Microstrip Patch Antenna Based Hairtail Fish Freshness Detection: A Novel Approach

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***Abstract*—This paper proposes a novel and non-invasive approach for detecting the freshness of Hairtail fish using a compact microstrip patch antenna operating at 2.45 GHz. The antenna, with dimensions of 38.6 mm x 47.6 mm x 1.6 mm, was used to measure the resonant frequency and return loss of fresh and stale fish at different distances. The results indicate that the proposed method is reliable and effective for detecting the freshness of fish, which is important for reducing food waste and ensuring food safety. This method offers a practical solution for the seafood industry to monitor and maintain the quality of their products during transportation and storage.**

Keywords—Antenna, Freshness, Dielectric Properties, Stale Fish

I. INTRODUCTION

About 44% of the world's people live within 150 km of a big body of water, and 37% live within 100 km [1]. This large population depends on different types of sea species, such as lobster, prawns, dulse, Salicornia, Nori, Irish moss, and sea purslane. [2-3]. Among them, fish is a major source of protein for the global population. [4]. Hairtail (Trichiurus lepturus) [5] is a commonly found fish along the coasts of various seas associated with the Indian Ocean, Pacific Ocean, and Atlantic Ocean [6]. Hairtail fish is widely consumed in countries such as Korea, China, India, Japan, and others [7]. Fish are exported from one location to another, and it is crucial to store them at very low temperatures to preserve their freshness [8].

The freshness of fish is dependent on various factors such as water content (water activity), muscle tissue, protein content, fat content, etc. [9]. The action of bacteria is the primary factor contributing to fish spoilage [10]. When fish are caught, bacteria are present on the surface of all fish and begin to multiply rapidly [11]. The rate of bacterial growth is influenced by several factors, including temperature, type of bacteria, oxygen availability, pH, and salt content [12-13]. Freezing is a highly effective method of preservation as it reduces microbial and enzymatic activity without the need for preservatives or heat application [14].

To assess the freshness of hairtail fish, oxide sensors can be utilized to monitor the fish's freshness under various storage temperatures (-5, -10, and -15°C) and different storage durations, namely, 3, 4, and 5 days [8,15]. The study reveals a significant finding that a decrease in storage temperature to 2°C extends the fish's shelf life for up to 5-6 days. During fish processing, the bacterium "Pseudomonas fluorescens" contaminates hairtail fish, leading to spoilage. This bacterium is capable of growing on the surface of hairtail fish as well.

Hairtail fish are characterized by forked tails and long, slender bodies [10]. They are found in temperate and tropical waters worldwide, including marine environments [5]. The diet of hairtail fish varies among different species. Some hairtail fish species are predators and feed on smaller fish, while others are scavengers. Additionally, some species are filter feeders, consuming plankton. In many regions, hairtail fish are commonly consumed fresh, dried, and salted [16]. The moisture content of freshwater fish is generally higher than that of seawater fish. The water content of fish is also influenced by habitat conditions, age, gender, and the season of the year. Moisture content in fish can range from a maximum of 97% to a minimum of 62%. The objectives of the present study aim to provide a clearer understanding of the effects of water activity on the moisture sorption isotherms of large head hairtail fish at 25°C and 35°C [17-18].

II. HAIRTAIL FISH SPOILAGE

Microbial activity alone is responsible for the loss of one-fourth of the world's food supply and thirty percent of all landed fish [19]. With the global population continually increasing and the need to transport and store food where it is required, it becomes essential to preserve food in order to extend its shelf life while maintaining its nutritional content, texture, and flavors [20-21]. Various methods are employed to extend the shelf life of hairtail fish, including drying, smoking, fermentation, salting, and canning. Spoilage of hairtail fish can occur through three main types: oxidation, enzymatic autolysis, and microbial growth [22].

OXIDATIVE SPOILAGE : The double bonds of fatty acids are often prone to oxidation, which is what makes hairtail fish go bad and go bad. In lipid oxidation, there are two types of oxidations that occur: enzymatic and non-enzymatic. Enzymatic is caused by lipases, which is also associated with fat deterioration. During this process, lipases split the glycerides, forming free fatty acids, which are responsible for a common off flavour, frequently referred to as rancidity, and reducing the oil's quality. Hematin compounds are the main cause of oxidation in non-enzymatic spoilage, which produces hydroperoxides. In fish muscles, lipid oxidation can be caused by pro-oxidative hemoglobin [19,23].

