Semi-conductor Applications to Printed Circuits on Flexible Surfaces

Nazmi Ekren and Ali Samet Sarkin

***Abstract*— The most common type of identification system today is RFID. RFID circuits are used as covered with plastic. With the increase in usage areas, it is also used on metal, wood, paper, and plastic product. In this study, the behavior of the same circuit on different surfaces was investigated. The surface impedance and signal reflection coefficients of RFID tag antennas were investigated based on paper, plastic, and textile surfaces. According to the results of the electrical and mechanical tests, the best results in terms of reflectance coefficients and surface impedances of RFID tags are on PET surfaces. The surface impedance and the reflection coefficients were high on paper surfaces. The lowest values were measured on textile surfaces. According to the results, it has been seen that RFID antenna application on plastic, paper, and textile surfaces is possible and usable.**

Index Terms— **Flexible surface, Identification, Reflection coefficient, RFID, Surface impedance**

I. INTRODUCTION

AUTOMATIC IDENTIFICATION and data capture (AI/DC) systems are the identification of information or feature by matching with a person or object [1]. Identification processes are made with barcode, optical character recognition, magnetic stripe, smart cards, RFID, and biometric systems. The oldest type of automatic identification and data capture systems is the barcode system. Barcodes can be encoded by Code 39, EAN (European Article Numbering) 8, EAN 13, and QR Code standards. In the Code 39 coding system, 29 letters, 10 numbers, and 8 special characters can be defined in the barcode [2]. The EAN standard works with the logic of the binary code system. By encoding thin and thick bars as numerical logic, a series of numbers is obtained, and information is kept in the database as the equivalent of this number. All commercial products are made under the EAN standard. A large amount of information cannot be entered into the content of the barcode and no direct information is available. Barcode systems are very low costs, rapid, and easy to implement. In addition to their advantages, barcode systems cannot respond to long-distance needs and collective readings due to the need for individual processing and the need to be read from a short distance. In addition, the barcode can be scratched, torn, and unreadable.

The RFID system can respond to these needs. Magnetic stripe and optical character recognition systems are other systems used in product/identity identification. In these systems, reasons such as tearing and scratching in the barcodes may occur due to deformation, where the identity cannot be identified. In biometric systems, retina, iris, fingerprint, face, voice, hand geometry, vascular map, and signature are used [3]. However, for the application of these methods, a person and close distances are required [4]. In addition, they cannot be applied to commercial products and goods.

The RFID system is expressed as Radio Frequency Identification. The RFID system works based on radiofrequency. It consists of an antenna called a tag, a processor where the data is recorded, a transmitter-transceiver, and an interface program where the data is processed (Fig.1.) [5]. When the signal sent by the transmitter is captured by the antenna on the RFID tag, the unique ID number in the processor on it is sent back to the transceiver device via the magnetic field [3]. Electrical circuits are located on the PCB surface. The RFID antenna, on the other hand, can be found in a flexible form without the need for a hard surface PCB.

Fig.1. RFID Components[5]

RFID systems can be classified according to usage purposes. Its usage areas have increased considerably today,

NAZMİ EKREN, (*corresponding author), is with the Department of Electrical and Electronical Engineering, Marmara University, Istanbul, Türkiye, (e-mail: nazmiekren@marmara.edu.tr).
https://orcid.org/0000-0003-3530-9262

ALİ SAMET SARKIN, is with Department of Electrical and Energy, Osmaniye Korkut Ata University, Osmaniye, Türkiye, (e-mail: sametsarkin@osmaniye.edu.tr).
https://orcid.org/0000-0001-6261-0531

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and it is frequently used in daily life. It is common in areas such as supply chain and tracking, animal identification, libraries, cargo, bridges and highways, parking lots, container tracking, city bus cards, bank cards, and hotels [6].

RFID systems are divided into active, passive, and semi-active. Passive RFID, examples of which are given in Figure II., interacts with the power of the incoming signal without a power supply. They are inductively coupled, and AC current is induced. The induced voltage, which is converted to DC current with a simple rectifier, enables the chip to work [7]. For coupling to occur, the antenna and the reader must be close enough to each other. The range capacity is the reading distance. To increase the reading distance, it is necessary to increase the frequency and power.

