Performance Assessment of an RFID System for Automatic Surgical Sponge Detection in a Surgery Room

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***Abstract*— A retained surgical instrument is a frequent incident in medical surgery rooms all around the world, despite being considered an avoidable mistake. Hence, an automatic detection solution of the retained surgical instrument is desirable. In this paper, the use of millimeter waves at the 60 GHz band for surgical material RFID purposes is evaluated. An experimental procedure to assess the suitability of this frequency range for short distance communications with multiple obstacles was performed. Furthermore, an antenna suitable to be incorporated in surgical materials, such as sponges, is presented. The antenna's operation characteristics are evaluated as to determine if it is adequate for the studied application over the given frequency range, and under different operating conditions, such as varying sponge water content.**

I. INTRODUCTION

Medical errors can be defined as the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim. Preventable medical errors are still a frequent occurrence in hospitals all around the world. In fact, according to major studies, at least 44.000 people and perhaps as many as 98.000 people die each year as a result of these errors [1].

A persistent and poorly understood mistake is the misplacement of surgical instruments and sponges inside patients' bodies in the course of surgery. It can lead to serious consequences for the patients and medical care providers. There are reports of retained instruments in different types of surgical procedures such as prostatectomy, thyroidectomy, cardiothoracic surgery (e.g. sponges in the lung parenchyma, pleural space, and pericardium), neurosurgery (e.g. sponges in the neck, spine), and orthopedic surgery [2]. The incident of a foreign body varies from 1 in 8000 to 1 in 18000 overall, and up to 1 in every 1000 intra-abdominal operations [3, 4]. This roughly translates to one case per year in a hospital that conducts at least 10,000 cases per year [2].

In most hospitals, current prevention measures include a surgical count performed by two members of the surgical team [2, 3, 5]. Other recommendations state that only X-ray detectable sponges are to be used, and that they should be counted once at the beginning and twice at the end of every open-cavity procedure. If a count is incorrect, that is, if all materials are not accounted for, manual or X-ray oriented exploration is to be performed [3].

Despite this, however, errors keep occurring. Counting is heavily dependent on human performance and is subject to inherent error. There are three separate circumstances where reliance on counting can be misleading: either no count is performed, or there is a miscount (cases where the count is incorrect) or falsely correct counts [3, 5].

The need for an automatic solution to this problem is evident, as it would erase the unavoidable human mistake from this equation. The use of radiofrequency identification (RFID) systems holds great promise in this issue and there are already applications in the market [6, 7].

In this paper we present an experimental procedure to evaluate the usefulness and suitability of millimeter waves for RFID purposes. Also, we studied the influence of a surgical sponge, and its water content, on the operation of an integrated antenna with a dimension of 980 µm at 60 GHz.

II. MMID IN THE 60 GHZ ISM BAND

Automatic identification procedures (Auto-ID) are very popular in various service industries, providing information about people and products in transit [8]. RFID is an acronym for radiofrequency identification, which is a wireless communication technology used to uniquely identify tagged objects [9]. Millimeter-wave frequencies refer to frequencies ranging from 30 GHz to 300 GHz, with wavelengths from 10 mm to 1 mm [10]. Millimeter-wave identification (MMID) updates the RFID system to millimeter waves [11] and gathers all the advantages of the use of higher frequencies.

For this specific application, we are more interested in one significant advantage provided by the higher carrier frequency: the physical size of antennas at millimeter-wave frequencies is so small that it becomes practical to build complex antenna arrays and further integrate them on *chip* or PCB [12, 13, 14], leading to ultra small tags. The goal is then to identify and count surgical instruments, like sponges, that are more easily lost during surgical procedures. These circuits would then be integrated in the instrument, allowing RFID techniques to be applied without interfering with its normal manipulation during surgery.

