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Electromagnetic Absorber Made by Natural Rubber

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SUMMARY This paper proposes fabrication process of a pyramidal electromagnetic (EM) absorber made by natural rubber. The advantage of this research is to generate value-added latex from Thai rubber and to reduce number of chemical absorber by using natural rubber based absorber. The proposed absorber in the research is mainly made from latex with carbon black filler. The proposed absorber is in the form of rubber foam which provides suitable characteristics to serve as an EM absorber. The results of this research are chemical formulas for fabrication of pyramidal rubber foam with carbon black filler. The fabrication cost is very low when compared to an available commercial absorber. The electrical properties of the proposed EM absorber are measured. Also the reflectivity is measured and compared well with a commercial EM absorber.

key words: *electromagnetic absorber, natural rubber, latex, rubber foams, absorption*

1. Introduction

The progress of electronic industries and wireless communication technologies becomes a part of human life which creates freedom in communications. This leads to dramatically increasing of using EM wave. Thus, the EM interference (EMI) and EM susceptibility (EMS) have predominantly become a crucial problem. All electric and electronic products from manufactures are required to comply with a certain EM compatibility (EMC) standard such as Thai Industrial Standard Institute (TISI), FCC, CISPR, ANSI and EN, etc. In order to pass the EMC standard, all products must pass the EMS and EMI testing. It is noted that an EM absorber is the major part of the EMC/EMI testing room or so called RF anechoic chamber. In addition, the EM wave absorber is used for reducing an EMS/EMI in various communication industries such as all electric and electronic devices, especially in wireless and radio frequency (RF) devices. In Thailand, the EM wave absorber made by urethane foam loaded with conductive carbon black (CCB) has been imported with high cost per unit [1]. This leads to the limited number of EMS/EMI testing room available due to its expensive cost of construction which can cost up to US$ 320,000. This definitely affects the cost of testing which can be a major factor of rising manufacturing costs of electronic devices assembled in Thailand. Furthermore, lacking of number of the RF anechoic chamber can impede the development of academic and research on electromagnetics in Thailand. Therefore, it is of interest to develop a low cost EM wave absorber by using local natural material available in Thailand which can substantially reduce the cost per unit. It is found that Thailand is the world's largest natural rubber exported. Only 10% of all Thailand's natural rubber production is used for domestic consumption while over 80% is exported [2]. The exported natural rubber is used by various industries outside Thailand such as tires and tubes for motorcycles, airplanes, cars and bicycles, gloves, condoms, bedding industry, cushion/furniture industry etc. This leads Thailand to miss opportunities to gain additional income from exporting natural rubber to be value-added products. From [3], the overall physical properties of natural rubber are outstanding resilience, high tensile strength, superior resistance to tear or abrasion, good low temperature flexibility and ability to accept a high loading of magnetic material. This makes the natural rubber to be an excellent candidate for a low cost EM wave absorber. In this research, it is of interest to develop a low cost EM wave absorber made by latex for sustainable development of Thai electrical/electronic industries, to generate value-added rubber product and enhance its competiveness for Thai rubber industries. Furthermore, the result of this work would be beneficial to the development of academic and research on electromagnetics in Thailand as well. Most of research works on EM absorber in literature are based on how to fabricate a material by using chemical filler to obtain the best EM absorption rate and how to design geometry of absorber with very wide bandwidth. The work in [4] developed a planar EM absorber made from rubber with conductive fillers such as aluminum powder, tin powder and CCB and tested with standard of EN 50147-1 [5] and [6]. It was found that the conductive fillers in [4] increase hardness and weight of absorber. The works in [7] and [8] shows that carbon-based materials such as graphite, carbon black, carbon nano-tube and activated carbon can operate at higher frequencies and are light weight when used in radar absorbing material. The work in [9] used latex with a filler of an activated carbon from coconut shell based for low cost and light weight radar

