# An Innovative and Efficient Method to Measure Small Antennas in Water Conduits

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## Abstract

Wireless Sensor Networks have been recently proposed for applications in a large variety of systems. Among all, the possibility to insert a terminal node inside a dissipative liquid medium has attracted attention by few authors. For this reason, the paper presents the design and construction of a test bench for the experimental characterization of antennas inside liquids. The design has involved the classification of a large variety of pipelines, among which three different samples have been selected. The pipeline has consequently been configured in order to host fixed or mobile antennas, which can be wired towards the external part of the conduit, to facilitate their connection to a network analyzer. The speed and pressure of the liquid, as well as the speed of the antenna, can be controlled remotely. Finally, in case of metallic pipelines, a procedure has been introduced to test the attenuation along the longitudinal direction of the conduit.

## 1. Introduction

Antennas are crucial devices in transmission systems since, they represent the interface between the transmitter and the propagation medium. The design of the antenna involves, as listed in the IEEE Standards [1], parameters like gain, return loss, radiation patterns and cross-polar diagrams. The simulation analysis is important to define the characteristics of antennas but the measurements are fundamental in order to verify if the antenna's parameters meet the required constrains. A rigorous method to measure the device is to test it in a proper setup [2], [3], that should be as close as possible to the final environment [4].

In most cases the propagation medium is the free space, as for example in all applications like broadcast services, space applications or communications between devices. In fact, in these cases antennas are usually measured in facilities like anechoic chambers, reverberation chambers or open-field test ranges, depending on the operating frequency and the final installation.

However, the scenario becomes more complex when an antennas must operate in lossy media. A typical application is represented by Radiofrequency Identification Tags (RFIDs) deployed inside the human body to sense vital signs [5], but it is possible to find many papers where the tag reader (or transmitter) is embedded in a lossy medium [6]. Another example, where the antennas are inserted in lossy media, are the probes used to measure the Specific Absorption Rate (SAR). In such case the measurements are performed by inserting the device in a liquid that has the same electromagnetic properties of the biological tissues [7].

In general, the number of cases of antenna's measurements in complex environment is increasing, thanks also to the growing interest in Wireless Sensors Networks. In fact, in the last 15 years, WSNs have been widely used in very different fields like industrial control, health care monitoring, manufacturing automation, logistics or in general in any situation in which some parameters over a huge area should be monitored. The network topology is usually formed by a central station and several nodes which communicate through wireless channels among them and with the central unit. In some situations, like ground monitoring [8] or constructions (concrete) survey [9], it could be possible that the antennas were buried within a dissipative medium. This environment, from the simulation point of view, does not represent a huge problem, as the most common electromagnetic simulation softwares are able to solve it. Nevertheless such scenario could be critical in the measurements phase.

More recently, our group published a paper [10] showing a system to monitor water conduits using a wireless sensor deployed inside the pipes filled with water. In that case the propagation medium is water, because the transmission is in the transversal plane of the pipe, between the antenna and the receiver on the surface [11]. This is another example where it is necessary to verify the simulation results in a specific test bench.

## 2 Antennas in Conduits

The idea to monitor the status of the water conduits using a wireless device that flows without any anchorage in the pipes is appealing but requires the construction of a complex experimental setup to measure the antenna’s performance.

Since the device is not fixed, the amount of water surrounding the antenna could vary and this condition, from the electromagnetic point of view, could affect some parameters getting worse the received signal of the antenna on the surface. This condition can be simulated with a software but it is very difficult and computational expensive.

Furthermore the situation is more complex because the antenna is inserted in a liquid under high pressure and exposed to any kind of shocks. For this reason also the mechanical strength of the external shell assumes an important key point.

In order to verify all these aspects a first experimental setup has been built on the roof of Politecnico di Torino building to guarantee the possibility to construct a long pipe with different diameters. In this specific test set the pipe is made of polypropylene but it could be potentially extended to any kind of pipe, concrete or also metallic.

In the last case the propagation in the transversal plane of the pipe is not possible, but it is possible to use, for example, the pipe itself as a waveguide and propagate the signal along the longitudinal direction. In this scenario a series of sensors are installed in the pipe, and, like in a mesh network, they can communicate each other and then with a central station. An interesting parameter for this type of pipe could be the attenuation loss along the longitudinal direction.

As matter of fact, in all these cases the most important parameter to monitor is the return loss of the antenna during his activity. In order to do that a wired connection should be established between a network analyser and the antenna terminals, even when the pipe is filled of water and under pressure. In the same time it should be interesting to move or rotate the antenna to measure the same parameters in different boundary conditions.

In the next paragraph a description of a particular test bench will be listed but in general, the same setup can be built using a different pipe’s diameter or material.

