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Characterization of E-Shaped Wifi Antenna by Various Substrate

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Abstract: This study aims to develop and characterize an E-shaped patch microstrip antenna design that resonates at 2.6 GHz. The design and simulation of the E-shaped patch microstrip antenna were carried out with the CST microwave studio suite. The matrix used was BUEHLER Epoxy resin and hardener with a variety of loading filler Barium strontium titanate (BST), Barium titanate (BTO), Nickel copper zink ferrite (NCZF) of different compositions $Ni_{0.1}Cu_{0.4}Zn_{0.5}Fe_2O_4$ and $Ni_{0.3}Cu_{0.2}Zn_{0.5}Fe_2O_4$. The substrate design is 50×50×2 mm. The results of the five-substrate of various compositions have different permittivity, it resonates at around 2.6 GHz band, S11 of -26 dB, and bandwidth 94 MHz. The resonance shift to the higher frequency when using magnetic filler, while it shifts to the lower band when using dielectric filler.

Keywords: Patch Antenna, Relative Permittivity, S11, Bandwidth, Return Loss

1. Introduction

Antennas are essential today because they enable long-range communication by transforming energy from mechanical vibration or analog signals to electrical pulse or digital signals an antenna is a transducer [1]. Due to the increasing need for faster mobile communication networks and the rising number of customers, data rates are increasing today [2]. Some key elements in obtaining good internet connectivity are bandwidth, signal polarization matching, performance sensitivity in the environment, resonant frequency shift, and signal loss and interference. Very wide or ultra-wide bandwidth is more economic because of its high performance and is available for indoor and outdoor wireless communication systems [3]. Many antennae are designed to polarize incoming signals, a mismatch between the incoming signal and the antenna can affect negatively the antenna's performance [4]. When an antenna is used in the real environment, the conditions can cause degradation to the antenna due to temperature, humidity, and other environmental factors [5]. The permittivity is key to the antenna resonant frequency, if the substrate degrades in structure or chemical properties its performance will degrade [6]. Lastly, is the signal loss and interference, any other electromagnetic wave source or obstruction can interfere with the incoming signal and affect the performance of the antenna, especially

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electromagnetic wave with high frequency because it is easily scattered by solid objects which is why low-frequency signal is used in low population areas because it can retain its signal at a longer distance which is one of the challenges of 5G system. Therefore, a wide band, high frequency and little interference of incoming or transmitted signals are essential for high-speed and reliable antennae.

The microstrip antenna is some of the most common types of miniature antenna used in smartphones due to its low cost, low weight, and ease to fabricate [7]. Other advantages of microstrip patch antennas are that they can be integrated into printed circuit board (PCB) and their performance can be adjusted using different substrate materials [8] [9]. A microstrip antenna is composed of a substrate sandwiched between two metallic patches [10]. Antenna performance can be customized using different substrate types, fillers, sizes, and patch shapes [11]. However, some weakness present in microstrip antenna is its narrow bandwidth [10].which can limit its application. By using certain designs and material the bandwidth problem can be resolved.

The substrate permittivity of antennae can be tailored by using various types of material of different permittivity to adjust to a desired performance and design. In reducing the antenna size the material of the substrate with high permittivity can be used [6]. New ways of fabricating substrates are adding magnetodielectric (MD) powder into the base material, due to MD material properties like high resistivity, low dielectric loss, and high Curie temperature [12]. Besides, Eddy current loss and saturation magnetization was known to be reduced by nanomagnetic materials [13]. When tailoring an antenna, power efficiency comes into a factor, a low dielectric loss tangent (tanδ) allows better power efficiency, in addition using a polymer/particle composite has more advantages in durability [14][15] and MD substrate can be tailored in resonance frequency, polarization, and radiation pattern by external magnetic field bias [12]. The most common substrate used is RT Duroid and FR-4 where their permittivity can be tailored by the manufacturer [10]. Another type of substrate is dielectric composites that are made of epoxy resin or polymer and mixed with filler such as ceramic powder, fiberglass, lenses, carbon nanotubes, graphene, carbon fiber, and zero-index material, etc [10]. In addition, nanoparticle ceramic is a material that is gaining more interest due to its high resistivity, high permeability, and low dielectric loss in RF technology [15].