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absorber but the bandwidth is quite narrow. The pyramidal absorber based resins was proposed in [10] and [11] by using agricultural waste from rubber tire dust and rice husk. Unlike a planar absorber, the pyramidal structure in [10] and [11] can operate in wider bandwidth but due to the texture of resin, the absorber, developed in [10] and [11] are solid and not light weight. Foamed polyimide with carbon black was used to design a planar EM absorber in [12] by using genetic algorithm to find an optimum amount of carbon black. Besides the amount of carbon-based materials, the shape of absorber plays an important role to the efficiency of absorption. The work in [13] shows the parametric study of the pyramidal shape for EM absorber. It was found that the best configuration for EM wave absorber is pyramidal shape and important dimensions are pyramid base and height. The pyramid height should be more than half of wavelength of lowest operating frequency. Shapes of pyramid base such as triangle, rectangle, pentagon, hexagon, etc., are also studied in [14] to find the best suitable shape for EM wave absorber. It was found that changing shape of pyramid base does not significantly improve the EM wave absorption. Also the works in [15] and [16] developed planar absorbers from rubber composite with CCB filler. The CCB filler can be loss material inside the rubber composite. Recently, a planar EM absorber made by natural rubber is proposed in [17] but it is restricted to only flat absorber because it is quite difficult to form a foam shape with large number of thinkness by using the dry rubber (STR5L). It is not possible to use STR5L for pyramidal configuration. Thus, the natural rubber in form of latex can be used instead.

From literature, it is obvious that the ability to absorb an EM wave depends on the amount of carbon-based material and absorber configuration. The more amount of carbon-based the more absorption can be obtained. The planar configuration provides sudden change in wave impedance which creates high reflectivity but the pyramidal shape has gently changing in wave impedance which makes low reflectivity for wider bandwidth. Therefore, the natural rubber foam with CCB filler and pyramidal configuration is an excellent candidate for a low cost and wideband EM wave absorber. It is of interest in this work to develop an EM absorber which mainly uses latex from Thai farmers together with chemical fillers. Those chemical fillers allow one to make the latex to be an EM absorber which has the characteristic of absorbing EM energy and has physical property closed to foam. The reflectivity is measured to study the effect of the interested parameters and compared to a commercial EM absorber available in the market.

2. Fabrication of Absorber Foam

The sponge or foam is the most desirable property for an EM absorber because it has the dielectric constant closed to free space. The proposed fabrication aims to construct low-cost rubber foam to be pyramidal shape with CCB filler. The fabrication procedure of EM absorber starts from a study of a chemical formula for of a rubber doll or rubber pillow from natural latex. It is found that the natural latex can be formed to be rubber foam with any configuration. The fabrication procedure begins with dispersion process of the CCB with water and two chemicals, namely Bentnite and Vultamol as shown in Table 1. The amount of CCB in the dispersion process has been varied from 20%, 25% and 30%. Then all of chemicals are mixed by using ball mill 64 rpm for 24 hours. It was found that only the 20% CCB can be mixed well to be liquid with other chemicals. Therefore the 20% CCB is obtained from the dispersion process. It was found that it is necessary to immerse the CCB in water with room temperature before dispersion process; otherwise the CCB cannot be blended well with other chemicals.

Table 1 Chemicals for dispersion process.

Chemicals	Ratio	Ratio	Ratio
Conductive carbon Black (CCB)	20%	25%	30%
Bentonite	2%	2%	2%
Vultamol	2%	2%	2%
H_2O	76%	71%	66%

Table 2 Chemical formulation for forming absorber foam.

Chemicals	Weight (g)	Order
Concentrated natural latex	167	
10% K-oleate	15	First set
50% Sulfurl 50% ZDEC 50% ZMBT 50% Wingstay L	4 2 2 2	Second set
33% DPG 50% ZnO	2 10	Third set
20% Carbon Black	20, 30, 40, 50, 60, 70	Fourth set
12.5% SSF	6	Fifth set

The absorber foam is fabricated by preparing 5 sets of ingredients as shown in Table 2 by varying the 20% CCB from 20 g to 70 g to find the proper ratio. Then ones can start to mix the concentrated natural latex with the first set in the mixer for 4 minutes, follow by the second set for 1.30 minutes and third set for 1.30 minutes. Finally the fourth set is mixed for 1.30 minutes and the fifth set consecutively. After the mixing process has been done, ones can pour the mixed substances into a mold and heat in the oven with 100 °C for 2 hours.