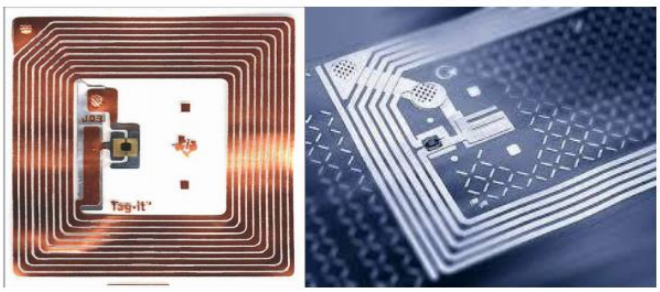

Fig.2. Passive RFID antennas[8]

Passive RFIDs are usually used at distances of less than 15 mt. It is the most cost-effective and simple type of RFID. For this reason, it has wide uses as identity control, contactless bank cards, bus cards, animal ID, and security alarms for goods. They contain a power supply in the active and semi-active systems. Because it has a power source, they do not need an electrical signal wave from the reader for communication. The power supply supplies energy to the chip on which the data is located and provides the energy for communication. Semi-active tags provide readings up to 50-100 mt, while active tags can be used in applications at a longer distance [9,10].

There are 4 operating frequencies used in the active, semi-active, and passive RFID systems. These frequencies are shown in Table I.

TABLE I
RFID FREQUENCY AND USAGE AREAS

Frequency Type	Frequency Range	Usage
Low Frequency	125-134 kHz	Short Distance- up to 15 cm
High Frequency	13.56 MHz	Short Distance- up to 1 mt
Ultra-High Frequency	860-960 MHz	Supply Chain- up to 10 mt
Microwave	5.8 GHz	Long-Distance and active RFID- up to 100 mt

RFID applications use the frequency ranges in Table I. RFID tags are used not only on flat and rough surfaces but also on flexible and bendable surfaces. Similar studies in the literature were investigated, and the effect of RFID tags operating at UHF (865-868 MHz) frequency on the adhesion of chips to the textile surface and textile antennas was performed in a study. Three different adhesive interfaces were used. The reading distances were compared, and it was seen that the RFID tag was read from a distance of 3.41 m in the laboratory environment and a distance of 2.05 m when measured on a human. Although the human body reduced the reading distance, the antennas on the textile showed stable performance [11]. An RFID antenna in the 902-908 MHz UHF band was designed and tested on curved and flat surfaces. The antenna performance was evaluated through simulations of input impedance, reflection coefficient, gain and read range. According to the results of the analysis, it has been proven that it can be used on flexible and curved surfaces by obtaining a reading distance of more than 1 m on cylindrical surfaces [12]. In another study, tensile and bending tests were performed by placing the RFID tag in glass epoxy resin, and the effect of the RFID tag on the bending test was determined. It was observed that the RFID tag did not affect the tensile test [13]. Another study, it was aimed to design and produce flexible UHF RFID tags used in bad environmental conditions. Flexible labels are intended to perform well even underwater and chemical exposure when applied to non-metallic surfaces. Polyamide surface was chosen as the surface to be printed. After the RFID circuit was applied to the surface, the reflection coefficient (dB) was examined, and it was found at which frequency the best result was measured [14].

II. MATERIAL AND METHOD

Within the scope of the Master's thesis entitled “Semiconductor Applications to Printed Circuits on Flexible Surfaces”, the effects of RFID tag application on flexible surfaces such as textiles, fabrics, and plastics were investigated [15]. Avery Dennison brand Passive UHF inlay antennas/tags were provided for the first phase of the thesis work. The protective plastic layer on the labels was dissolved by applying chromic acid (H_2SO_4+$K_2Cr_2O_7$) in an amount of 1 ml for 7 minutes. Afterward, the passive RFID inlay adhered to the paper and the knitted fabric textile surface with a butadiene-acrylonitrile-based adhesive at 150-200°C for 3 minutes and at 150-200°C for 5 minutes, respectively. It was adhered to the plastic surface without applying heat. Akramin BA-N adhesive was preferred because of its high binding capacity, high mechanical stability, and softness and elasticity to the prints [16, 17].

The obtained samples for each surface are shown in Fig.3., Fig.4., and Fig.5.

Fig.3. Application on the paper surface

Fig.4. Application on the plastic surface

Fig.5. Application on the textile surface

After the antennas were applied to the surfaces, the surface resistances were measured firstly with a multimeter. Then, with the Rohde Schwarz ZVL brand Network Analyzer capable of measuring in the 9 kHz – 13.6 GHz frequency range, the frequencies of the RFID tag samples operating at maximum efficiency, that is, minimum loss, and their impedances at these frequencies were measured. A 500-ohm resistive cable was used in the Network Analyzer and the device was set to S11. In the last experimental setup, a transmitting antenna and a receiving antenna setup were set up. A dipole antenna is placed at 1 meter from the transmitting antenna as the receiving antenna. RFID antennas were connected to the Anritsu MT 2605B signal generator. The dipole antenna used as the receiving antenna was connected to the Anritsu MS710C spectrum analyzer that can measure in the range of 10 kHz – 23 GHz. The signal generator was adjusted to the frequency value of each sample measured in the network analyzer. In this way, the signal at the frequency at which the RFID antenna operates was sent to the tag. The frequency applied to the RFID antenna and the loss of this frequency in dBm of the dipole antenna were examined. The dipole antenna was fixed, but the RFID antenna was 0, 45, 90, 135, 180, 225, 270, and 315 degrees directional difference was created. This method allowed two antennas to compare power loss in a single direction.

