Development of Composites for Nonlinear Transmission Lines

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Abstract: *Nonlinear transmission lines (NLTLs) offer a robust, solid state solution for generating high power microwaves (HPM). NLTLs use nonlinear dielectric and/or magnetic materials whose permittivity and permeability, vary with voltage and current, respectively, to modulate a delivered pulse and generate RF. Materials such as barium strontium titanite (BST) and nickel zinc ferrites (NZF) are used for their nonlinear dielectric and magnetic properties, respectively. This study examines the development of composites containing various volume loads of BST, NZF, or combined loadings to tune dielectric and magnetic properties. It was found that by increasing the volume fraction of BST, one can effectively increase the permittivity of a bulk sample. Similarly, by increasing the volume loading of NZF, a samples permeability can also be increased. These results are promising for the development of tunable NLTLs.*

Keywords: Nonlinear transmission lines; High power microwaves; Dielectric properties; Barium strontium titanite; Nickel zinc ferrite.

Introduction

Nonlinear transmission lines (NLTLs) are of increasing interest for directed energy because they can sharpen input pulses to create an electromagnetic shockwave that generates microwave oscillations. NLTLs modulate the input pulse using nonlinear magnetic and dielectric materials whose permeability and permittivity vary as a function of current and voltage respectively. Nonlinear materials such as BST and NZF are often used in various NLTL topologies for their nonlinear dielectric properties [3]. More recent approaches have used combinations of nonlinear inductors and capacitors in hybrid NLTLs. By manipulating the volume fractions of BST and NZF inclusions, one can adjust a composites bulk permittivity, permeability, and conductivity.

An alternative approach under investigation involves developing a transmission line that would have tunable dielectric and magnetic properties by modifying the material inside. Rather than using either BST or NZF, such an approach would leverage the concept of effective medium theories to create composites comprised of various volume loadings of BST and/or NZF to tune permittivity and/or permeability [2]. Adjusting inclusion volume loading, inclusion geometry, and either inclusion or host material permits tuning the composite's effective dielectric and magnetic properties to alter its electromagnetic performance [1]. The present study focuses initially on the linear regime; a future study will measure nonlinear permittivity and permeability.

Others have examined the dielectric properties of nickel zinc ferrites coated in barium titanite however, the host matrix was ceramic [3]. We manufactured single inclusion composites comprised of various volume loadings of 5%, 10%, 15%, 20%, and 25% of BST or NZF. Multi-inclusion composites containing 5% of NZF with 5 or 10% of BST, 10% of NZF with 5,10, or 15% of BST, 15% of NZF with 10% of BST, and 10% of both NZF and BST were also produced. The composites are enclosed in a silicone-based host. Four duplicates of each condition were manufactured to quantify statistical variation in parameters.

To elucidate variation of the permittivity and permeability as a function of volume loading, we obtained the S-parameters from 1-4 GHz using a network analyzer and then calculated the dielectric properties using Keysight Material Measurement Suite Software. Table 2 summarizes the linear regime permittivity for BST, NZF, and the combined sample while Table 3 summarizes the linear regime permeability. For composites consisting of only BST inclusions, the relative permittivity increased with volume fraction while the permeability remained relatively constant. For composites consisting of only NZF inclusions, both permittivity and permeability increased with volume fraction. Interestingly, the permeability exhibits a frequency dependence, especially at higher volume loadings, in the linear regime. The permittivity of composites containing both BST and NZF inclusions increased with BST volume fraction while increasing NZF volume fraction increased permeability. A similar frequency dependent permeability was observed however is significantly dampened.

Future studies will subject the composites to external magnetic and electric fields to measure the functional dependence of permeability and permittivity. This data will ultimately be useful for designing composites to use in cable-based NLTLs to achieve specific electromagnetic behavior.

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Table 2. Permittivity of NZF, BST, and a mixture of both

Single inclusion NZF	ε_r	Single inclusion BST	ε_r	Mixture (BST/NZF)		ε_r
5	3.41±0.23	5	3.47 ±0.15	5	5	4.01 ±0.20
10	3.69±0.19	10	4.20 ±0.10	5	10	4.89 ±0.20
15	4.02±0.26	15	5.14 ±0.04	10	5	5.15 ±0.10
20	4.73±0.22	20	6.29 ±0.20	10	10	6.08 ±0.12
25	5.77±0.33	25	7.44 ±0.29	10	15	6.65 ±0.21
/	/	/	/	15	10	7.11 ±0.15

Table 3. Permeability of BST, NZF, and a mixture as a function of frequency.

μ_r				
Frequency (GHz)	**1**	**2**	**3**	**4**
BST 5%	1.00±0.01	1.01±0.01	1.02±0.01	1.03±0.01
BST 10%	1.07±0.01	1.04±0.01	1.02±0.01	1.04±0.01
BST 15%	1.02±0.01	1.04±0.01	1.04±0.02	1.03±0.01
BST 20%	1.01±0.01	1.01±0.02	1.03±0.01	1.05±0.01
BST 25%	1.01±0.01	1.01±0.01	1.01±0.01	1.00±0.02
NZF 5%	1.08±0.03	1.07±0.03	1.06±0.02	1.06±0.02
NZF 10%	1.09±0.02	1.09±0.05	1.08±0.02	1.08±0.02
NZF 15%	1.24±0.05	1.19±0.04	1.16±0.04	1.16±0.04
NZF 20%	1.30±0.08	1.26±0.06	1.21±0.06	1.21±0.06
NZF 25%	1.49±0.04	1.32±0.02	1.23±0.01	1.22±0.01
NZF 5% BST 5%	1.06±0.02	1.05±0.01	1.05±0.01	1.04±0.01
NZF 5% BST 10%	1.05±0.01	1.06±0.01	1.05±0.02	1.03±0.03
NZF 10% BST 5%	1.15±0.03	1.13±0.04	1.11±0.03	1.08±0.04
NZF 10% BST 10%	1.13±0.02	1.12±0.05	1.10±0.05	1.09±0.04
NZF 10% BST 15%	1.11±0.01	1.10±0.02	1.08±0.02	1.06±0.03
NZF 15% BST 10%	1.19±0.02	1.17±0.04	1.13±0.03	1.11±0.05

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