OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 5, No. 6, June 2011, p. 627 - 630

Dielectric resonator notch filter design with experimental bismuth lanthanum titanate material

M. J. SINGH*, N. K. LOKE[a]

Department of Electrical, Electronic & Systems Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia

[a]*School of Electrical and Electronic Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Seberang Perai Selatan, Pulau Pinang, Malaysia*

The design of a dielectric resonator notch filter utilizing an experimental composition of dielectric material pellet at microwave frequencies is proposed. In this paper, an electrical model of a dielectric resonator filter is designed and fabricated utilizing a new dielectric material composition variation. Recent advances and designs in dielectric resonator structures have shown the advantages of using various dielectric materials types and shapes in microwave devices which yield different microwave characteristics. Thus, the design of this dielectric resonator filter that incorporates the experimental type of dielectric ceramic material will present the feasibility and performance of the filter design and dielectric material. The design will first be designed and simulated in microwave simulation software and the final design will be fabricated into a working prototype.

(Received January 6, 2011; accepted June 9, 2011)

Keywords: Notch filter, Titanate material, Dielectric resonator

---

1. Introduction

The objective of this project is to design a dielectric resonator notch filter utilizing an experimental composition of dielectric material at microwave frequencies. A derivative of the microstrip loop coupling is used for this filter. The dielectric material will be chemically synthesized and machined into a solid form in order to be used in this design. The dielectric properties of this material will then be characterized using a HP Material Analyzer. The dielectric properties will then be entered into the simulation software to replicate the software model of the dielectric material in order to be used in the design process. On top of this, an electrical model of the dielectric resonator notch filter design will be constructed, simulated and tuned in CST microwave simulation software. The final filter design will then be fabricated and tested at microwave frequencies using RF measurement apparatus. The results will be compared to the simulation data and the final design can then be validated. Measurements and tests carried out on the prototype filter will be able to determine the functionality and performance of the design. Advantages and drawbacks of the filter design and dielectric material will then be discussed.

2. Proposed architecture

The design criteria for the filter will be first determined. By using CST Microwave Studio software, the geometrical and electrical parameters of the dielectric pellets that are fabricated will be modeled into the software. Depending on the type of dielectric resonator filter (DRF) design that will be determined most suited for the new dielectric material, the electrical model of the design will then be added on. Simulations will be carried out within the software to determine the RF characteristics and response of the circuit and amendments and tuning will be further carried out on the design to obtain the most desired results. Once the electrical model is finalized, the final structure will be fabricated on a Rogers dual sided substrate. The completed prototype DRF structure with the dielectric pellet in place will be tested using signal generators and analyzers to verify the validity of the simulated results and the performance of the filter.

3. Preparation of dielectric material

The method used to synthesize the material will be of wet chemical method as it requires less heat to start the chemical reaction. The Bismuth Lanthanum Titanate (BLT) sample was doped with a 0.5 Lanthanum ratio. The value of ratio is substituted into stoichiometric equation in Fig. 1 and balanced accordingly to obtain the relative molar weight and volume for each needed element. Fabrication of pellets is then carried out by pressing the powdered BLT into pellet form and sintering them at a higher temperature of 1000 ˚C. Previous attempts to sinter similar dielectric ceramic materials were carried out at 950 ˚C. By experimenting the sintering phase at higher temperatures above 950 ˚C, the density of the molecular lattice in the dielectric can be increased which in most cases, increases permittivity. The sintering temperature chosen here must be ideal for the dielectric to achieve the highest permittivity possible without the material breaking down, in which produces an unusable dielectric material with inconsistent permittivity at various microwave frequencies and very high dielectric loss.

$$\boxed{\begin{array}{l} 4-x\,Bi(NO_3)_3.\,5H_2O + x\,La(NO_3)_3.\,6H_2O + 3Ti_3[OCH(CH_3)_2]_4 \\ \longrightarrow Bi_{4-x}La_xTi_3O_{12} + 12NH_3 + 24H_2 + 36CO + 11H_2O \end{array}}$$

Fig. 1. Chemical reaction for Bismuth Lanthanum Titanate.