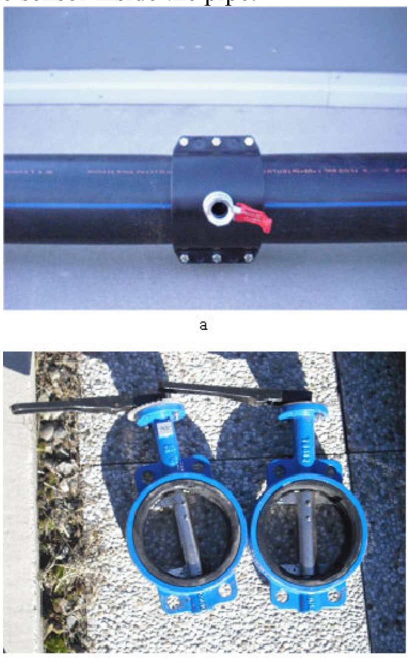
## 3 Experimental Setup

The pipe chosen in this setup has an internal diameter of 160 mm, while the external one is 169.5 mm. The thickness of the pipe walls increases with the diameter, but this feature has no role in the leakage localization process. Thus, it does not produce any variation in the measurement results. The material of the selected pipe is polypropylene, which is the most used one in water conduits. Moreover the pipe used in the test is compliant with the standard UNI EN 12201 – UNI EN 15494 and it is able to work at a pressure up to 10 bars. The present experimental setup consists of a 30 meters long pipe, Fig. 1. The entire length of the pipe has been reached connecting five segments of 6 meters each, in order to facilitate the installation procedure. The connection between the modules is realized by means of two metallic flanges as they ensure a perfect matching in the transition among bars, avoiding the existence of gaps. Furthermore, the presence of these connections does not affect the working conditions in terms of supported pressure; in fact, the realized connection can be used up to a pressure of 10 bars as guaranteed also by the chosen pipe. The designed experimental setup, thanks to its modularity, ensures a good flexibility and manageability; it offers the possibility of extending or shortening the total length of the pipe simply adding or removing bars. The complete setup consists also of two caps installed at the ends of the pipe and of a tap placed at one side in order to permit the filling of the pipe with water (or any other liquid). Along the pipe, five ball valves, Fig. 2a, are installed to give the possibility to insert another antenna or to make measurements in different locations. The use of ball valves instead of normal taps has been preferred as is more easy to insert a device connected by means wire and assure a waterproof thru. The pressure inside the pipe is managed by a glycerin manometer installed at one end of the system.

The evident flexibility of the presented setup is guaranteed also by its possible operation modes. In fact, the experimental structure can work both with flowing and static water. The first operation mode is easy to set up as it requires just the removal of the pipeline termination from one side. Furthermore, such mode does not need any control on the sensor, which is simply carried by the water flow. The second method, indeed, requires the management of the sensor that should be manually driven along the pipe. To do so, the sensor is bonded to a cable and wrapped/unwrapped around two screws located at the two opposite terminations of the pipe. The only requirement is related to the screws that must be waterproof and rotatable from the outside. Such proposed solution has been realized properly modifying two butterfly valves, type 150N Aquaria DN 150. In particular the two wings have been removed, so that only the central part of the valves remains, see Fig 2b. Moreover, the two external hooks used to stop the movement of the lever have been removed allowing, in this way, the lever to perform a rotation up to 360 degrees.

The sensor driving system has been deployed by placing the two butterfly valves at the two opposite sides of the pipe at a distance of 1.5 meters from the ends, Fig. 3. The connection between the two valves, in the present configuration, is ensured by a round trip cable. The two little wings, left on the top and on the bottom of the screw, keep the wire in the middle of the pipe. In this way the movement of the sensor is completely guided and there is not possibility for the sensor to hit the wall. The cable is made of plastic to assure a strong friction between the cable itself and the cast iron valves. Finally, an electronically controlled motor has been installed on the two valves: it makes possible to rotate the two valves with a constant speed and consequently to check the speed of the sensor inside the pipe.

Fig. 1 The test set installed on the roof of Politecnico di Torino



a

b

Fig. 2 a) zoom of a ball valve, useful to insert antennas inside the pipe; b) The two butterfly valves modified to manage the movement of the sensor along the path Politecnico di Torino

## 4 Antenna's Measurements

Following the description of the experimental setup in the previous chapter, the measurements of the return loss of an antenna under test have been performed using a network analyzer connected by means a radiofrequency cable to the device inside the pipe. The connection can be realized by using a waterproof through connection to pass the pipe. In static water conditions the antenna can be inserted by using the ball valves at different positions. Since the long pipe is modular it is possible to measure the return loss also in pipe bars with different diameters or different material. Exploiting the fact that there are more valves, it could be interesting to study the propagation inside the pipe, inserting two or more antennas at different distances. The whole system is electronically controlled, so also the network analyzer as well is synchronized with the antenna movement. Finally, the radiation pattern or the cross polar pattern of the antenna in the transversal plane can be measured by using a known external antenna. As shown in Fig. 4 the external antenna could be placed on the top of the pipe, pointing the pipe itself. The distance or the type of antenna could vary depending on the operating frequency. The external antenna is connected to one port of the network analyzer, while the second one is connected to the antenna under test. All around the pipe absorbing materials must be installed to avoid any reflection from the obstacles in the surroundings. The whole full characterization of the diagram is possible by using a rotating motor.

## 5. Conclusion

The paper presents a useful test bench to characterize antennas in pipelines filled with liquid under pressure. Some relevant aspects, to manage the connection between the antenna inside and the network analyzer outside, have been addressed and solved. The proposed test set can be used to characterize antennas mounted in fixed or mobile devices. The setup could represent a reference point for any other similar test bench to characterize sensors in liquids.

Fig. 3 A zoom of one termination of the pipe with the butterfly valve installed

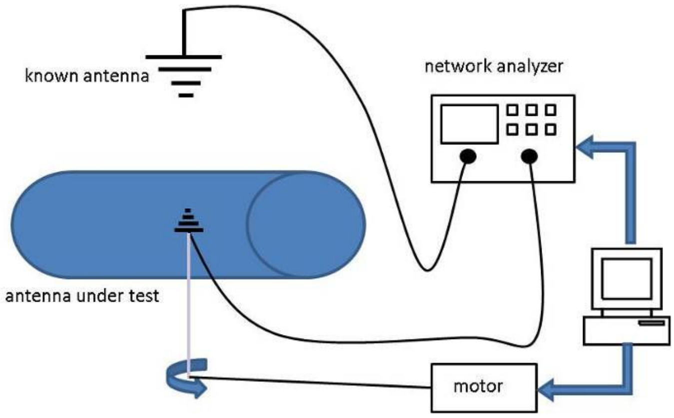



Fig. 4 A scheme of a possible measurement scenario

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