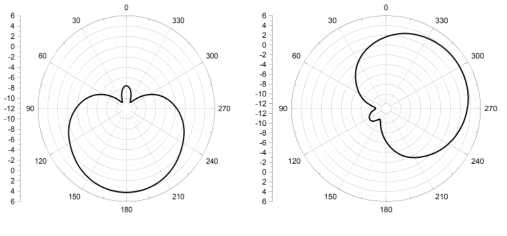


Fig. 4. Geometry of the proposed ESPAR antenna.

antenna, it has to significantly be reduced height as compared to the previous papers [14], [15], the original concepts while its radiation patterns can successfully be used to provide accurate direction of arrival estimation, a number of constructions based on the number of radiators have been investigated [16]. The position of the parasitic elements will be in the vertex points or peak points of two hexagonal (inner and outer or in two iterations). The angle between the each outer parasitic elements and the angle between the each inner parasitic elements from the active element are. Each inner parasitic element will maintain the equal distance from the two outer parasitic elements in such a way that a single inner parasitic element with two outer parasitic elements will form an equilateral triangle and the distance between them are λ/4. Conversely, the two inner parasitic elements with one outer parasitic element will form the isosceles triangle. Also, the distance among the active element and the inner parasitic elements is λ/4. The proposed technique may be free from the mutual coupling because the elements will present at an optimum distance. We numbered the inner parasitic elements as 1, 3, 5, 7, 9, 11 (odd numbers) and the outer parasitic elements as 2, 4, 6, 8, 10, 12 (even numbers). The active monopole here is fed by the coaxial connector via the central pin in order to provide 50Ω impedance appropriately and its height, ha = 29 mm. The parasitic elements can be opened (directors that pass through the electromagnetic wave) or shortened (reflectors that reflects the energy) to the ground by the pin diode switching circuits designed on dielectric substrate whose height, hp = 26.2 mm. The central pin of every surrounding passive elements can be connected to the ground via a corresponding switching circuit realized using SMP1320-040LF PIN diode. The switching mechanism influences the passive elements resonance by involving additional, centrally located load (close to open or short circuit). As a consequence, the proposed antenna provides beam steering with each discrete step using n = 6 directional radiation patterns. In such setup, nth radiation pattern will have its main beam direction equal to for which the radiation pattern will have its maximum in the horizontal plane. During the each switching state only two parasitic elements in the outer and one of the inner elements will be shorted (ON) with the active element. All considered steering vectors together with associated main beam directions and radiation pattern numbers are gathered in table 1, in which the radiation pattern have the main beam direction $\varphi^n_{\max}$= 180° and 300° which are created separately by shorting three constructive steering vectors illustrates in Fig. 5.

By which the antenna will definitely provide the strength connectivity in any wireless networks even though there is a difference in height of installed wireless sensor network (WSN) nodes[19]. Also, the antenna provides standard gain values which are sufficient for WSN system; IoT- based smart city deployments, and so on.

Moreover, the impedance matching of the proposed antenna is very good as depicted in Fig. 6,



(a) $\varphi^4_{\max}$=180° (b) $\varphi^6_{\max}$=300°

Fig. 5. Polar radiation pattern of the ESPAR antenna.

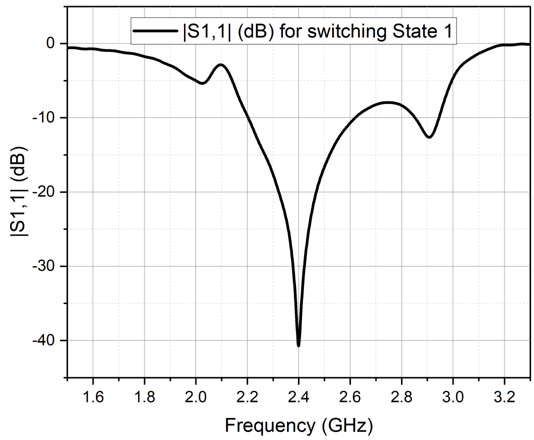


Fig. 6. Reflection coefficient of the antenna.