For an application where a tag is placed in a surgical instrument, with the intent of communicating with a RF reader, MMID offers a great advantage by allowing ultra-

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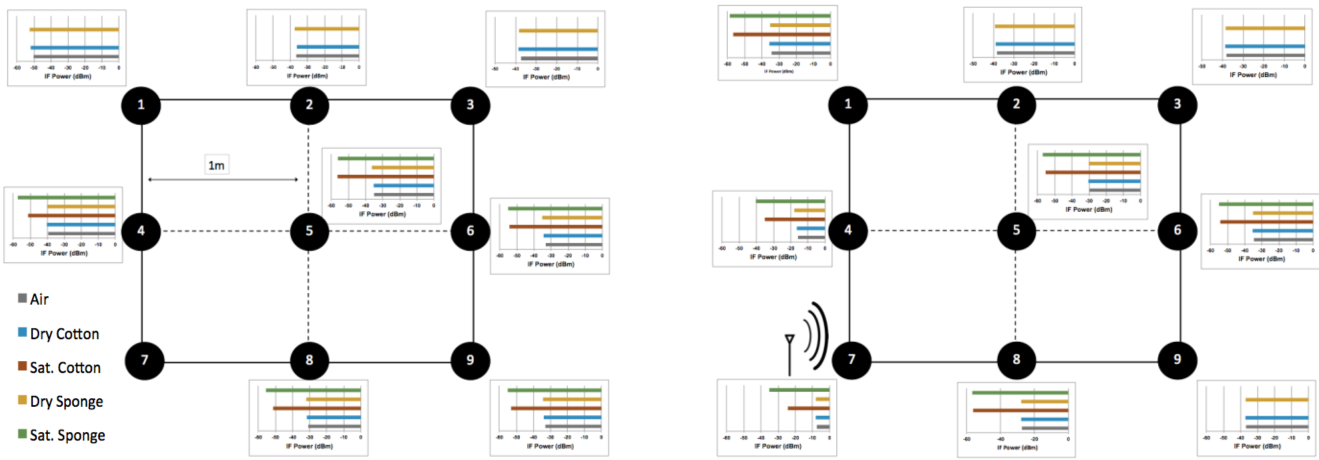

Figure 1. Illustration of the placement of the tags and reader. Nine positions were tested each one with two different heights, making a total of eighteen different spots. For each one, five power measurements were made. The bar charts indicate the obtained power values. The reader was placed in position number 7, as indicated in the figure to the right, at a height of 1 meter from the ground.

small antennas that provide the possibility of selecting a transponder by pointing toward it.

III. EXPERIMENTAL PROCEDURE

To test how the tag's position in a surgery room can influence the ability to detect the tag attached to a sponge, representative measurements were made in our laboratory facilities, where different objects and equipment that can interfere with the characteristics of the established link were randomly deployed. A schematic grid is shown in fig. 1, as to explain the eighteen total positions where the receiver was placed (nine positions where the tag was placed near the ground – left picture, and another nine at the transmitter's height – right picture). The reader was placed in position 7, at a height of 1 meter from the ground.

To establish a link in the 60 GHz ISM band, a V-band converter FC1005V00 by *Siversima* was used. The transmitting device was placed in a fixed position, while the receiving device (the tag) was placed in several positions around the room.

It's relevant to state that the test equipment only allows for an indirect measure of the received power, as an uplink to 58 GHz was made from an input intermediate frequency (IF) of 3 GHz at transmission, and subsequent downlink at reception. As so, the power measurements are relative to the output IF.

In addition, five different measurements were made at each position in an attempt to test the influence of two widely used materials for surgical gaze and sponges: cotton and PVA [15]:

- Direct link with no material in between the receiver and the transmitter;
- Dry cotton placed in front of the receiver antenna;
- Cotton saturated with water in front of the receiver antenna;
- Dry sponge in front of the receiver antenna;
- Sponge saturated with water in front of the receiver antenna;

Fig. 1 shows a bar graph for each position in which the measurements were attempted. For better understanding of the retrieved data, tables I and II show the power measurements for the two different heights.

TABLE I. IF OUTPUT POWER MEASUREMENTS WITH THE TAG PLACED ON THE GROUND, WITH DIFFERENT MATERIALS BLOCKING THE SIGNAL PATH

Positions	IF Output Power (dBm)				
	Air	*Dry Cotton*	*Saturated Cotton*	*Dry Sponge*	*Saturated Sponge*
1	-50,03	-51,93	UM	-52,53	NA
2	-36,62	-36,18	UM	-37,45	NA
3	-37,41	-38,6	UM	-38,32	NA
4	-39,48	-40,27	-51,32	-40,04	-57,36
5	-35,02	-35,26	-56,41	-36,35	-56,2
6	-33,28	-34,37	-54,35	-35,19	-55,12
7	UM	UM	UM	UM	UM
8	-30,73	-31,65	-51,4	-31,96	-55,6
9	-33,12	-33,91	-53,12	-34,35	-55,1