III. RESULTS AND DISCUSSIONS

After the applications were made on 3 different surfaces, the surface resistances were measured. The surface resistances of 3 samples prepared from each surface were measured and the average surface resistances of each sample are given in Table II.

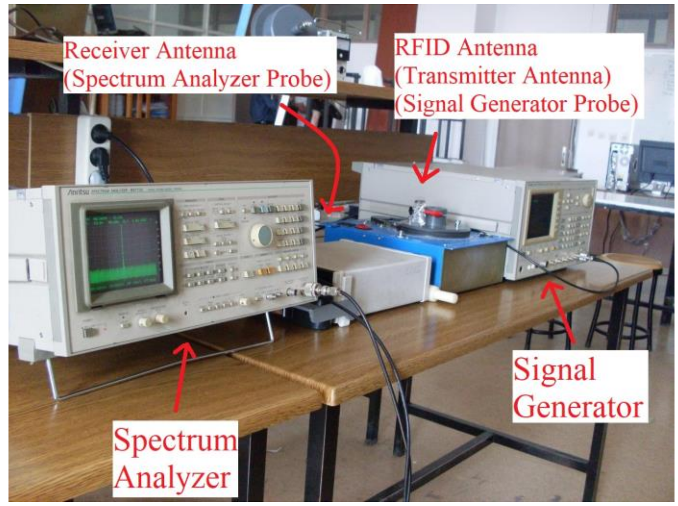

Fig.6. Experimental setup

TABLE II
SURFACE RESISTANCES

Surface	Sample-1 (Ω)	Sample-2 (Ω)	Sample-3 (Ω)	Average (Ω)
Plastic	0.39	0.40	0.38	0.39
Paper	0.80	0.90	0.88	0.86
Textile	1.2	0.9	1.3	1.13

Although the same RFID antenna was used in the 9 samples, different surface resistances were measured on different surfaces due to the surface effect when measuring surface resistances. While the surface resistance was very low on the plastic surface, more resistance was measured on the paper surfaces. It has been evaluated that the surface resistance had increased on all textile surfaces than others, and therefore the RFID reading distance would have decreased or a higher operating frequency would have been required.

TABLE III
FREQUENCY, RETURN LOSS, AND IMPEDANCE

Surface	**Frequency (MHz)**	**Return Loss (dB)**	**Impedance (Ω)**
Plastic-1	982.600	-7.661	121.74-j4.063
Plastic-2	982.600	-7.786	102.66-j33.239
Plastik-3	982.000	-7.741	113.56-j26.452
Plastic Average	982.400	-7.730	112.65-j21.251
Paper-1	980.000	-7.882	98.194-j24.051
Paper-2	983.000	-8.293	111.04-j15.516
Paper-3	980.600	-8.006	104.22-j18.429
Paper Average	981.200	-8.060	104.484-j19.332
Textile-1	983.200	-9.621	81.922-j31.454
Textile-2	980.000	-7.268	111.60-j34.508
Textile-3	983.000	-8.800	96.650-j32.698
Textile Average	982.066	-8.563	96.724-j32.886

The operating frequencies, return losses, and impedances of the samples on the surfaces were measured with a network analyzer device. According to these results, as can be seen from Table III, there is no surface effect on the operating frequency. In examples of all surfaces, the operating frequency range is in the range of 980-983.2 MHz. It will be able to respond to RFID antennas in this frequency range.

Since the operating frequency range is close and equal to the values before applying, there will be no need to change the frequency on different surfaces. When the reflection coefficients and impedance are evaluated, the loss on plastic surfaces is lower due to the high surface resistance and impedance. Textile surfaces have more reflection loss due to low impedance and high surface resistance.