In this research the weight percent of NCZF ($Ni_xCu_{0.5-x}Zn_{0.5}Fe_2O_4$) of Ni 0.1 wt% and 0.3 wt%, BTO (Ba-Ti-O), BST (Ba-Sr-Ti-O) in the epoxy mixture. Ferrites are being used in a lot of ways in high-frequency microwave systems. Microwave antenna applications benefit greatly from polycrystalline ferrite properties compared to standard dielectric materials [13]. Ferrite has tensor properties, when it is biased with DC magnetic field, it will have anisotropic permeability [14]. The E-shaped patch microstrip antenna design was inspired by [15], which uses a 2.2 GHz frequency band.

This study aims to fabricate four types of substrates, test their permittivity, and run a simulation using an E-shaped microstrip patch antenna design. Finally, to make a comparison of the antenna performance in loss coefficient (S11), bandwidth, and frequency resonance of various substrate compositions. The designed microstrip substrate has dimensions of 50×50×2 mm.

2. Materials and Methods

2.1 Substrate fabrication

The equipment used was METTLER TOLEDO weighing balance, BAINPOL METCO grinding/polishing machine, Impedance Analyzer Agilent E4991B, KEYSIGHT 16453A Dielectric Material Test Fixture. Next, the simulation tool used was Laptop/PC and CST Microwave Studio Suite software. The materials used were BUEHLER Epokwick FC Epoxy resin and hardener, Barium strontium titanate (BST), Barium titanate (BTO), $Ni_{0.1}Cu_{0.4}Zn_{0.5}Fe_2O_4$ (NCZF 0.1) and $Ni_{0.3}Cu_{0.2}Zn_{0.5}Fe_2O_4$ (NCZF 0.3).

Initially, BST powder or the filler was weighed using a balance. A weighing boat was used and was put into the balance, then it was TARE after it stabilizes. Next, BST powder was put onto the weighing boat using a sampling spoon until the desired amount was achieved. The second step was the weighing of epoxy resin, the resin was poured into a clear plastic cup to avoid contamination and minimize loss. After, that an empty cup was TARE to zero when it stabilized in the balance. Then a syringe was used to put the resin into the cup and then weighed until the desired mass was achieved. The same steps as epoxy resin were used for the hardener while using a different syringe in the same cup. The third step was to mix the resin and hardener, the mixture was stirred carefully to prevent the formation of air pockets. A glass stirrer was used for mixing until it was ready.

The final step was to pour the mixture into a silicon mold slowly to avoid air pocket formation. After all the mixture was poured it was stirred again so the filler spread evenly in the matrix. Lastly, it was left to hard for 24 hours. And then it was removed from the mold and the substrate was ground with a grinder to flatten it. The amount and unit used for substrate fabrication are displayed in the table below.

Table 2.1 Materials and mass of the composite

Composition	Filler wt%	Matrix wt%	Filler weight (g)	Matrix weight (g)		The total weight (g)
				Resin	Hardener	
BST	10%	90%	0.6000	5.4000	1.2273	6.6273
BTO						
NCZF 0.1						
NCZF 0.3						
Epoxy	N/A	100%	N/A	6.0000	1.3636	7.3636

2.2 Relative permittivity measurement

The permittivity of each substrate was taken after grinding and recorded as a plot graph in figure 3.0. The permittivity of the composite was measured with Impedance Analyzer Agilent E4991B and KEYSIGHT 16453A Dielectric Material Test Fixture. Meanwhile, the real and imaginary permeability was measured with KEYSIGHT 16454A Magnetic Material Test Fixture, the permeability was very low and the real and imaginary permeability was not declared and instead use a default permeability of 1.