UM – Unable to measure. Means the received power was too low to measure

TABLE II. IF OUTPUT POWER MEASUREMENTS WITH RECEIVER PLACED AT ANTENNA'S HEIGHT

Positions	IF Output Power (dBm)				
	Air	*Dry Cotton*	*Saturated Cotton*	*Dry Sponge*	*Saturated Sponge*
1	-34,52	-35,64	-56,7	-35,2	-58,71
2	-38,27	-38,91	UM	-39,24	UM
3	-38,21	-38,73	UM	-38,55	UM
4	-15,81	-16,45	-35,12	-17,94	-40,25
5	-29,81	-30,4	-55,33	-30,18	-57,01
6	-34,52	-35,4	-54,32	-35,17	-55,07
7	-7,31	-8,1	-24,34	-8,04	-35,15
8	-27,31	-27,91	-56,3	-27,89	-56,79
9	-36,98	-37,14	UM	-37,02	UM

UM – Unable to measure

From the previous data, it can be concluded that the received power decreases with the distance between the two devices. We can also state that the objects placed in between devices interfere with the received power, as the values are lower in all nine positions for the measurements with cotton or a sponge placed in between devices. When the materials are soaked with water, the received power decreases significantly, in the order of 20 dB.

Another important note is that the received power is higher for the measurements where the tag and reader antennas were at the same height, not only because the distance is shorter, but also because of the effect of the ground surface, that may reflect the signal.

IV. Sponge Effect on Antenna Performance

Besides the RF link behavior and the detect power, another important issue is the analysis of the influence of sponge material in the RF signal propagation and antenna behavior. Resorting to Ansoft's HFSS, simulations were conducted in order to evaluate the effect of surgical sponge material in the behavior of the proposed antenna for RFID. In this section, the antenna design is presented and simulation results are discussed.

A. *Proposed ultra-small antenna*

The HFSS model and the dimensions of an electrically small antenna are shown in fig. 2. It is noteworthy that only the lateral side of the antenna is detailed, since its top has the same shape, only extending over 980 µm.

Since the intended study contemplates objects such as sponges, it is necessary for the antenna to be able to operate in several different conditions, as the sponge can be more or less soaked with water or blood. For the presented simulations, the extreme cases were tested, where the sponge is completely dry or water saturated.

B. *HFSS simulation analysis*

For the simulations, different models were designed, where the antenna was placed in the middle of the sponge or closer to the surface, in order to evaluate if its placement had significant influence on its performance. Another tested parameter was the sponge's wetness, as previously mentioned. For clarity reasons, the four setups will be designated as A (dry sponge with antenna in its center), B (dry sponge with antenna 1 mm from the surface), C (saturated sponge with antenna in its center) and D (saturated sponge with antenna 1 mm from the surface).

The dry sponge's dielectrical properties required for the simulation (permittivity and conductivity) were extrapolated from [16] and were considered as a first approximation to this experimental study towards a medical equipment with RFID. As for a saturated sponge, the properties' values were approximated to those of regular water, due to its high

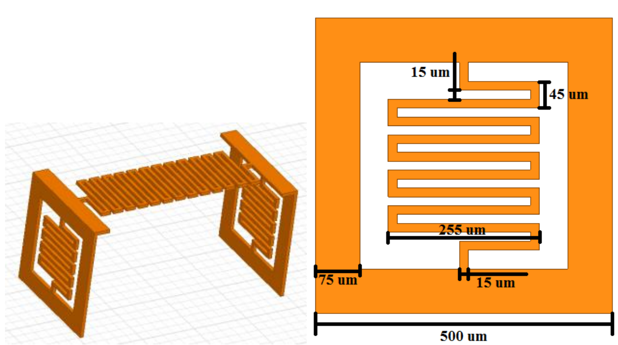

Figure 2 – a) HFSS model of the antenna (left) and b) its detailed dimensions.

