Microwave Food Processing and Effect of Pathogens in Dielectric Properties

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Abstract

The Objective of this study was to investigate the effect of food's dielectric characteristics on the effectiveness of inactivation of foodborne pathogens in white bread when subjected to microwave energy and measuring the variation in the reflection coefficient to determine the absorption impact of fresh and pathogenic bread to extending the bread shelf-life. At Microwave frequencies and temperatures between 25 and 85 degrees Celsius, while having a variety of dielectric properties, moisture content, the conventional and metamaterial antennas are designed using the Computer Simulation Technology (CST) microwave studio. The results show the comparison of traditional and metamaterial infused antennas in terms of gain, reflection coefficient, radiation efficiency, antenna size, and absorption efficiency. These study shows how microwave heating and the Split Ring Resonator (SRR) metamaterial effect on inactivate pathogens without affecting the food's nutrient benefit and how heating can affect dielectric properties.

1. Introduction

Microwave food processing is widely used in both households and industry at the frequency of 300 MHz to 300 GHz by generating rapid heat throughout the material to particular extent. Dielectric properties play an important role in how materials interact with electromagnetic energy, and when dielectric energy interacts with food products at any frequency range, it provides essential information on microwave frequency processing [1]. Low energy microwave radiation can cause a food molecule to be stimulated. This radiation process is known as heat treatment, effectively detects and inactivates pathogens. The characteristics of food products, rate of heating, and size of microorganisms all affect how effectively food is irradiated. Microstrip patch antenna is widely utilized due to its low weight, low fabrication cost, ability to operate in several bands, and suitability for applications in the food processing industry. SRR Metamaterial structure are used in antenna environments to improve their radiation properties, narrow band, gain, bandwidth, and to design a compact antenna without compromising performance by using artificial magnetic conductors (AMC) [2].

II. Antenna Design

CST Software is used in the design of both the conventional patch antenna and the metamaterial structural antenna. The antenna is 47.9 x 40 x 1.6 mm in size and is mounted on a FR-4 substrate with a dielectric constant of 4.3 shows in Fig 1. Fig.2 shows SRR metamaterial unit cell was placed on the ground with a size of 5.4 x 5.4 mm and 0.2 mm gap.

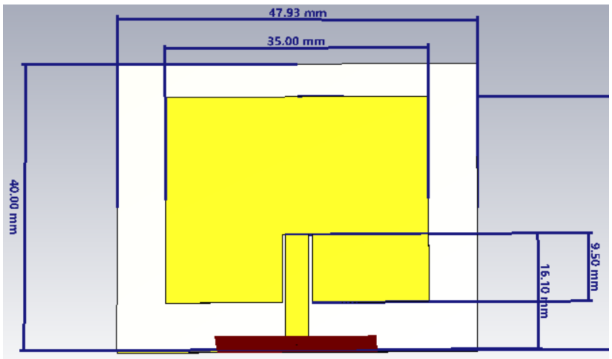

Figure 1 Conventional Patch antenna

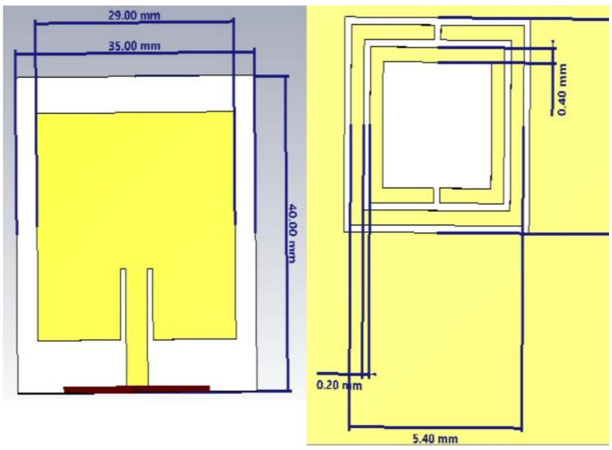

Figure 2 Front and Back view of SRR metamaterial antenna

The metamaterial improves the reflection coefficient, gain, and radiation efficiency of the conventional antenna.

A. On-Food analysis method

The flat section of white bread shown in Fig.3 is where the traditional antenna is worn to analyze the radiation characteristics of the material under various moisture and temperature conditions with associated dielectric properties [3]. Both ε′ and ε″ remain constant after 2-3 minutes of microwave food processing and the dielectric constant rises from 25 to 60 °C before becoming constant from 60 to 95 °C, while the dielectric loss tangent rises and falls linearly with food salt content from 25 to 95 °C [4].