It is noted that the concentrated latex with high ammonia (HA Latex) is used in this work. It is the most common grade of latex used worldwide and after compounding it has variety of applications such as medical gloves, industrial gloves, rubber thread, balloons, condoms etc. It contains 60% Dry Rubber Content (DRC). To determine the proper ratio of CCB, the 20% CCB is varied from 20 to 70 g. It was found that the 20% CCB more than 50 g cannot be mixed well with latex composite. Therefore the most 20% CCB is up to 50 g, which can be used with natural latex 167 g or approximately 10 phr (Parts per Hundred Rubber). To study of the effect of CCB ratio in the latex composite the flat sheet rubber foams are fabricated with different amount of CCB as shown in Fig. 1. The reflectivity is measured by using the same approach in [17] and the result is shown in Fig. 2. It is

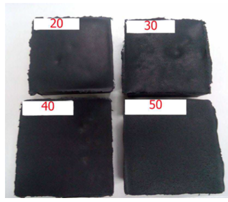


Fig. 1 Flat sheet rubber foams with various amount of CCB from 20 to 50 g per DRC 167 g.

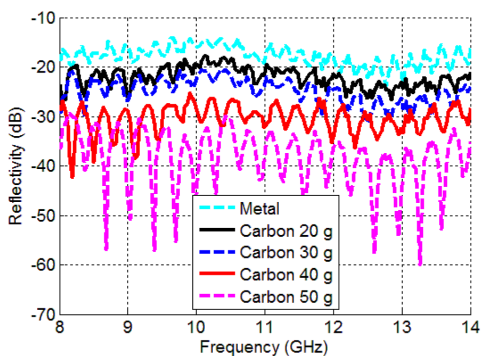


Fig. 2 Comparison of reflectivity of various amount of CCB from 20 to 50 g.

verified that the more amount of CCB the more absorption or less reflection can be obtained which can be observed from Fig. 2.

The complex permittivity (ϵ) of dielectric material [18] can be written as

$$\epsilon = \epsilon' + j\epsilon''. \tag{1}$$

The relative complex permittivity (ϵ_r) of dielectric material can be calculated by

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} = \epsilon_r' + j\epsilon_r'' \tag{2}$$

where ϵ_0 denotes permittivity of free space ($\approx 8.854\times10^{-12}$). The ϵ_r' and ϵ_r'' denote real and imaginary parts of the relative complex permittivity. From Maxwell-Ampere equation, we found that the equivalent conductivity (σ_e) of dielectric material can be written as

$$\sigma_e = \sigma_s + \sigma_a. \tag{3}$$

where σ_s denotes static field conductivity and σ_a denotes alternating field conductivity ($\sigma_a = \omega\epsilon''$). The alternating field conductivity (σ_a) generates loss in dielectric materials in term of heat at high frequency. It is very important parameter of electromagnetic absorber. Moreover, loss in dielectric materials can be described by effective electric loss tangent ($tan(\delta_e)$), which can be written as

$$tan(\delta_e) = tan(\delta_s) + tan(\delta_a) = \frac{\sigma_s}{\omega\epsilon'} + \frac{\sigma_a}{\omega\epsilon'}. \tag{4}$$

At high frequency, the σ_s is approached to zero. The $tan(\delta_s)$ denotes static electric loss tangent. The $tan(\delta_a)$ denotes alternating electric loss tangent at high frequency. The alternating electric loss tangent ($tan(\delta_a)$) can be written as

$$tan(\delta_a) = \frac{\epsilon''}{\epsilon'} = \frac{\epsilon_r''}{\epsilon_r'}. \tag{5}$$

Higher loss tangent value provides more dielectric loss inside material. EM wave incident energy will be converted to heat inside material and provides low reflection of EM wave.