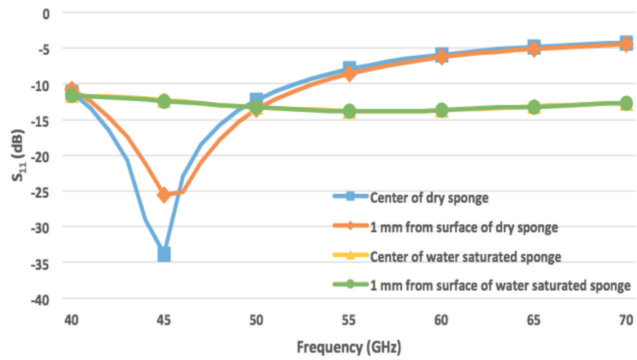

Figure 3 – Simulated S_{11} parameter for the four study cases.

content in the saturated state.

1) *Return Loss*

The S_{11} parameter obtained for the four studied situations is presented in fig. 3. When evaluating the location of the antenna in the sponge, it is clear that for both saturated and dry sponge conditions, the placement of the antenna has little effect on its return loss. The most noticeable difference happens at 45 GHz with the dry sponge, where the S_{11} value of the antenna closer to the surface is 10 dB greater than the one placed in the middle of the sponge. Even so, it can be concluded that the placement of the antenna has no significant influence over its S_{11} parameter.

The presence of water in the sponge, however, introduces unequivocal changes to the return loss of the antenna. With the dry sponge, a minimum is visible around 45 GHz. When the sponge is saturated with water, such does not happen, since the permittivity of the antenna's operation environment has drastically risen, which would have displaced this peak to higher frequencies than the ones covered in this study. Even though differences were noted between dry and saturated sponges, it is possible to say that the proposed antenna is suitable for the application under study, since for both extreme conditions the antenna shows a reasonable return loss. For the saturated sponge, the S_{11} parameter is below -10 dB for the frequency range of interest (40 to 70 GHz), while the dry sponge's S_{11} goes above -10 dB at around 52.5 GHz. Even so, we can safely admit that the antenna is capable of operating in both conditions at 58 GHz, which was the used frequency in the experimental tests.

2) *Gain patterns*

In fig. 4 the simulated gain patterns are presented. Since 58 GHz was the chosen frequency for experimental tests, these diagrams are also calculated at that frequency.

Analyzing the A and B setups, corresponding to dry sponge, it is noticeable that the gain diagrams are fairly similar in shape in both cases, being quite directive in the negative side of the Z axis. Even so, when the antenna is closer to the surface of the sponge, it presents a larger gain, 6.35 dB in B against 2.43 dB in A, which leads to the conclusion that placing the antenna closer to the surface would allow for better communication. Comparing C and D, it is visible that the diagrams' shapes differ for both cases. They are mainly directive in the positive Z axis direction and both sides of the Y axis. Again, it is possible to verify that when the antenna is closer to the surface of the sponge it

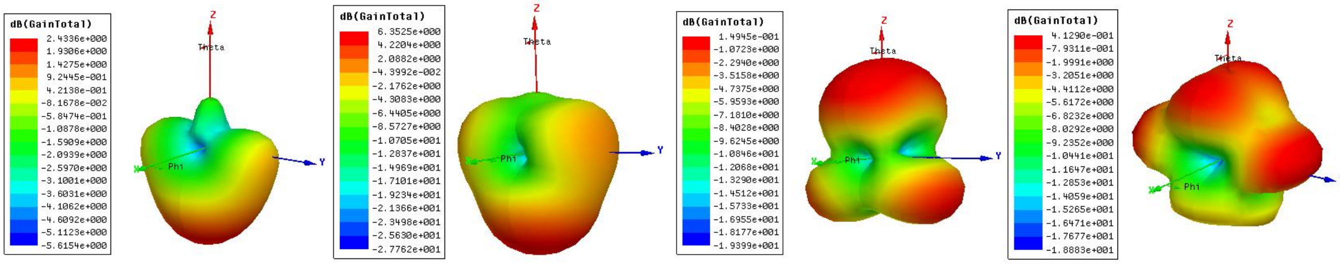

Figure 4 – Simulated gain diagram at 55 GHz of the four evaluated situations. From left to right: A, B, C, D.

presents a larger gain than when it is in its center (0.41 dB and 0.15 dB, respectively), thus supporting the previous conclusion that antenna placement is a fundamental parameter in the system's performance.

The addition of water to the sponge drastically changes the radiation diagrams and, most of all, it decreases the antenna's gain, which can be explained by the losses introduced in the antenna's operation environment by its water content.