2.3 Antenna performance simulation

The data set was saved as a ".txt" file and uploaded into the app with the steps Modeling>Shape>New material>Dispersion>Dielectric dispersion>User. The frequency range of the simulation was from 0 GHz to 5 GHz, and the port impedance used was 50 Ω.

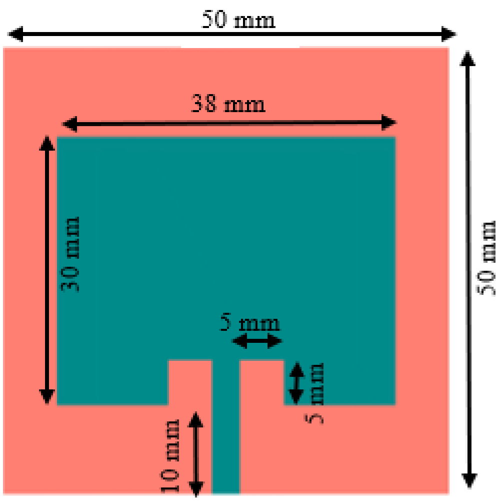


Figure 2.0 antenna design

Table 2.3 dimension of the antenna

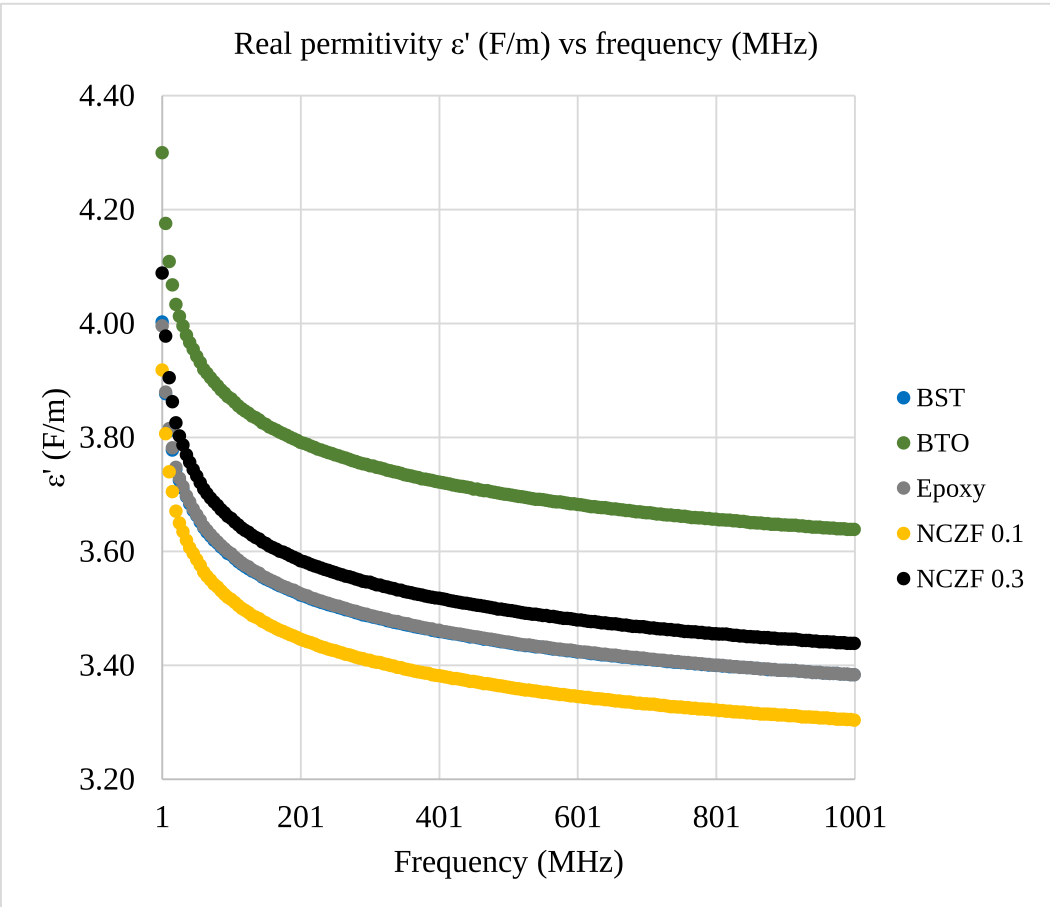
Parameter	Size (mm)	Parameter	Size (mm)
Substrate width and length	50×50	Copper patch thickness	0.035
Substrate thickness	2	Feed width	3
Ground patch width and length	50×50	Feed length	10
Patch width	38	Inset width and length	5×5
Patch length	30		