3. Fabrication of Pyramidal Absorber Foam

The fabrication process of pyramidal absorber foam is discussed in the section. Plaster and coir are used to construct a pyramidal mold because it is low cost and easy to construct. It is noted that a square frustum shape is chosen to be archetype of developed absorber. It is well known that the pyramidal shape provides the best EM absorption. There are various sizes (lengths) of pyramidal absorber available in the market. Their sizes depend mostly on the lowest frequency. The size increases with the decreasing frequency. For the wireless communication application with the frequency more than 1 GHz, the length of 200 mm is sufficient. The dimension of the square frustum shape in this work is intentionally chosen to be the same as the commercial absorber ECCOSORB VHY-12 [19] which has the dimension of base side length=150 mm, top side length=57 mm and height=253 mm with the weight of 3 kg per 16 cell or approximately 188 g per one cell. This allows ones to compare the ability of EM absorption between the developed absorber and the commercial absorber. The pyramidal mold made by plaster can be found in Fig. 3.

We can construct a square pyramidal EM absorber as shown in Fig. 4 with final dimension of base side length=120 mm, top side length=45 mm and height=200 mm, which is approximately 20% smaller than the original plaster mold because it is shrunk during desiccation. The texture of developed pyramidal EM absorber made by latex is spongy with the weight of 450 g per one cell.

It is found that there is white stain from plaster mold left on the surface of the developed absorber as shown in Fig. 4. Although this stain may have small effect to EM absorption of the developed absorber, it is of interest in this work to remove this stain. Thus it is necessary to modify the fabrication process of plaster mold to be silicone mold. This can be done as follows:

Step 1 Again the dimension of the square frustum shape from commercial is intentionally chosen but add 10–30% more to compensate shrinking during desiccation. From our previous study, it is found that the developed absorber was shrunk around 20% from the original plaster mold but it is 25–30% from silicone mold. Thus we increase the dimension of the silicone mold to be as follows base side length=185 mm, top side length=72 mm and height=312 mm which is approximately 25% bigger than the commercial

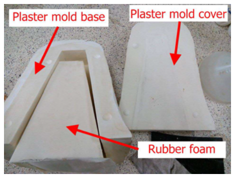


Fig. 3 Pyramidal mold made from plaster.

Fig. 4 Developed pyramidal EM absorber made by latex.

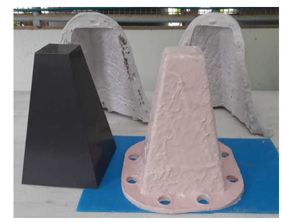
Fig. 5 Wooden mold, encircled by plasticine and plastic coins.

Fig. 6 Mask silicone over the pyramidal wooden mold.

(a) Encircle the silicone mold with plasticine on one side.

(b) Mask plaster on one side of silicone mold.

(c) Plaster molds and silicone mold.



(d) Pyramidal mold made by silicone and wooden mold.

Fig. 7 Frabrication of pyramidal mold.

Fig. 8 New proposed absorber obtained from silicone mold.

absorber.

Step 2 It is necessary to construct a wooden mold which has smooth surface as shown in Fig. 5.

Step 3 Use the plasticine to encircle around the base of wooden mold to keep the silicone in the desired area and put plastic coin or bottle cap around the base of the wooden mold to make the holder for silicone mold as shown in Fig. 5.

Step 4 Then we can start mix the liquid silicone and chemical filler and mask the mixed silicone over the wooden mold as shown in Fig. 6. Leave the mold to dry and mask the mixed silicone over again then cover with any thin cloth to strengthen the silicone mold and leave it dry as shown in Fig. 6. Repeat to mask the silicone and cover with cloth one more time. Leave the silicone to completely dry.

