# A Sensing Antenna for Liquid Leak Detection System Using Synthesized Transmission Line on Integrated Passive Device Process

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***Abstract* – In this paper, we propose a sensing antenna for detecting leaks in pressurized pipes or industrial storage tanks with a simple passive on-chip network. The chip, fabricated using the integrated passive device (IPD) process, is composed of a section of dual-operational mode synthesized transmission line. The electrical properties of the synthesized line are a function of the material medium surrounding the chip. In air, it is identical to a common transmission line well matched to the system impedance while in a liquid, the high dielectric loading detunes the transmission responses of the chip to block signal flows. This, in turn, prevents the antenna from radiation. The communication link is interdicted, and hence an alert indicating a suspected leak of liquid is released. The design principle and preliminary results are introduced and discussed.**

***Index Terms* —Sensing antenna, synthesized transmission line, liquid, leak detection system, integrated passive device.**

## 1. Introduction

Pressurized pipes and industrial storage tanks are common facilities in heavy industry factories. A variety of liquid chemical compounds or water are pressurized and delivered between storage tanks through pipelines. Leaking at junctions of the pipelines is extremely hazardous and could result in disaster if not properly dealt with in time. Accordingly, sensing systems to provide real-time monitor of the facilities are essential and of great importance.

In this paper, a low-cost radio-frequency solution is discussed by utilizing a sensing antenna integrated with an on-chip liquid detector. The on-chip detector simply consists of a section of dual-operational mode synthesized transmission line using the integrated passive device (IPD) process [1]-[2]. The dual-mode operation is associated with the material medium by which the chip is surrounded. In air, the chip functions identically to a section of common transmission line, but in a liquid, the network is detuned and even becomes an open circuit in order to prevent signal flows. The design principle and preliminarily experimental results are introduced.

## 2. Prototype Sensing System

Fig. 1 shows the schematic diagram of the proposed sensing system for detecting liquid leak. It is simply composed of a signal source, an on-chip liquid detector, and a radiator. The on-chip detector is sensitive to the change of environments. In air, it is operated in the *line* mode and identical to a conventional transmission line. This ensures the antenna could radiate efficiently. In a liquid, the chip is instead operated in the O.C. mode. It automatically reconfigures itself as an open circuit with high input impedance when looking into either side. The signals are therefore blocked from flowing through. Accordingly, the chip detector functions as an on-off modulator in response to the material medium by which the chip is surrounded. In this demonstration, without loss of generality, the liquid is set to water, with very high relative dielectric constant (81 at room temperature) when compared to that in air. The loss tangent, meanwhile, is 0.005 or 200 μS/cm. The working frequency is 475 MHz.

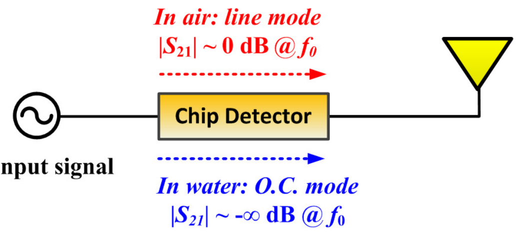
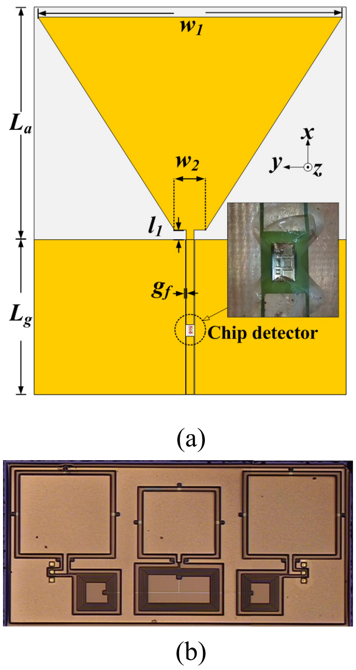


Fig. 1. Schematic diagram of the sensing system.

## 3. Layout of Sensing Antenna

Fig. 2(a) shows the layout of the sensing antenna. It is a simple triangular-shaped monopole antenna, which was fabricated on a 0.8-mm FR4 substrate. When radiating in free space, the -10-dB operating bandwidth ($|S_{11}| < -10$ dB) is from 400 to 500 MHz. The antenna was fed by a CPW line. The dimensions (in mm) are $L_a = 120$, $L_g = 80$, $l_1 = 5$, $w_1 = 16$, $w_2 = 156$, and $g_f = 0.3$. The total efficiency, without installing the detector, is 92%. The chip detector, simply consisting of a section of synthesized transmission line, is attached to the CPW line by bond wires. The chip photo is shown in Fig. 2(b). The capacitance of the synthesized line changes in accordance with the dielectric constant of that medium, which in turn shapes the transmission response of the line. It is a 50-Ω line segment in air, but turns to an open circuit (in the ideal case) in water. By integrating the liquid detector as a part of the feeding line, the on-off switch in Fig.