3. Results and Discussion

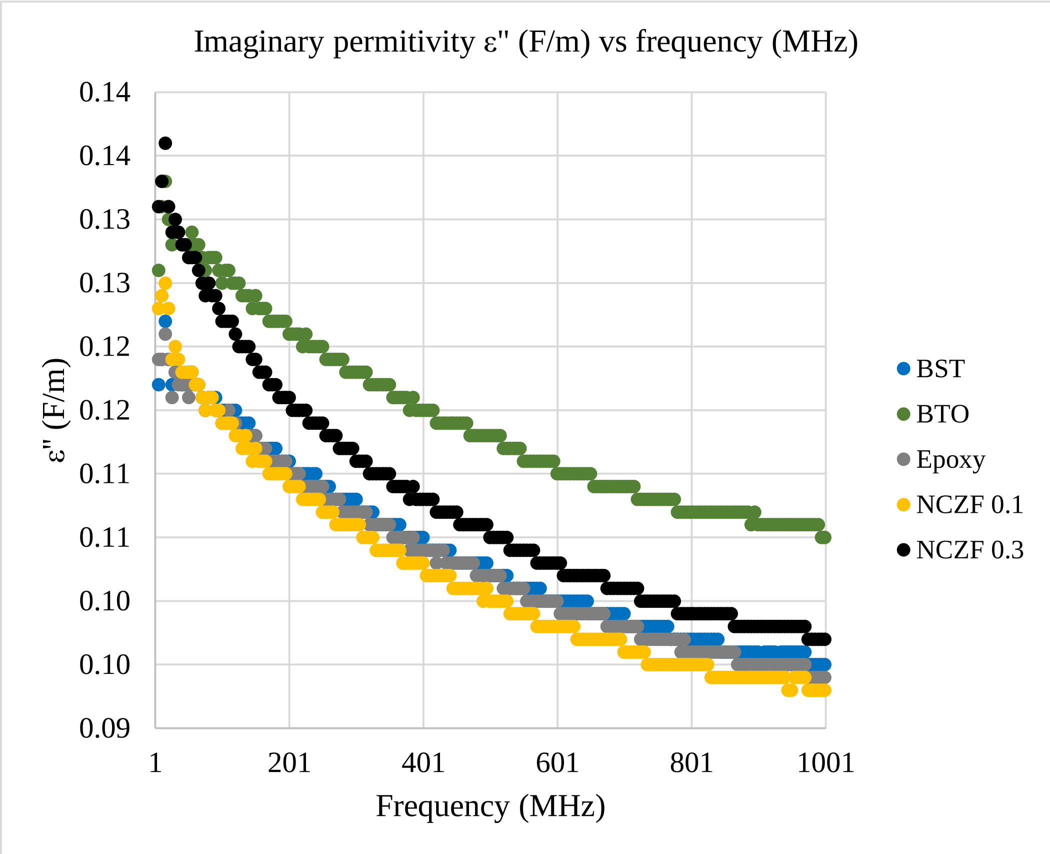
3.1 Substrate permittivity

Figures 3.1 (a) and (b) show the experimental result of permittivity in farad per meter (F/m) from frequency 1 MHz to 1001 MHz. Figure 3.1 (a) is the experimental data of the real permittivity ε' while (b) is the imaginary permittivity ε". In figure (a) the highest ε' is BTO while, BST and epoxy have identical permittivity and are placed at the third highest meanwhile, NCZF 0.3 is the second highest and finally, NCZF 0.1 has the lowest ε'. Besides that, in figure (b) the highest ε" is BTO while the lowest is NCZF 0.1 in addition, the same trend can be observed in both figure (a) and (b)

Table 3.0 is the result of ε at 1 GHz for the experimental, Epoxy and BST have identical permittivity which places it in third lowest, while NCZF 0.3 has the second highest permittivity of 4.09 F/m.