Step 5 To form the pyramidal shape from compound latex, the mold needs to be solid but the silicone mold is flexible. Thus it is necessary to use plaster to cover the silicone one side at a time. We use the plasticine to encircle the silicone mold on top, side and base as shown in Fig. 7(a). Then we can mask the plaster to the silicone mold as shown in Fig. 7(b). Leave it dry and start to do the same to another side of silicone mold. Two side plaster molds can be obtained as shown in Fig. 7(c).

Step 6 Take the wooden mold out and clean the silicone mold as shown in Fig. 7(d). Now the pyramidal mold is ready to use.

After the pyramidal mold has been obtained, we have to leave the compound latex from Table 2 to settle down for 2 hours and put in the oven for 3 hours. Then we have to leave the rubber foam to completely dry for 7–10 days. The final dimension of the new proposed absorber is base side length=168 mm, top side length=68 mm and height=268 mm, which is shrunk around 9–14%. The surface is smooth without any stain as shown in Fig. 8. The total weight per one cell is 680 g. The texture is soft and the pore distribution is uniform which is similar to spongy but sometimes the bubbles may occur on edges or corners of the pyramidal rubber foam. This can be fixed in the process of

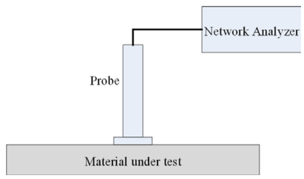


Fig. 9 Dielectric measurement system.

pouring the compound latex to the mold.

4. Results and Discussion

The electrical properties of proposed EM absorber with various amount of CCB from 0 to 50 g are measured by using high precision dielectric measurements system. It is noted that the CCB 0 and 10 g means the amount of 20% CCB from Table 2. The system consists of the DAK coaxial probe and Rohde & Schwarz ZXX Network Analyzer. The DAK is a dielectric measurements of liquids, solids, and semi-solids operating in 10 MHz to 67 GHz. Measurement procedure is shown in Fig. 9. The proposed absorber is measured by using coaxial probe model DAK 3.5 in the frequency range of 1 GHz to 20 GHz and coaxial probe model DAK 1.2 E in the frequency range of 18 GHz to 50 GHz. Thus, it is expected that the discontinuities can be occurred around 20 GHz in the measurement results of Figs. 10 to 12.

Figure 10 shows the real part of the relative complex permittivity (ϵ_r'). The ϵ_r' is decreased as a function of frequency at 1 GHz to 20 GHz and shows a little variation at very high frequency range of 18 GHz to 50 GHz. The imaginary part of the relative complex permittivity (ϵ_r'') as a function of frequency is shown in Fig. 11. Alternating electric loss tangent ($tan(\delta_a)$) is shown in Fig. 12. EM energy loss inside dielectric materials depends on an alternating field conductivity (σ_a) and loss tangent value. Higher alternating field conductivity (σ_a) value provides more dielectric loss inside material. EM wave incident energy will be converted to heat inside material and provides low reflection of EM wave.

It is of interest to investigate the performance of the proposed absorber in the frequency range from 1 to 18 GHz because they are the most common frequency ranges used for wireless communication in Thailand. It is desired to measure the reflectivity by using network analyzer. Due to lacking of such a wide band antenna, ones chose the frequency range only 6 to 18 GHz. First, the measurement setup of reflectivity in frequency range from 6 to 18 GHz is shown in Fig. 13, by using horn antennas and the 4×4 pyramidal absorbers with metal back. There are 3 scenarios in Fig. 13, namely (a) only metal, (b) commercial absorber with metal back and (c) proposed absorber with metal back. The scenario of only metal in Fig. 13(a) is used to be a reference because all of EM wave energy can most likely be reflected back from metal. It is noted that the cut-off frequency of the horn antennas in Fig. 13 is around 8 GHz. Thus it is not possible to use them to measure the reflectivity in the frequency lower than 8 GHz.