Table 2. ESPAR antenna dimensions

Dimension	Value (mm)	Dimension	Value (mm)
ha	29	hp	26.2
a	λ/4	r	130

for the first switching state. The reflection coefficient below -10 dB in the considered frequency band of the antenna is shown. The minimum return loss exhibits as -40.73 dB, from where, we could observe that the antenna exactly

Table 1. Reactance Set of the Proposed Espar Antenna

Direction	Lumped Ports											
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
0^0	0.45nH	0.45nH	0.3 pF	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF
60^0	0.3 pF	0.3 pF	0.45nH	0.45nH	0.3 pF	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF
120^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.3 pF	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF
180^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.3 pF	0.45nH	0.3 pF	0.3 pF
240^0	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH	0.3 pF	0.45nH
300^0	0.3 pF	0.45nH	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.3 pF	0.45nH	0.45nH

resonates at 2.40 GHz for each steering vectors.

V. Link Budget Analysis For RFID

Using the Friis equation, the expected received power by an RFID reader can mathematically be expressed as [11]

$$\begin{aligned} P_{reader}(dB_m) &= P_{tag}(dBm) + G_{reader}(dB) \\ &+ G_{tag}(dB) + 10\log_{10}(1-|\rho|^2) \\ &+ \triangle G(dB) - L_{sys}(dB) - L_p(dB) \end{aligned} \quad (1)$$

where Ptag is the transmitted power by the tag, Greader and the Gtag are the gains of the reader and tag, ρ is the reflection coefficient of the tag, represents the gain penalty when the tag is on contact, Lsys is the cable loss or system loss, Lp is the path loss.

When the power is received by the reader, and due to the backscatter communication, radio link budget Preader (dBm) can be written as

$$\begin{aligned} P_{reader}(dB_m) &= P_{tag}(dB_m) + 2G_{reader}(dB) \\ &- L_{sys}(dB) + 10\log_{10}\left(\frac{RCS}{4\pi}\right) \\ &+ 20\log_{10}\left(\frac{\lambda}{4\pi}\right) - 40\log_{10}(r) \end{aligned} \quad (2)$$

where r is the distance between tag and reader, λ is the wavelength; RCS stands for radar cross section (RCS) of the tag. The modulated backscattered signal is proportional to the antenna mode of the RCS and can be written as a function of the antenna gain[5,11].

$$RCS = G^2\lambda^2\rho_0^2/4\pi \quad (3)$$

here, ρ_0^2 is the differential reflection coefficient of the tag ρ_0^2 = |ρ1 - ρ2|; ρ1 and ρ2 are on the 0 and 1 states of the chip's reflection coefficient.

The gain penalty factor *TRIANGLEG* is introduced to take into account to notify the change in the antenna gain and impedance[12]. Due to the material change, *TRIANGLEG* represented as

$$\Delta G = G_{reader,\, material(dB)} - G_{read,\, free\, space(dB)} \quad (4)$$

Therefore, the power received in the RFID reader is given by

$$\begin{aligned} P_{reader}(dB_m) &= P_{tag}(dB_m) + 2G_{reader}(dB) + 2G_{tag}(dB) + \\ &+ 20\log_{10}(\rho_0) + 2\Delta G(dB) - 2L_{sys}(dB) - 2L_p(dB) \end{aligned} \quad (5)$$

Although RFID is a line of sight (LOS) communication system[2,13], the influence of reflections in the environment must be considered. Path loss from equations (1) and (5) can be modeled as the sum of several waves reflected in ground, hills, walls or other objects. Thus, we have

$$L = -20\log_{10}\left(\frac{\lambda}{4\pi}\right)^2 - 20\log_{10}\left[\frac{e^{-jkr_0}}{r_0} + \sum_{i=1}^{N}\Gamma_i\sqrt{t_i}\,\frac{e^{-jkr_i}}{r_i}\right] \quad (6)$$

where r0 is the direct path length, ri is the length of the ith reflected ray path, N is the total number of reflections and k is the wave number, ti is the normalized antenna radiation pattern, Γ_i is the Fresnel's reflection coefficient. Only for the direct path ro , the path loss, Lp implied as

$$L_p = -20\log_{10}\left(\frac{\lambda}{4\pi}\right)^2 - 20\log_{10}\left(\frac{e^{-jkr_0}}{r_0}\right) \quad (7)$$

Again, only when the direct path is considered, equation (7) reduces to free-space Friis model.