TABLE IV
EFFECT OF DIRECTIONAL

Direction (degree)	Plastic-1 (dBm)	Plastic-2 (dBm)	Plastic-3 (dBm)	Plastic-Average (dBm)	Paper-1 (dBm)	Paper-2 (dBm)	Paper-3 (dBm)	Paper-Average (dBm)	Textile-1 (dBm)	Textile-2 (dBm)	Textile-3 (dBm)	Textile-Average (dBm)
0=360	-50	-54	-53.6	-52.53	-46	-46.6	-46	-46.2	-53.1	-51	-54	-52.7
45	-58	-57.4	-56	-57.13	-53	-55	-53.4	-53.8	-56.6	-57.1	-58	-57.23
90	-61	-63	-62.8	-62.27	-56	-59	-57.5	-57.5	-60.2	-65	-61.7	-62.3
135	-57.1	-59.8	-58	-58.3	-53.6	-58.8	-55	-55.8	-57.8	-60	-59	-58.93
180	-53.4	-56	-54	-54.47	-46.5	-50.6	-48.9	-48.67	-52	-56	-53	-53.67
225	-59.3	-60	-59	-59.43	-53.6	-59.2	-55.2	-56	-57.2	-61.4	-60.5	-59.7
270	-61.2	-61.2	-59	-60.47	-54	-63	-57	-58	-57.7	-64	-62	-61.23
315	-57.8	-58	-57	-57.6	-49.8	-54	-52	-51.93	-57.4	-62.6	-58	-59.33

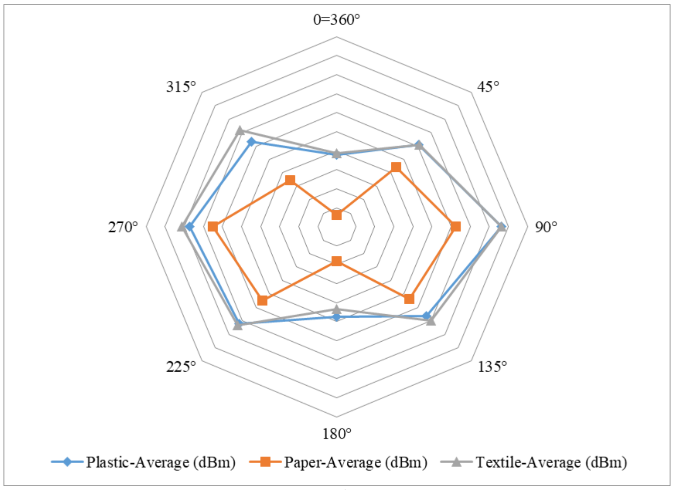

Fig.7. Chart of the reading loss

Table IV. shows the effect of direction on the response of RFID tags to the transmitting source. The results for all the samples are given in Table IV. Fig.7. is derived from Table IV. by taking the average values of each surface. The minimum power loss was observed on paper surfaces. The next minimum loss was on plastic surfaces. The highest power loss was on textile surfaces. It was observed that the loss was minimal on all surfaces in cases where the source and receiver antenna were located exactly opposite (0-180). The highest losses were measured in the reading directions of 90 and 270 degrees. It has been analyzed that the best results are on paper surfaces where power loss is minimal. According to these results, it has been evaluated that RFID tags (tags) can be applied to plastic, paper, and textile surfaces.

Operations and applications to be performed with RFID systems are made more practical and faster. While accuracy and reliability are increasing with RFID systems, system reliability is also increasing because manpower is reduced in the workflow. It is known that other biometric systems have their advantages and disadvantages. But the digital RFID system is also advantageous because they do not allow outside intervention compared to barcode systems.

IV. Conclusion

The study aims to examine the effects of the application of RFID systems on different surfaces. There are reading problems and high reflection losses on metal and wet surfaces. It has been investigated whether such losses also occur on the applied surfaces. It has been observed that the reflection losses of RFID application on all three surfaces are less than on metal or wet surfaces. According to the results on paper and plastic surfaces, no change was observed in the operation of the RFID tag. Although reflection losses are higher in RFID tags on the textile surface, the RFID tag will work normally like other surfaces at shorter distances. According to the analyzed results, it has been evaluated that RFID applications are usable on flexible surfaces.

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BIOGRAPHIES

NAZMİ EKREN Esenler, Istanbul, in 1966. He received the B.S. and M.S. degrees in electrical engineering from the Yıldız Technical University, Istanbul, in 1983 and from Marmara University, Istanbul, in 1992. He received a Ph.D. degree from Istanbul University, Istanbul, Türkiye, in 1996.

He has been an Associate Professor with the Electrical and Electronics Engineering Department, Faculty of Technology at Marmara University. He is the author of more than 70 articles, and almost 100 proceedings. His research interests include electrical energy, lighting technology, renewable energy, biomaterials, and nanomaterials.

ALİ SAMET SARKIN Kadıköy, İstanbul, in 1987. He received the B.S. and M.S. degrees in electric education from the Marmara University, İstanbul, in 2010 and 2013, respectively. He received a Ph.D. degree in electrical and electronics engineering from Marmara University, Istanbul, Türkiye, in 2022.

Since 2014, he has been working as a Lecturer with the Osmaniye Korkut Ata University. His research interests include identification systems including RFID, renewable energy, photovoltaic systems, and their applications.