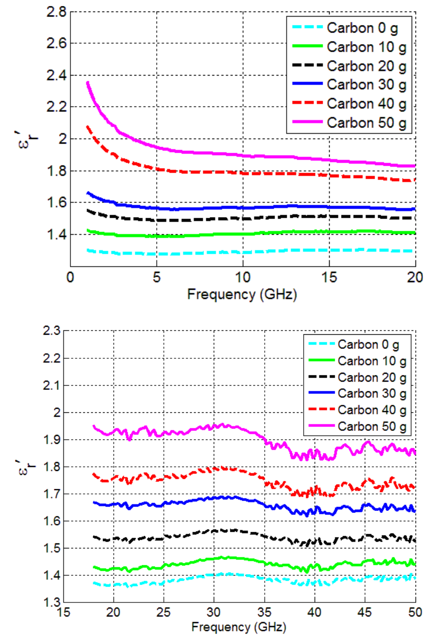


Fig. 10 Real part of the relative complex permittivity (ϵ_r').

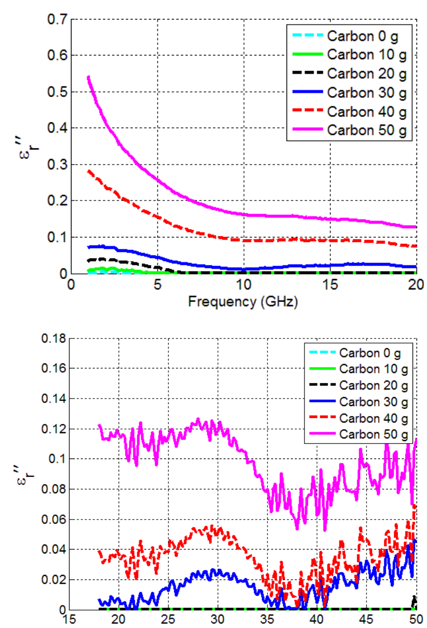


Fig. 11 Imaginary part of the relative complex permittivity (ϵ_r'').

It is obvious from Fig. 14 that the reflectivity of both commercial and proposed absorbers with metal is lower than that of metal case. This means that some of EM energy is absorbed by both commercial and proposed absorbers for all frequency ranges of interest. In addition, although the size of developed absorber is 20% smaller than the commercial absorber, the reflectivity of developed absorber is comparable to commercial absorber [19] for all frequency ranges of interest. It is also found that the reflectivity of the proposed absorber with stain and the new proposed absorber without

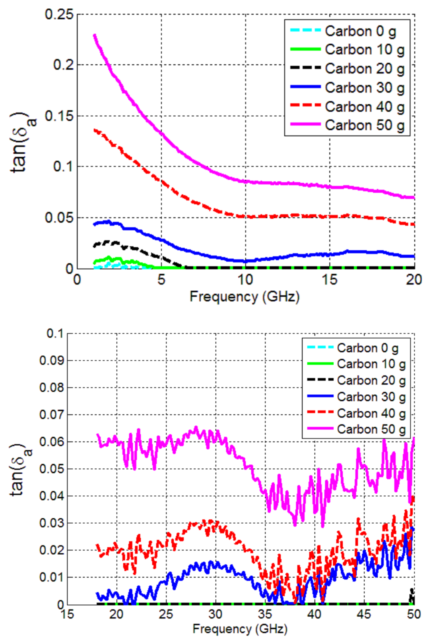
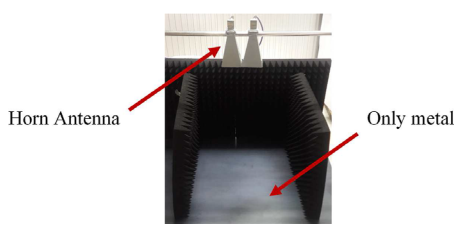
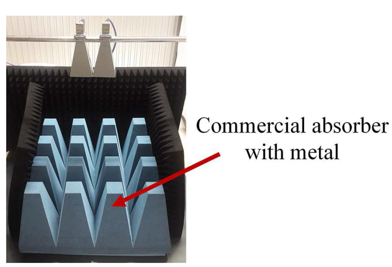


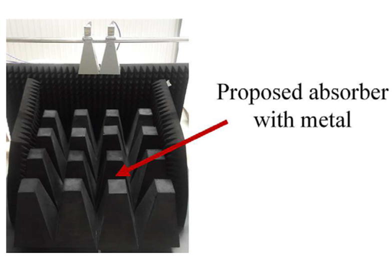
Fig. 12 Alternating electric loss tangent ($tan(\delta_a)$).