A sample pellet was measured using the HP Material Analyzer at a frequency range of 1GHz to 1.8GHz. The sample produced a relatively consistent dielectric readout with slightly increasing permittivity and loss tangent in relation to the frequency. The measured dielectric properties at the center frequency of 1.4GHz are ε_r = 49.416 and tanδ = 20.296E-03 respectively. The obtained values are within the usable range as the material has high permittivity ($\varepsilon_r > 20$) and moderate dielectric loss. By comparing to the material fabricated in, this sample of Bismuth Lanthanum Titanate sintered at 1000˚C has lower permittivity and higher dielectric loss. Thus, it is observed that the samples fabricated and used in are of higher grade. However, the current set of samples will be used in the design of the notch filter in order to additionally observe the effects of using lower grade dielectric materials in dielectric resonator filter designs.

4. Dielectric resonator notch filter design

By using CST, a model of a dielectric resonator filter was build and simulated as shown in Fig. 2. The first approach used in the design is to simulate a microstrip line at the frequency range of 2GHz. The substrate used is Rogers with permittivity of 3.5398, dielectric loss of 4.5364E-03 and thickness of 0.763mm. Calculated using a simple line impedance tool in CST, strip width is 1.806 mm at 50.03Ω. The dielectric values used for the dielectric material model in the CST software model is εr = 49.416, tanδ = 20.296E-03. In order to create an excitation method for the dielectric structure, a derivative of the microstrip loop coupling in is used. Transverse magnetic (TM) mode of resonance is similarly achieved by using the ring coupling as shown in Fig. 2. Electric field lines generated by surface current of the strip ring radiate at the edges of the microstrip line that fringe onto the ground plane. These in turn generate transverse magnetic (TM) field lines that are perpendicular to the E-fields. The radiation mode here is identified with the $TM_{01\delta}$ mode.

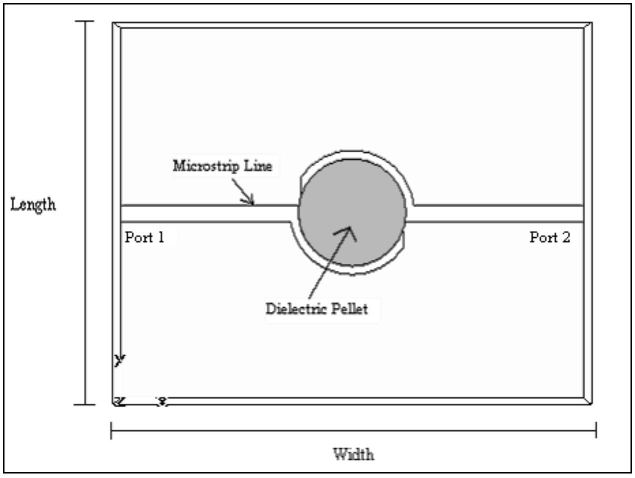

Fig. 2. Microwave structure layout in CST.

The dielectric material that is excited by the conducting strip at its circumference provides a high permittivity medium for the electromagnetic energy that emits from the radial strip at Port 1 to be transmitted onto the strip at Port 2 via the presence of an oscillating transverse magnetic field in the dielectric material. The resonant properties of the dielectric resonator notch filter are determined by the permittivity value of the dielectric material, while the amount of energy lost through transmission is affected by the material's dielectric loss tangent. The full CST model layout for the design is shown in Fig. 2. A thin layer of epoxy resin is additionally simulated between the dielectric and the microstrip substrate to model the use of adhesive material on the structure. Iterative fine tuning of the frequency response is achieved at these parameters shown below in Table 1.

Table 1. Dielectric resonator filter geometrical parameters.

Dielectric Diameter	11.67mm
Dielectric Thickness	1.15mm
Substrate Length	40mm
Substrate Width	50mm
Substrate Thickness	0.763mm

5. Test and measurement

The design that was constructed in CST was exported into DXF format to be photo-etched onto a Rogers type double-sided copper-clad substrate. The substrate measured with permittivity of 3.5398, dielectric loss of 4.5364E-03 and thickness of 0.763 mm. A 50Ω SMA connector is used at the feed of the microstrip transmission line at both ports. Meanwhile, the sintered and polished pellets are then measured again using a HP Material Analyzer for their permittivity and dielectric loss values at 1.4GHz for consistency. The sample dielectric cylindrical pellet was observed and measured to have a good solid form and also good and consistent dielectric properties before measurements were made on the overall resonator structure. The sample is very dense and is not brittle or porous. This is to ensure that the material does not contain any physical deformations and cracks as these will affect the dielectric and resonant properties of the RF structure.