From the analysis of all diagrams, we can say that even though the antenna is capable of performing adequately, it is very directive, which would potentially introduce some setbacks if the transmitted or received power isn't high enough to compensate the negative gain in several directions of the antenna.

V. CONCLUSION

From this feasibility study it was possible to conclude that the use of MMID technology presents a good potential for application in real surgery environments, since the small size of the device will not offer any handling difficulties for medical staff. It was also shown that the 60 GHz ISM band is suitable for short distance communications. From the HFSS simulation's results, it was possible to sustain that the antenna shows promising capabilities, having performed adequately, even though its high directivity is a negative point that should be addressed.

As future work, experimental tests must be made using a more complete setup, already equipped with the proposed antenna, in order to truly assess the full system's performance and obtain concrete and irrefutable evidence about its suitability. The dielectric properties of surgical sponges must also be measured with different levels of water and blood content, in order to improve the HFSS model and allow for more reliable and representative simulations. Furthermore, the inclusion of blood and blood plasma in the measurements constitutes an essential step towards the evaluation of this system. Testing in an operating room could also help to conclude about the feasibility of the proposed solution, as wave propagation is affected by reflections and attenuations caused by the multiple obstacles present in the room.

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REFERENCES

[1] I. of Medicine, To Err is Human: Building a Safer Health System, no. November. Washington D. C.: National Academy Press, 1999.

[2] V. C. Gibbs, F. D. Coakley, and H. D. Reines, "Preventable Errors in the Operating Room: Retained Foreign Bodies after Surgery-Part I," Curr. Probl. Surg., vol. 44, no. 5, pp. 281–337, 2007.

[3] A. A. Gawande, D. M. Studdert, E. J. Orav, T. A. Brennan, and M. J. Zinner, "Risk Factors for Retained instruments and Sponges After Surgery," N. Engl. J. Med., vol. 348, no. 3, pp. 229–235, 2003.

[4] T. F. Dagi, R. Berguer, S. Moore, and H. D. Reines, "Preventable Errors in the Operating Room-Part 2: Retained Foreign Objects, Sharps Injuries, and Wrong Site Surgery," Curr. Probl. Surg., vol. 44, no. 6, pp. 352–381, 2007.

[5] F. Kiernan, M. Joyce, C. K. Byrnes, H. O'Grady, F. B. V Keane, and P. Neary, "Gossypiboma: A case report and review of the literature," Ir. J. Med. Sci., vol. 177, no. 4, pp. 389–391, 2008.

[6] Stryker (2014). *SurgiCount Safety Sponge System* [Online]. Available: http://www.surgicountmedical.com/

[7] RF Surgical Systems (2014) [Online]. Available: http://www.rfsurg.com/

[8] K. Funkenzeller, RFID Handbook, Third. Wiley, 2010.

[9] V. D. Hunt, A. Puglia, and M. Puglia, RFID: A Guide to Radio Frequency Identification. Wiley, 2006.

[10] Y. Yu, P. G. M. Baltus, and A. H. M. van Roermund, Integrated 60 GHz RF Beamforming in CMOS. Springer, 2011.

[11] J. P. Curty, N. Joehl, C. Dehollain, and M. J. Declercq, "Remotely powered addressable UHF RFID integrated system," IEEE J. Solid-State Circuits, vol. 40, no. 11, pp. 2193–2202, 2005.

[12] Yu Y, Baltus PGM, Roermund AHM van. Integrated 60GHz RF Beamforming in CMOS. Springer; 2011.

[13] Zamith M, Magalhães J, Anacleto P, Mendes PM. 60 GHz On-Chip Antenna Array with Efficiency Improvement Using 3D Microfabrication Technology. Accepted for the 9th European Conference on Antennas and Propagation (EuCAP). Lisbon. 2015.

[14] Zamith M, Dinis H, Magalhães J, Fernandes J, Mendes PM. On-Chip , Efficient and Small Antenna Array for Millimeter-Wave Applications. Accepted for the International Workshop on Antenna Technology 2015 (iWAT2015). Seoul, Republic of Korea. 2015.

[15] American Surgical Company (2015). *Products* [Online]. Available: http://www.americansurgical.com/products/

[16] O. G. Abdullah, S. a Hussen, and A. Alani, "Electrical Characterization of Polyvinyl Alcohol Films Doped with Sodium Iodide," Asian Trans. Sci. Technol., vol. 01, no. 04, pp. 1–4, 2011.