(a) Only metal



(b) Commercial absorber with metal



(c) Proposed absorber with metal

Fig. 13 Measurement setup of reflectivity in frequency 6 GHz to 18 GHz.

stain are in the same trend. Thus the stain from plaster mold on the surface of the absorber does not evidently affect the absorption performance of the proposed absorber. However,

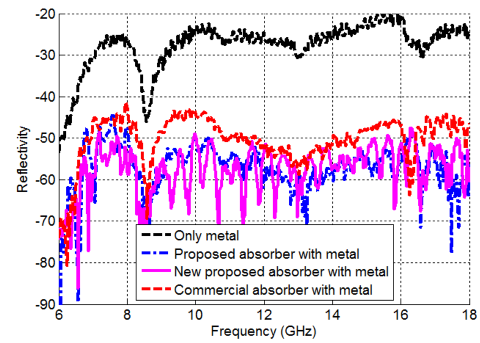


Fig. 14 Comparison of reflectivity of metal, commercial absorber with metal and proposed absorber with metal from Fig. 13.

the fabrication process of the proposed absorber with stain is much more easier. It is noted that the reflectivity level of both commercial and proposed absorbers below 8 GHz of Fig. 14 are closed to metal case because the performance of horn antennas is reduced when the frequency is closed to its cut-off frequency [20]. The weight per one cell of the proposed absorber (450 g) is lighter than the new proposed absorber (680 g) because the proposed absorber is 20% smaller than the new proposed absorber. Also it is found that the weight of commercial absorber is 188 g per one cell, which is lighter than the weight of both proposed absorbers. This is the limitation of the absorber made by latex. However, according to the parametric study, it is found that the physical weight of the absorber made by latex is possible to reduce. It will be reported in the future research article.

It is important to note that the total cost of fabrication (material, manufactering overhead and labors) per one cell of the proposed absorber made by latex is only US$20. However, the commercial absorber [19] costs almost US$300 per one cell, which may include material, manufacturing overhead, labors, marketing cost, etc. Therefore, it is possible to use natural latex to be an EM absorber with low cost. Due to the lack of available instrument and antennas, the measurement set up in this work is limited to the frequency range of 6–18 GHz. However, the performance of the proposed absorber trends to be comparable to the commercial one for the frequency higher than 18 GHz but for frequency lower than 6 GHz, it is under investigated.

5. Conclusion

Two fabrication procedures of an EM absorber made by latex are presented in this paper. Low-cost production of EM absorber made by latex is proposed in this work. The square pyramidal EM absorber like frustum can be constructed by using latex with CCB and chemical fillers. The texture of developed pyramidal EM absorber made by latex is spongy with the weight of 450 g and 680 g per one cell, which are heavier than the commercial one with the weight of 188 g per one cell. The electrical properties such as ϵ and loss tangent are measured in this work. In addition, the reflectivity is measured by network analyzer with frequency range 6 to 18 GHz. It was found that the proposed absorber can absorb EM energy for all frequency ranges of interest and the reflectivity of the proposed absorber is comparable to the commercial one. With the low cost production, the total cost of fabrication is only US$20 which is much cheaper than the commercial absorber. Therefore it is possible to use natural latex to be an EM absorber with low cost. This allows one to generate value-added latex from Thai rubber.

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References

[1] Cuming Microwave, "An Introduction to Anechoic Chamber Application Note 300-1," 2011, http://www.cumingmicrowave.com (Accessed: Feb. 2017).

[2] Rubber Research Institute Department of Agriculture, "Thailand NR Production in 1999-2014," http://www.thainr.com /en/?detail=stat-thai (Accessed: April 2018).