Another simple model takes into account such as direct ray and reflection in the ground[2,16], assuming the flat earth model, N=1. In this case, the distance between tag-reader is larger than antenna height h1, h2 (r>>$\frac{4h1h2}{\lambda}$) and the Γ_i is almost real and the worst when Γ_i = -1, the path loss when flat earth model is considered can be written as

$$L_p = -10 * \log_{10}\left[\frac{(h1h2)^2}{r^4}\right] \quad (8)$$

An empirical model is often used in the indoor environments of RFID. The path loss is based on slope model[2,16] is given by

$$L_P = -10*\log_{10}[\frac{(h_1 h_2)^2}{r^4}] \quad (9)$$

where n is the path loss factor for distances shorter than the turn on distance in RFID system. For fee space the value of n= 2. Simply, by having the value of Lp, the distance between the tag and reader could be found out.

The link margin, Lm, informs how much margin there is on the communication link before starting to get packet errors,

$$L_m = P_{reader}(dBm) - S_r(dBm); (L_m > 0) \quad (10)$$

here, Sr (dBm) is the Preader (dBm) Sensitivity. Absolute maximum range can be calculated by setting the link margin to zero (0).

$$L_m = P_{reader}(dbm) - S_r(dBm) = 0 \quad (11)$$

For 2.40 GHz frequency the path loss, Lp can be represented by

$$L_P = -40 + 2*10*\log_{10}(r) \quad (12)$$

Equation (5) can be written as

$$\begin{aligned} &P_{reader}(dB_m) = P_{tag}(dB_m) + 2G_{reader}(dB) \\ &+ 2G_{tag}(dB) + 20\log_{10}\rho_0 + 2\Delta G(dB) \\ &+ 2L_{sys}(dB) + 2L_p(dB) \end{aligned} \quad (13)$$

It is important to keep in mind is that the loss terms here are written as positive but at the time of substituting values, these will be negative as they can never be greater than 0 dB. Just by using equations (12) and (13), the range between tag and reader can easily be known just have to keep in mind is that the link margin, must be greater than zero and other parameters are in the standard levels.

The link budget is an important technique to calculate the distance with an optimum SNR (Signal to Noise Ratio) value in any line of sight communication system. The effective isotropic radiated power (EIRP) method[7,17] is used in the link budget to guess the distance and standard SNR, which is given by

$$EIPR = P_{reader} + L_t + G_{tag} \quad (14)$$

here, Preader = Power at the receiver (RFID reader), Lt = Transmission losses, Gtag = Gain of the tag antenna (transmitter antenna).

Thus, the SNR at the RFID reader (at the ESPAR antenna) is defined as

$$\begin{aligned} SNR &= EIPR - L_S + \frac{G}{T} - k \\ &= P_{reader} + L_t + G_{tag} - L_s + \frac{G}{T} - k \end{aligned} \quad (15)$$

where k is Boltzmann's constant, Ls is the free space loss, is the merit figure measured in dB/ 0k at the receiver.

Now, equation (15) can be simplified to calculate the SNR value as

$$SNR = P_{reader} + G_{tag} + \frac{G}{T} - K - L_p \quad (16)$$

here, Lp is the total path loss.

Just by minimizing the noise terms, the signal power at the RFID reader (receiver) could be maximized of the system. From equations (15) and (16), it is implied as

$$\begin{aligned} &SNR(dB) = P_{reader}(dB) + G_{tag}(dB) + \frac{G}{T}(dB) \\ &- \log_{10}K(dB) - 20\log_{10}(\frac{\lambda}{4\pi}) + n*10*\log_{10}(r) \end{aligned} \quad (17)$$

The distance, r between the RFID reader and RFID tag should be selected in such a way the optimum SNR value must be ensured by nulling the noise parameters of the system.