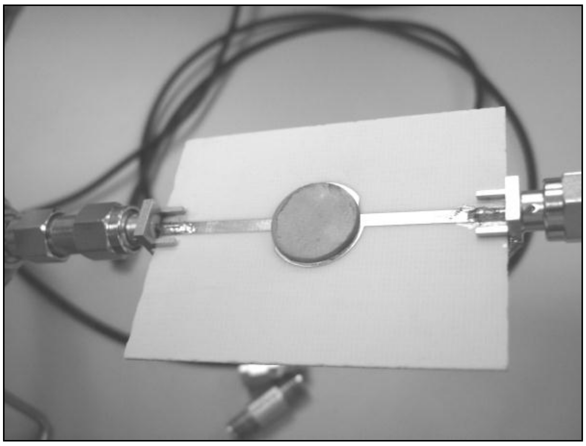

Fig. 3. Dielectric Resonator Filter Structure.

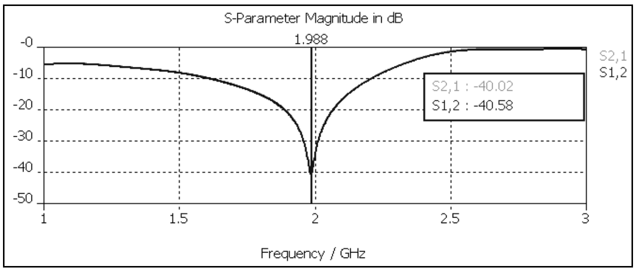

Fig. 4. S(1,2) and S(2,1) Frequency response of structure.

Fig. 4 above shows the simulated S(1,2) and S(2,1) frequency response of the resonator structure at a sweep frequency range of 1GHz to 3GHz. The bandstop center frequency is fine tuned to 1.988 GHz by varying the strip lengths and width. The simulated DRF structure exhibits a notch type filter response with a low quality factor. From the frequency response, the cutoff frequencies are gradual and the resulting notch bandwidth is wide. This can be slightly improved by using higher permittivity dielectrics with lower loss tangent. Fig. 5 shows the readout on the spectrum analyzer obtained from the measurements performed on the DRF. A high frequency signal generator is connected to the filter at Port 1 via a 50 Ω transmission line and connector and the output from Port 2 is connected to the spectrum analyzer using the same method. The signal generator is swept from 1GHz to 3GHz at a power output of -10 dBm. The null reference of the spectrum analyzer is at approximately -57 dBm before input signal is fed into the filter. The key measurement values are as follows in Table 2.

Power delivery and attenuation is then observed at the spectrum analyzer. Comparison with the measured S(1,2), S(2,1) response showed a near accurate bandstop center frequency at 2.055 GHz. Power attenuation due to lossy transmission line medium and also dielectric effects is at a combined approximate of -19.23 dBm. As observed from the scattering response and measurements, there is slightly higher attenuation at the lower frequency range below 2GHz. This unwanted attenuation can be lowered by using dielectric materials with lower dielectric loss on the DRF structure.

Table 2. Transmission power measurements.

Frequency (GHz)	Power (dBm)
1.000	-34.82
2.055	-56.48
3.000	-29.23

Fig. 5. Measured power attenuation (1 - 3GHz).

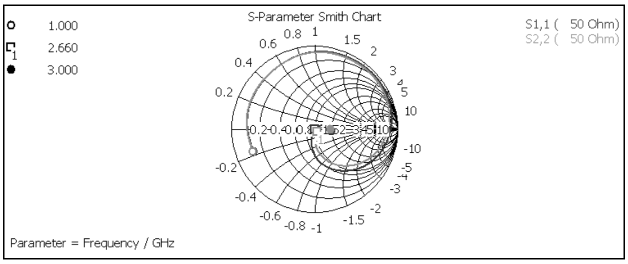

Fig. 6. Input impedance response of structure.