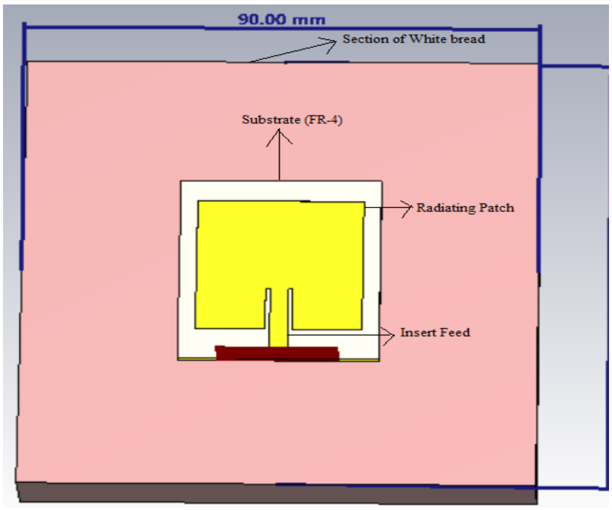

Figure 3 Patch antenna worn on flat section of bread

TABLE 1

White Bread Dielectric Properties

F(GHz)	M %	T °C	ε′	ε″	Ref
2.4	34.6	25	1.81	2.08	Liu et al.,2009
		55	1.94	2.17	Liu et al.,2009
		85	2.13	2.26	Liu et al.,2009
2.4	38.6	25	2.08	0.69	Liu et al.,2009
		55	2.17	0.83	Liu et al.,2009
		85	2.26	1.15	Liu et al.,2009

Table 1 Shows the frequency at 2.4 GHz, Moisture %, temperature range from 25 to 85 °C, dielectric constant ε′, and dielectric loss factor ε″ using these parameters the flat section of white bread is designed.

III Results & Discussion

According to Fig. 4, a conventional patch antenna operating at 2.4 GHz has a 90 MHz bandwidth and a reflection coefficient of -50.5 dB. Radiation efficiency is 50%, gain is 2.19 dBi, directivity is 5.42 dBi, and overall efficiency is 53%. The 2.4 GHz SRR metamaterial-infused antenna has a 220 MHz bandwidth and a reflection coefficient of -62.3 dB. Radiation efficiency is 70%, gain is 2.82 dBi, Directivity is 4.78 dBi, and overall efficiency is 72%.

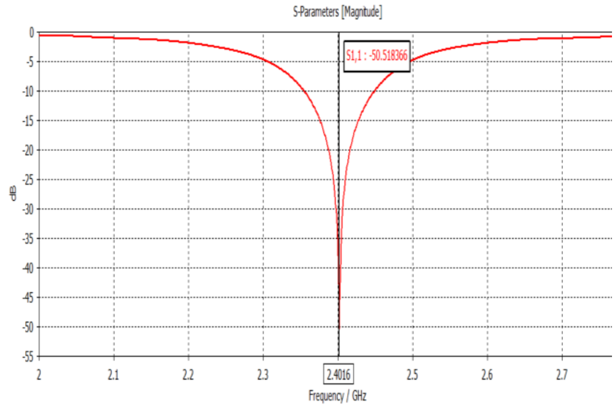

Figure 4 S11 Parameter of convention antenna

This study showed that the traditional patch antenna's reflection coefficient, gain, directivity, efficiency, and reduced antenna size are all enhanced by the metamaterial unit cell. The section of white bread used for testing these conventional and metamaterial antennas was designed using various values of dielectric constant, loss factor, temperature, and moisture content, as mentioned in table 1. The SRR metamaterial is appropriate for microwave food processing applications.

Table 2 Shows the antenna characteristics for different dielectric properties of white bread and temperature from 25 to 85 °C.

TABLE 2

Metamaterial Antenna Properties of White Bread Section

f(GHz)	M %	T °C	S_{11} (dB)	Gain dBi	Directivity dBi	Radiation efficiency %
2.4	34.6	25	-25	1.22	4.9	44
		55	-23	0.817	4.75	39
		85	-20	0.349	4.74	35
2.4	38.6	25	-22	0.88	4.3	39
		55	-20	0.512	4.26	37
		85	-18	0.37	4.27	34

The antenna parameters decrease by up to 2 to 3 dB when the temperature rises. Beyond a certain temperature and moisture %, the antenna's properties are either constant or barely fluctuate.

Conclusion

In this study, the various dielectric properties of white bread were used to analyze a conventional patch antenna with an SRR metamaterial structure infused in the ground plane. The antenna's gain, radiation efficiency, and reflection coefficient have all significantly increased, and its size has decreased. Understanding the dielectric characteristics of food and the specific temperature that the microorganisms are affected by makes it easier to detect and eliminate pathogens. The On-food analysis method shows how bacteria affect the dielectric characteristics.

7. References

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