Fig. 7 shows the path loss simulation based the distance between the transmitter tag antenna and the receiver reader antenna based on the path loss model. It's observer that the path loss is zero at 20 meter. The received power estimation is depicted in Fig. 8, with respect to the range between the tag and reader of the proposed system. An optimum power (dB) is obtain at 20 meter of the simulation. The SNR (signal-to-noise ratio) over the distance between the tag and reader is obtained at Fig. 9.

Finally, to improve the signal-to-interference ratio (SIR) within the system, we have proposed antenna nulling technique which leads to the SIR value of 18.63 dB (11 dB + 7.63 dB), depicted in Fig. 10.

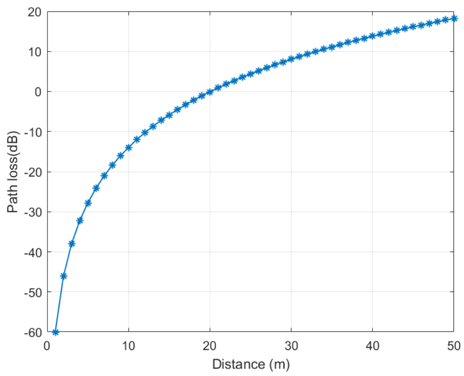


Fig. 7. Path loss (dB) vs Distance (meter) between tag and reader.

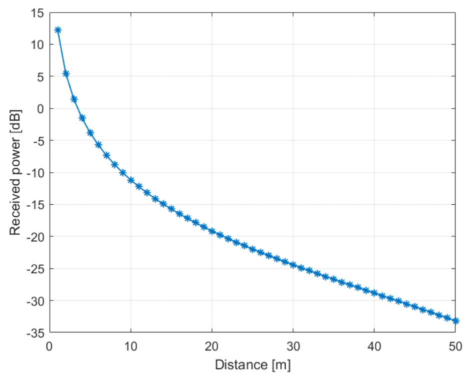


Fig. 8. Received power (dB) vs Distance (meter) between tag and reader.

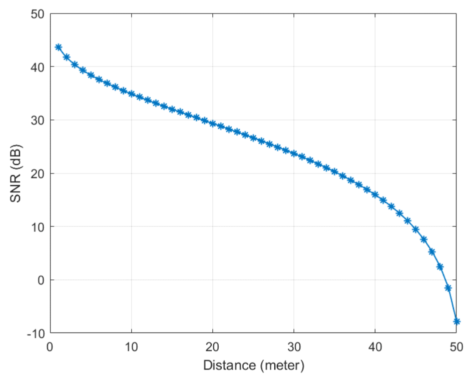


Fig. 9. SNR (dB) vs Distance (meter) between tag and reader.

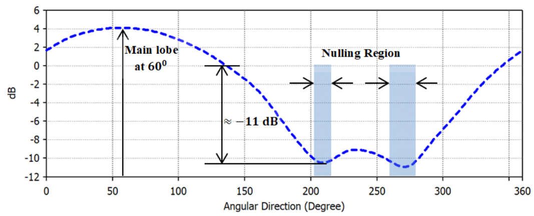


Fig. 10. Antenna nulling technique for SIR improvement.

Ⅵ. Conclusions

In this paper, we have suggested an UHF RFID wireless based ECG model to monitor heart activities through strength signals. The beam steering of the proposed antenna exhibits very high performance regarding radiation pattern, gain, and the reflection coefficient. The range based on the link margin is calculated and represented that the distance between sensor tag and RFID reader is approximately 20 meter in indoor environment. From which it is demonstrated that the range is higher than the previously published ones papers. Thus, the suggested design is considered to be a reliable, robust, relatively long distance, and low-power-transmission ECG monitoring system.

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