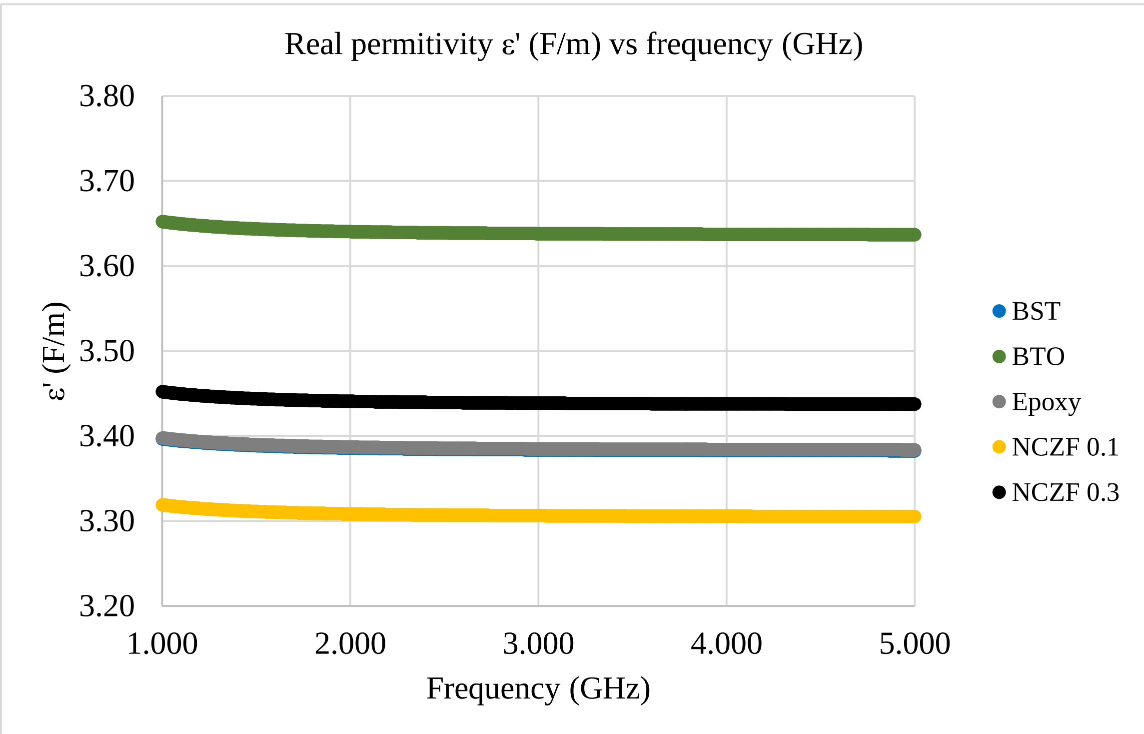


(a)