MICROBIAL GROWTH SPOILAGE : Microbial spoilage happens in fish mainly due to the microbial growth and metabolism that cause fish spoilage and produce bacterial species such as Pseudomonas, Alcaligenes, Vibrio, Serratia, and Micrococcus. In hairtail fish, the bacteria that spoils the fish is called "Pseudomonas fluorescens" [24].

ENZYMATIC AUTOLYTIC SPOILAGE : After capturing the fish, enzymatic breakdown in fish molecules occurs due to chemical and biological changes produced. During the early phases of deterioration, autolytic enzymes caused a reduction in the product's textural quality, but they did not produce the typical off-odors and off-flavors associated with spoiling. This suggests that autolytic breakdown, even at very modest quantities of spoilage microbes, can shorten the shelf life of products and diminish their quality. [25].

As we all know, the most perishable food consumed by humans on planet Earth is fish. Soon after its death, it started spoiling. One of the most effective methods for reducing fish spoilage is to reduce the temperature and control the microorganisms that cause deterioration. Crushed ice is commonly and mainly used to keep the fish fresh for a limited period of time. There are several problems in keeping the fish fresh: first, the tropical season that our country, India, has; second, the rapid melting of ice, which causes refrigeration to maintain the low temperature level [26]. In most of the fish industry, non-availability or shortage of ice empties the refrigerated storage facilities. Economy plays a vital role in the use of ice, which prevents the surging of the fish cost. To prevent surging, well-insulated containers are required, which can decrease or retard the quick meltage of ice [27].

In recent years, there has been a lot of interest in using 2.45 GHz antennas to find out how fresh the fish is [28]. The freshness of fish is one of the most important things that affects its market value and how well it sells. Traditional ways of figuring out how fresh fish is taking a long time and aren't always accurate. This is why faster and less invasive ways had to be found. Radio frequency (RF) dielectric sensors have emerged as a promising solution to this problem [30].

Temperature, salinity, and moisture content are just a few factors that affect the dielectric properties of fish [30]. As fish goes bad, its proteins, lipids, and carbohydrates break down, which changes the way it conducts electricity [31]. With a 2.45 GHz antenna, these changes can be found by measuring how much energy the fish absorbs or sends back.

Using a 2.45 GHz antenna has several advantages over traditional methods, such as measurements that are quick and don't hurt the person [32]. The antenna can be put close to the fish, which lets the freshness of the fish be checked in real time. Also, RF dielectric sensors are more accurate than traditional methods, giving objective and quantifiable information about how fresh fish is.

In the end, using 2.45 GHz antennas to find out how fresh fish is could improve the quality and safety of fish products. But more research is needed to improve the design and performance of RF dielectric sensors for judging the freshness of fish and to find out how well they work in real-world situations.

III. ANTENNA DESIGN

The lumped port ground plane patch antenna is a type of microstrip patch antenna that is widely used in wireless communication systems. It is a low profile and low-cost antenna that provides high gain and directivity. In this antenna, a rectangular patch is placed on the top of the substrate, and a ground plane is placed on the bottom of the substrate. The lumped port is connected to the patch, and it serves as the feeding point for the antenna.
The resonant frequency f_r of the lumped port ground plane patch antenna can be calculated using Equation 1 [33-34]

$$f_r = \left[\frac{c}{2\sqrt{\varepsilon_{eff}}\,(L+W)}\right] \qquad 1$$

where c is the speed of light, ε_{eff} is the effective dielectric constant of the substrate, L is the length of the patch and W is the width of the patch. The effective dielectric constant of the substrate can be calculated using the Equation 2 [35]

$$\varepsilon_{eff} = \left[\frac{\epsilon_r+1}{2} + \left\{\frac{\epsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-0.5}\right\}\right] \qquad 2$$

where ε_r is the relative permittivity of the substrate, h is the thickness of the substrate. The speed of light v in the substrate can be calculated through Equation 3

$$v = \left[\frac{c}{\sqrt{\varepsilon_{eff}}}\right] \qquad 3$$

The frequency drop Δf of the antenna can be calculated using the Equation 4

$$\Delta f = \left[\frac{f_r}{Q}\right] \qquad 4$$

where Q is the quality factor of the antenna and f_r is the resonant frequency [36].

