Design and Development of Radio Wave Absorber Using Eco-Friendly Materials

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Abstract—An investigation on using eco-friendly natural materials like coconut pith, rubber, and charcoal powder for developing radio wave absorbers has been reported in this paper. Two absorbers named CoR (Combination of Coconut pith powder and natural Rubber latex) and CoRC (Combination of Coconut pith powder, natural Rubber latex, and Charcoal powder) are made through proper mixing and drying. The absorptivity of these two absorbers (CoR and CoRC) is compared with the industrial standard polyurethane based absorber. The waveguide method is employed to measure the absorptivity of these absorbers in 3 different frequency bands. Band 1 (1.7–2.6 GHz) includes the mobile communication frequencies of 1.8 GHz and 2.4 GHz. Band 2 (4.9–7.05 GHz) is intended for sub 6 GHz band of 5G as well as WLAN frequencies while band 3 (8.2–12 GHz) is for higher frequencies of radar operation. The exact values of lower and upper frequencies of bands are determined by the physical dimensions of waveguides used. The absorption capability of the absorbers is found to increase as the frequency of operation increases. The CoR absorber has almost 63% average absorptivity in band 3, 56% in band 2, and 21% in band 1. The CoRC absorber has an average of 74% absorptivity in band 3, 63% in band 2, and 24% in band 1.

1. INTRODUCTION

Our surroundings are filled with swirling electromagnetic radiations. The major reason for this higher radiative environment is the over employment of wireless devices [1]. Even though these devices make modern-day life easy, they also cause serious issues in some other walks of life [2, 3]. For example, there are many places where zero radio wave is expected. These places include medical intensive care units, drug development plants, petrochemical purifying refineries, petrol bunks, etc. In many of these places either absorbers or power limiters [4] are used to reduce the effect of radiation. The only way to create "radiation-free zones" is by developing efficient radio wave absorbers. These absorbers are extensively used in sensors [5] and waveguide applications [6]. In the present scenario, radio wave absorbers based on polyurethane [7] or chemical resins are employed to cater to this purpose [8]. The microwave testing centers greatly rely on these artificial absorbers for creating an anechoic chamber or radiation free zone. But these costly artificial absorbers will create huge environmental or health hazards [9] during the decommissioning of it. So the way out from this critical problem is to create cost efficient and eco-friendly absorbers.

Recently, many researchers have shown keen interest in developing radio wave absorbers from natural materials. This is due to the widespread requirement of absorbers for military, medical, and research purposes. Simón et al. in [10] have investigated the suitability of using powdered coir for microwave absorption application. The capability of microwave absorption is discussed in terms of its transmission characteristics (S_{21}) using the waveguide method in X band. A more comprehensive

study on the absorbing characteristics of a composite made of coir powder, charcoal powder with a chemical thickener/binder is represented in [11] by Yah et al. This paper provides a detailed study of various parameters of the absorbing composites in the X band. The possibility of using rice husk as a radio wave absorber is presented in [12] by Nornikman et al. Free space measurement technique, using two horn antennas, is used to conduct the parametric study of the particulate board made from rice husk. A comparison of absorptivities of burnt and unburnt rice husk based absorbers is reported in [13] using a far field measurement system by employing a single horn antenna along with a vector network analyser. Salleh et al. have reported the possibility of using a single layer coconut shell-based absorber in [14]. Microwave Non-Destructive Testing (MNDT) method is employed for evaluating the absorption capability of this absorber. Nowadays, researchers are keenly concentrating on developing applications from organic materials. In [15], Abdulkarim et al. explain the design of a broadband coplanar waveguide-fed antenna incorporating organic solar cells with 100% insolation for Ku band satellite communication.

This paper investigates the possibility of using coconut pith powder, charcoal powder, and rubber latex to produce eco-friendly radio wave absorbers. No chemicals are added in the development process to ensure the eco-friendliness of the absorbers. All the raw materials used for creating the absorbers are abundant and cheap. The coconut pith is the by-product of coir industry, and charcoal powder can be obtained easily by burning the coconut shell. The additional requirement for developing the absorber is natural rubber latex which is abundantly available in India, especially in Kerala. Though a few works have been reported about the absorption analysis of coir-based absorber in X band, none of them has done a comprehensive study in other frequency regimes. In [16], Mishra et al. propose a coconut coir dust based absorber with good reflectance in X band. But this absorber uses chemicals like acetone and ethanol to achieve various properties. To the best of authors' knowledge, no other work has reported the behavior of a natural material based absorber in 3 different frequency bands. The complete manufacturing details of both the absorbers are furnished in this paper. Along with these details, the paper describes the waveguide method for analysing the absorption capability of these absorbers. The absorption capability in X band has also been verified using the VSWR method. A comparative study of the absorptivity of these absorbers with an industrial absorber based on polyurethane form (FU-SE-4) [17] and a sponge is also done and reported.