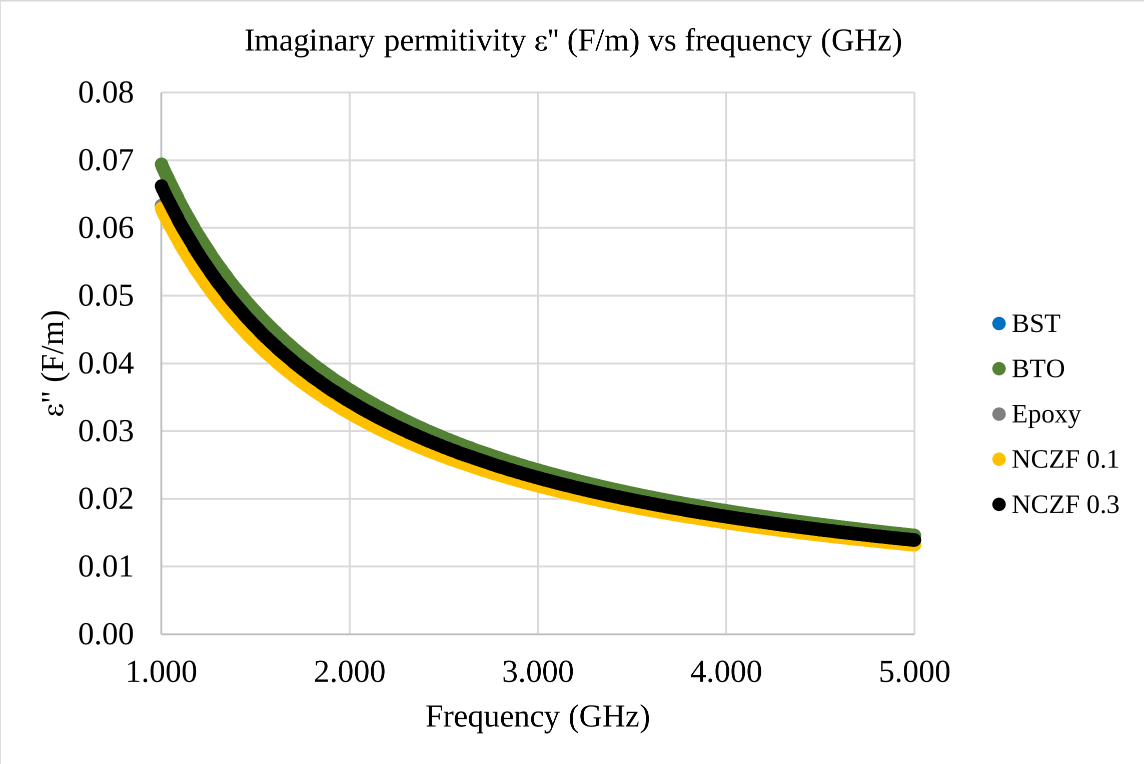


(b)

Figures 3.1 (a) and (b) show the real and imaginary permittivity for the measured.



(a)



(b)

Figure 3.1 (a) and (b) are the ε' and ε'' from the simulation.

Table 3.0 measured real and imaginary permittivity

Composite	BST	BTO	Epoxy	NCZF 0.1	NCZF 0.3
ε'	4.00	4.30	4.00	3.92	4.09
ε''	0.12	0.13	0.12	0.13	0.14

3.2 Antenna simulation

Figure 3.2 shows a plot graph of S11 against frequency. In figure 3.2 the five substrates have two resonating frequencies. The results are shown in Table 3.1. Meanwhile, with inspection among the five composites, BTO has the lowest frequency which is 2.585GHz, while NCZF 0.1 has the highest frequency which is 2.705GHz. Moreover, BST and Epoxy are overlapping which is 2.675GHz, which places them second. The third place belongs to NCZF 0.3 with a resonance at 2.655GHz. Next, the S11 of the first peak for the five substrates is identical which is around -26 decibels. Moreover, there is the existence of a second resonance which formed at around 4GHz. The highest is NCZF 0.1 at 4.185 GHz and the lowest is BTO at 4 GHz. The second resonance has low loss because it is below -10 dB. Subsequently, the highest S11 is naturally NCZF 0.1 at -14.105 dB, while the lowest is BTO at -11.88 dB. The second is BST, Epoxy, and NCZF 0.3 because they have an identical return loss.

In continuation, the bandwidth of BST, BTO, Epoxy, NCZF 0.1, and NCZF 0.3 at -10 dB are 92.738, 89.454, 91.867, 94.033, and 91.463 MHz respectively for the first resonance. Apart from this, they are all identical. The bandwidth of NCZF 0.1 is the highest while the lowest is BTO referring to table 3.1. In addition, BST, Epoxy, and NCZF 0.3 are in second, third, and fourth in bandwidth.