The lumped port ground plane patch antenna has a ground plane that covers the entire bottom of the substrate, which provides a good ground plane for the antenna. This results in a high-quality factor and a low-frequency drop. Additionally, the patch can be designed to resonate at the desired frequency by adjusting its dimensions.

The proposed lumped port ground plane patch antenna has an FR4 epoxy substrate, which is a popular choice for printed circuit board substrates because it has good electrical, mechanical, and thermal properties. This substrate has a relative permittivity of about 4.4, which is very important when designing microstrip antennas. In the proposed antenna, the FR4 substrate is 1.6 mm thick, which is a standard thickness for many commercial applications.
The lumped port of this antenna is designed for an input impedance of 50 ohms, which is a standard value for many RF applications. The antenna's ground plane covers the whole back of the substrate. This makes sure that there is a good connection to the ground and helps to cut down on radiation losses. The antenna is 38.6 mm x 47.6 mm x 1.6 mm in size, which makes it good for many small wireless devices.
The geometrical parameters of the antenna can be seen in Fig 1. The fresh fish dielectric permittivity is 55, while the stale fish dielectric permittivity is 44 or less than that. It is around a 20% change in the dielectric property of the fish meat [37-42]. Fig 2 covers the proposed antenna geometry.

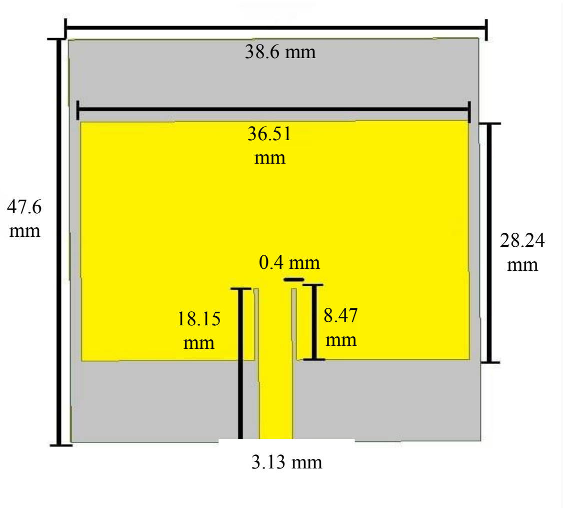

Fig 1: Geometrical parameters of the proposed antenna

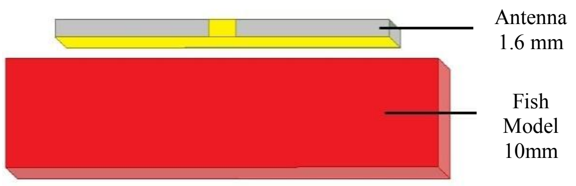

Fig 2: Antenna Placement

IV. Result and Discussion

As shown in Table 1, the resonant frequency of fresh fish was found to be 2.47 GHz when the antenna was kept at 0 mm

Distance Between Fish & Antenna	Fresh Fish		Stale Fish	
	Frequency	Return Loss	Frequency	Return Loss
0 mm	2.47	33.86	2.47	19.47
2 mm	2.46	40.82	2.46	22.06
4 mm	2.45	25.56	2.45	21.56

from the fish, while the resonant frequency of stale fish was 2.47 GHz at the same distance. The return loss of fresh fish at this distance was 33.86, while the return loss of stale fish was 19.47. At a distance of 2 mm between the antenna and the fish, the resonant frequency of fresh fish was 2.46 GHz, with a return loss of 40.82. On the other hand, the resonant frequency of stale fish was also 2.46 GHz, but with a lower return loss of 22.06. When the distance between the antenna and the fish was increased to 4 mm, the resonant frequency of both fresh and stale fish was found to be 2.45 GHz, with return losses of 25.56 and 21.56 respectively.