(a)

(b)

Fig. 2. (a) Geometry of the sensing antenna with chip detector; (b) chip photo of the liquid detector [1].

1 is readily achieved. The synthesis details can be found in [2]-[3].

## 4. Experimental Results

The on-chip liquid detector, fabricated using the IPD technology, was tested. The extracted characteristic impedance in the line mode is 45.7+$j$ 3.8 Ω, which is very close to an ideal 50-Ω line. The transmission loss is 4.4 dB. In the O.C. mode, the measured input reflection coefficient is 0.55 ∠ -1.1°. The transmission loss rises to 12.3 dB accordingly. In the two states, the ratio of power delivered to the output port of the chip is 6.2. Frankly speaking, the response is just barely acceptable in the O.C mode. Although the phase is close to zero, the magnitude of reflection coefficient is far from unity (ideal open). It can be explained by the power dissipation of the lossy silicon substrate.

Fig. 3 plots the simulated and measured $|S_{11}|$ of the sensing antenna operated in air as well as in water. At the center frequency, the reflection coefficient of the antenna system is well-matched as -12.7 dB in air, but becomes poorly-matched as -4.4 dB in water. Fig. 4 illustrates the simulated and measured radiation patterns of the antenna. The radiation patterns in both states are quite similar. It is a typical monopole antenna with omnidirectional radiation in the H-($yz$-) plane. The only difference is the realized gain. In air, the measured peak gain is -2.5 dBi and the total efficiency is 33.1%, while in water, the gain and efficiency drop significantly to -10.4 dBi and 5.4%. The significant drop of radiation parameters when operated in water makes the proposed sensing antenna suitable to be used in liquid leak detection systems. Finding a proper way to expose the chip to ambient environments without affecting other building blocks of the sensing system is an essential topic should be involved in a future study.

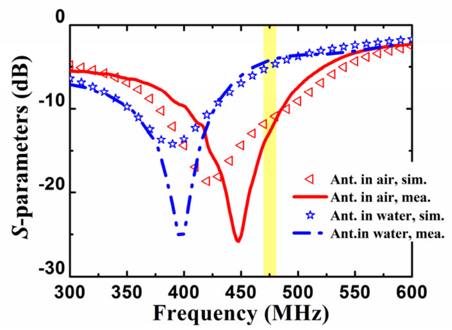
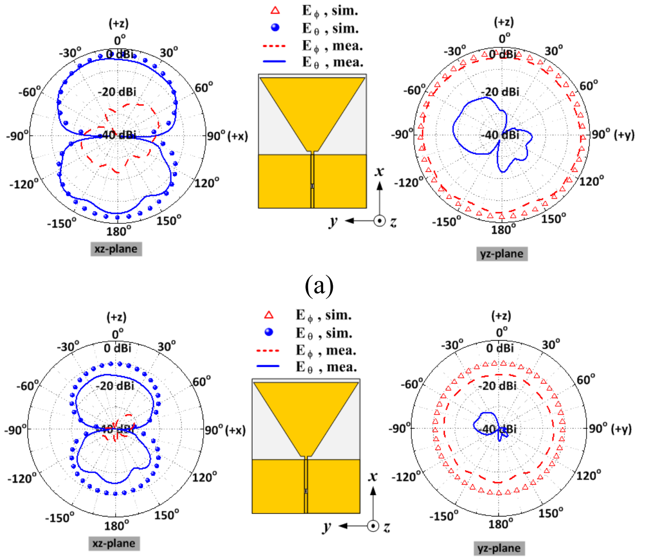


Fig. 3. Input reflection coefficient of the sensing antenna in air and in water.



(a)

(b)

Fig. 4. Radiation patterns of the sensing antenna in (a) air and (b) water.

## 5. Conclusion

A simple sensing antenna system for detecting leaks has been discussed in this paper. It simply comprises a signal generator, an on-chip liquid detector, and a monopole antenna. The liquid detector was a section of dual-operational-mode synthesized transmission line subject to the change of environments. The on-off switching is achieved automatically when the chip is surrounded by different media.

## Acknowledgment

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## References

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