[3] P.S. Neelakanta, Handbook of Electromagnetics Materials Monolithic and Composite Version and Their Applications, p.493, CRC Press, New York, 1995.

[4] A. Bunchuay, Electromagnetic Interference Sheilding Material Made from Natural Rubber, M.S. Thesis, Prince of Songkla University, Thailand, 2005.

[5] European standard, EN 50147-1, "Anechoic chambers Part1 Shield attenuation measurement," 1996.

[6] Electrical Engineering Standard, "CSN EN 50147-1," http://www.electricalengineeringstandards.com (Accessed: Jan. 2015).

[7] K. Naidasham and P.K. Kadaba, "Measurement of the microwave conductivity of a polymeric material with potential application in absorbers and shielding," IEEE Trans. Microw. Theory Techn., vol.39, no.7, pp.1158–1164, 1991.

[8] Z. Fang, C. Li, J. Sun, H. Zhang, and J. Zhang, "The electromagnetic characteristics of carbon foams," Carbon, vol.45, no.15, pp.2873–2879, 2007.

[9] M.K.M. Salleh, M. Yahya, Z. Awang, W.N.W. Muhamad, A.M. Mozi, and N. Yaacob, "Binomial multi-layer coconut shell-based rubber microwave absorber design" Proc. IEEE Int. RF and Microwave Conference, pp.187–190, Seremban, Malaysia, 2011.

[10] F. Malek, "Rubber tire dust-rice husk pyramidal microwave absorber" Progress In Electromagnetics Research, vol.117, pp.449–477, 2011.

[11] H. Nornikman, F. Malek, M. Ahmed, F.H. Wee, P.J. Soh, A.A.H. Azremi, S.A. Ghani, A. Hasnain, and M.N. Taib, "Setup and results of pyramidal microwave absorbers using rice husks," Progress In Electromagnetics Research, vol.111, pp.141–161, 2011.

[12] S. Takano, T. Yasuzumi, K. Moriuchi, T. Sakata, T. Ozaki, and O. Hashimoto, "Optimum design of wave absorbers using foamed polyimide containing carbon black based on genetic algorithm," Proc. Inter. Conf. on Electromagnetic in Advanced Applications, pp.664–667, Torino, Italy, 2011.

[13] H. Nornikman, P.J. Soh, A.A.H. Azremi, and H.M.R. Nural, "Parametric study of pyramidal microwave absorber design," Progress In Electromagnetics Research, vol.104, pp.145–166, 2010.

[14] H. Nornikman, P.J. Soh, and A.A.H. Azremi, "Performance of different polygonal microwave absorber design using novel material," Proc. International Symposium on Antennas and Propagation, pp.1151–1154, Bangkok, Thailand, 2009.

[15] Y. Zhai and Y. Zhang, "Electromagnetic characteristic and microwave absorbing performance of different carbon-based hydrogenated acrylonitrile-butadiene rubber composites," Elsevier Materials Chemistry and Physics, vol.133, no.1, pp.176–181, 2012.

[16] E.K. Lee and S.Y. Choi, "Preparation and characterization of natural rubber foams: Effects of foaming temperature and carbon black content," Korean J. Chem. Eng., vol.24, no.6, pp.1070–1075, 2007.

[17] K. Salayong and T. Lertwiriyaprapa, "Study of electromagnetic absorber made by natural rubber," Proc. 2015 IEEE Conference on Antenna Measurements & Applications, Chiangmai, Thailand, 2015.

[18] C.A. Balanis, Advanced Engineering Electromagnetics, 2nd ed., Wiley, 2012.

[19] Emerson & Cuming Anechoic Chambers, "ECCOSORB VX-NRL," http://www.ecanechoicchambers.com/absorbers1.html (Accessed Jan. 2016)

[20] C.A. Balanis, "Horn Antennas," in Antenna Handbook, Y.T. Lo and S.W. Lee, eds., vol.1, pp.431–516, Springer, New York, 1988.

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