It is worth noting that in the experiment, there was no visible change in Voltage Standing Wave Ratio (VSWR) of both fresh and stale fish models at different distances from the antenna. The VSWR is a measure of the amount of power that is reflected back to the source due to a mismatch in impedance. The absence of visible change in VSWR of both fresh and stale fish models at different distances from the antenna suggests that the impedance of the fish models was similar to that of the antenna, which is important for accurate measurements. Fig 3a, Fig 3b and Fig 3c gives the comparison of S_{11} parameter for the fresh fish (eatable) and stale fish (spoiled and not eatable) at 0 mm, 2 mm and 4 mm distance. Fig 4 covers the VSWR response of the fresh fish and stale fish.

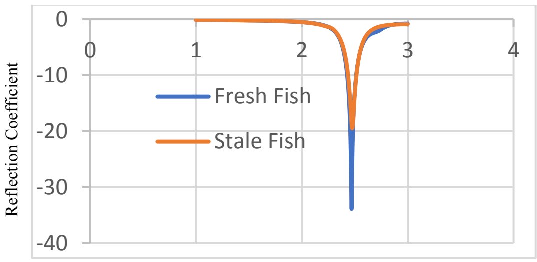

Fig 3a : Response of Fish at 0 mm distance

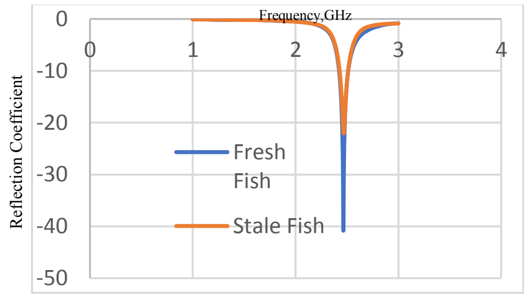

Fig 3b : Response of Fish at 2 mm distance

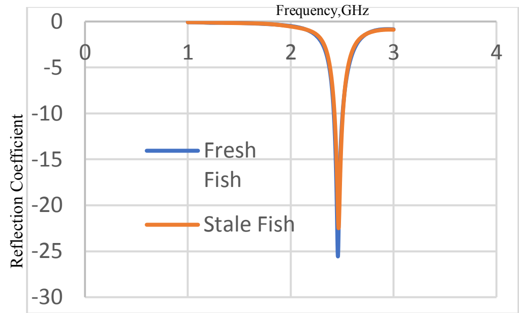

Fig 3c : Response of Fish at 4 mm distance

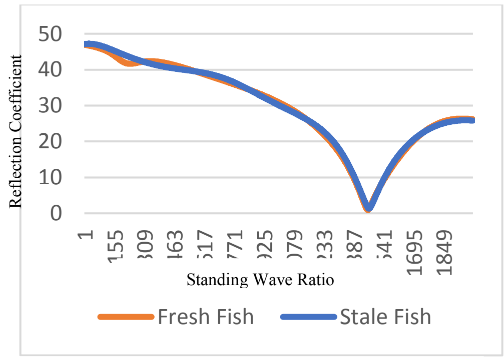

Fig 4 : VSWR response of the fish

V. Conclusion

This study introduces a novel approach utilizing a 2.4 GHz microstrip patch antenna for the detection of hairtail fish freshness. The resonant frequency of the antenna remained unchanged for both fresh and stale fish at various distances

(0mm, 2mm, and 4mm), indicating no significant differences. However, the return loss values exhibited noticeable variations with each distance and fish condition. For fresh fish, the return loss values at the respective distances were measured as 33.86, 40.82, and 25.56, while for stale fish, the values were 19.47, 22.06, and 21.56. These results demonstrate the potential of the 2.4 GHz microstrip patch antenna in distinguishing between fresh and stale hairtail fish. This innovative and non-invasive method holds promise for ensuring the safety and quality of fish products in the food industry, reducing the risk of foodborne diseases, and boosting consumer confidence. Further research is needed to explore the technique's sensitivity and specificity under different conditions and with a wider range of fish species, contributing to the advancement of non-destructive quality assessment methods for perishable food items. This technique can be utilized by fish processors, wholesalers, and retailers to verify the freshness and safety of fish products, thereby enhancing food safety and consumer satisfaction.

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