By using the equation in (1) as shown below, the actual insertion loss of the notch filter can be calculated from the power transmission data obtained previously. The transmitted power, P_T will be the power level measured at the output port of the filter. The received power, P_R will then be the power received at the input port of the filter that is compensated with transmission line losses. Using the transmission power values obtained at 1GHz, the maximum insertion loss of the filter can be calculated as shown in (2).

$$\mathit{Insertion\ Loss}\,(dB) = 10\,\log_{10}\frac{P_R}{P_T} \qquad (1)$$

Transmitted Power, $\boldsymbol{P_T}$ =

$$-34.84\ dBm = \left[10^{\left(-\frac{34.84}{10}\right)}\right]\times 10^{-3} = 3.296\times 10^{-7}\ \mathit{Watts}$$

Received Power, $\boldsymbol{P_R}$ = (*Input Power*) – (*Transmission Line Loss*) = $10^{-4} - 1.194\times 10^{-5} = 8.806\times 10^{-5}\ \mathit{Watts}$

$$\therefore\ \ \mathit{Insertion\ Loss}\,(dB) = 10\,\log_{10}\left(\frac{8.806\times 10^{-5}}{3.296\times 10^{-7}}\right) = \underline{\underline{24.27\ dB}} \qquad (2)$$

The maximum insertion loss of the notch filter at 1GHz is calculated at approximately 24dB. Although the insertion loss for this filter is high, it has very good bandstop properties at 2GHz. Major improvements can be further made to the dielectric material and further tuning of the microstrip coupling lines via slots and stubs can be introduced in order to further improve on the insertion loss and quality factor of the filter.

Although the overall performance of the filter obtained during measurements is average, the design has a useable notch bandwidth of approximately 600MHz which is suitable for notch filtering purposes over a broad frequency band. Microstrip design compensations can be further implemented in the future designs to fine tune and decrease the insertion loss, inaccuracies and also improve the quality factor of the filter that was inherent with the use of lower grade dielectric materials. From this project, it is observed that a dielectric resonator filter can be constructed using microstrip substrate and cylindrical dielectric pellets. This filter design can be further modified to function as a bandpass filter by means of experimenting with different shapes of dielectrics and also different designs of the microstrip lines and radiating ring strips.

While high permittivity and low loss materials yield better response at wider frequencies, it is observed here that lower grade dielectric materials can also achieve above average performance in a dielectric resonator device with some additional tuning and compensation. The objective of experimenting and studying the dielectric properties of a new dielectric material variation has been carried out. In addition, the design of a dielectric resonator notch filter utilizing the fabricated dielectric material for use in microwave applications at microwave frequencies has been successfully accomplished. A working prototype of the filter design has also been tested and verified to have desirable functionality and usability as a notch filter device for wideband frequencies. Further design variations based upon this filter can be developed that yield different frequency responses and characteristics.

6. Conclusion

Experimentation of a new synthesis variation for a new type of dielectric material has been discussed and carried out. The results from this paper show that as a new material, the variation of sintering temperatures is limited at an ideal threshold for Bismuth Lanthanum Titanate. Deviation from the ideal threshold temperature will degrade the dielectric properties of this material. From the result of this experimentation, a dielectric resonator notch filter was then designed around the use of this experimental dielectric material to study the performance of the material towards the microwave properties of the overall device. Furthermore, a prototype of the dielectric resonator notch filter structure has been tested, measured and verified with the implementation of the new dielectric material.

Acknowledgement

The author would like to acknowledge Universiti Kebangsaan Malaysia, Universiti Sains Malaysia, MOSTI grant Science Fund (01-01-92-SF0670), UKM-GGPM-ICT-108-2010,

References

[1] H. Boutayeb, A.-C. Tarot, K. Mahdjoubi, Progress In Electromagnetics Research, PIER **66**, 89 (2006).
[2] M. Khalaj-Amirhosseini, Progress In Electromagnetics Research, PIER **66**, 105 (2006).
[3] J. Mandeep, A. Lokesh, S. Hassan, M. N. Mahmud, M. Ain, Progress In Electromagnetics Research B, **2**, 207 (2008).
[4] J. Mandeep, N. K. Loke, S. Hassan, M. Ain, S. Sreekantan, K. Y. Cheong J. of Electromn. Waves and Appl., **22**, 1873 (2008).
[5] J. Mandeep, N. K. Loke, S. Hassan, S. Sreekantan, K. Y. Cheong J. of Electromn. Waves and Appl., **23**, 415 (2009).
[6] M. A. Martin, B. S. Sharif, C. C. Tsimenidis, Wideband and Multiband Antennas and Arrays, IEE (Ref. No. 2005/11059), 183–184, 2005.
[7] B. H. Moeckly, Y. Zhang, IEEE Trans. Appl. Supercond., **11**, 450 (2001).
[8] M. Rajabi, M. Mohammadirad, N. Komjani, Progress In Electromagnetics Research B, **2**, 115 (2008).

---

*Corresponding author: mandeeps75@yahoo.com