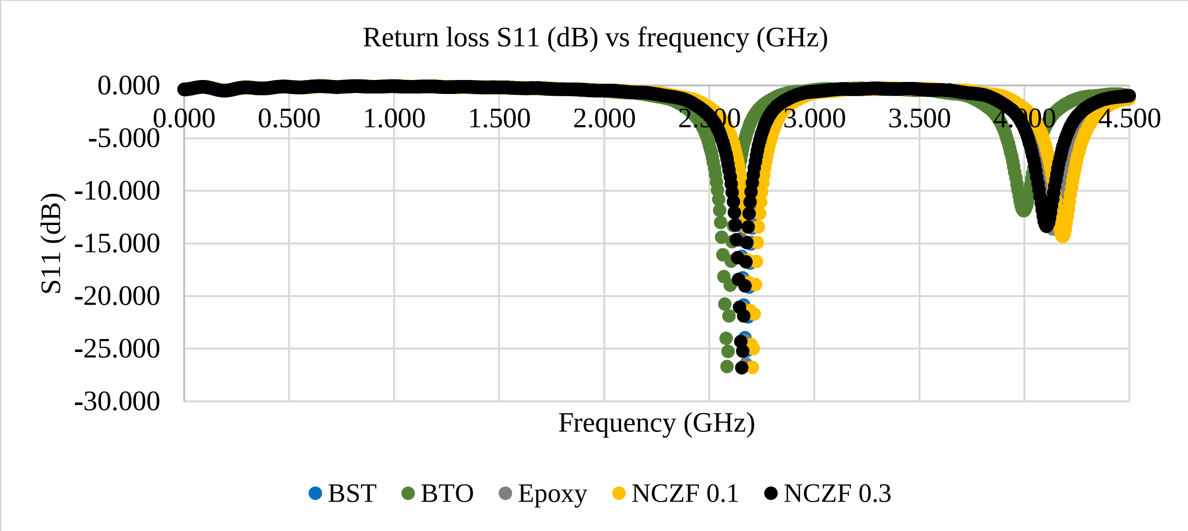


Figure 3.2 the S11 of the five substrates

Table 3.1 the frequency resonance, bandwidth, and S11

Material		**BST**	**BTO**	**Epoxy**	**NCZF 0.1**	**NCZF 0.3**
Resonance frequency (GHz)	1st	2.675	2.585	2.675	2.705	2.655
	2nd	4.135	4.000	4.135	4.185	4.105
Bandwidth (MHz)	1st	92.738	89.454	91.867	94.033	91.463
	2nd	73.308	54.283	73.617	79.634	70.855
S11 (dB)	1st	-26.442	-26.676	-26.508	-26.789	-26.819
	2nd	-13.616	-11.887	-13.614	-14.334	-13.365

4. Conclusion

The investigation to characterize the permittivity of the substrate using various fillers using 10 wt% filler was reached. In general, the permittivity of the BTO is the highest while the lowest is NCZF 0.1. In addition, by using a similar powder of the same chemical formula but with different composition of Ni and Cu, the substrate using NCZF 0.3 powder was observed to have higher ε and thus show a frequency shift to the left compared to NCZF 0.1. Finally, the permittivity of BST and Epoxy are overlapping.

Finally, an E-shaped patch design antenna performance was tested using simulation. The result showed that the substrate with the highest ε' resonate at a lower frequency, while the substrate with lower ε' resonate at a higher frequency. The highest frequency resonated was the lowest ε', while the lowest is the highest ε'. The simulation indicated that the antenna design can resonate with two frequency bands. Besides, using a magnetic filler can shift frequency higher, while a dielectric filler lowers frequency. The design has acceptable efficiency having S11 below -10dB, and acceptable bandwidth which can be used for future applications in 4G and 5G LTE in the frequency band of 2.6 GHz and 4 GHz bands. Furthermore, more study needs to be done to overcome the antenna narrow bandwidth suggested by [7] that adjusting the ground design could help, and the fabrication method with epoxy should be aided by a vacuum pump for accurate data.

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