2. DEVELOPMENT OF ABSORBERS

The naturally occurring agricultural products like coconut pith, charcoal powder, and rubber latex are used to form two different absorbers. The first absorber, named CoR, is made by combining coconut pith powder and rubber latex. The coconut pith is obtained by shredding the coconut fiber, which is abundantly available in India. The raw coconut pith is dried in a hot air oven at 50°C for 7 hours before the powdering process. The powdered pith is then passed through two sieving stages to process it into fine particles. In the last step, the sieved coconut pith powder is mixed with pure rubber latex in an industrial mixer. The mixed composite is pressed in a hydraulic press by applying 2 bar pressure at room temperature. The optimum proportion of coconut pith powder to the rubber latex is 3 : 2 to achieve properties for the absorber. This ratio ensures satisfactory compactness, dryness, and solidity, which determines the life of the absorber. An increase in coconut pith content adversely affected the binding property while an increase of rubber latex affected the dryness. Any negligence in proper dryness leads to fungi attack within a period of one week.

The second absorber (CoRC) is made by combining coconut pith powder, rubber latex, and charcoal powder. The charcoal powder is obtained by burning the coconut shell, which is again a by-product of coconut farming. The addition of charcoal powder (carbon) into the absorber is to provide more lossy behavior to the absorber so that it will be more effective for radio wave absorption applications. The CoRC is made through two major steps. In the first step, coconut pith powder is mixed with the charcoal powder in a sigma mixer at 300 rpm. After that, the rubber latex is blended with the powdered composite to create the absorber. This order of mixing is important since any other order will result in the precipitation of carbon above the absorber. The ratio of materials is optimized in CoRC as 3 : 2 : 2. This ratio provides better binding property and stability. The use of coconut pith ensures the reduction in cost in both absorbers. Fig. 1 shows both the absorbers with size 60 mm × 60 mm × 6 mm.
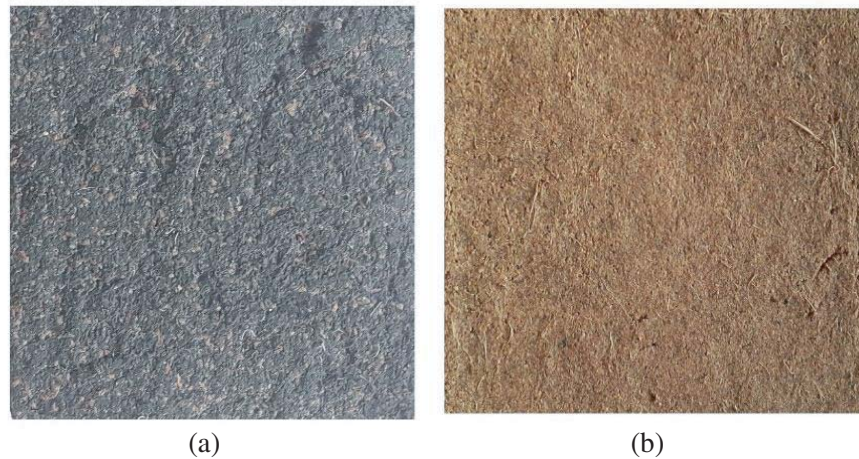
Figure 1. Absorbers based on natural materials. (a) CoRC — Coconut pith powder: Rubber latex: Charcoal powder — $3:2:2$. (b) CoR — Coconut pith powder: Rubber latex — $3:2$.

3. THEORY OF RADIO WAVE ABSORPTION

The absorptivity of a material is defined as the material's ability to attenuate or absorb the electromagnetic radiation inside it. When a radio wave propagates through any material/medium, it undergoes basic phenomena like reflection, transmission, and absorption as shown in Fig. 2(a). If the absorber is backed by a conductor, transmission can be reduced to zero as shown in Fig. 2(b).
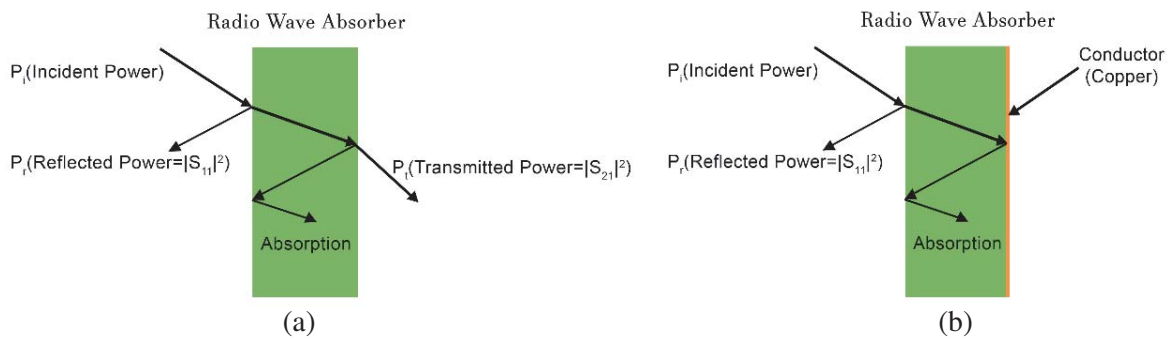
Figure 2. Propagation of radio wave through an absorber (a) without conductor backing, (b) with conductor backing.

The interaction of a radio wave with any material depends on its electric permittivity and magnetic permeability. These macroscopic properties play an important role in deciding the ability of the material to transmit electric and magnetic fields through it. Based on this, materials are classified either as dielectric or as magnetic. The complex permittivity and complex permeability [18, 19] of a material are given as

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \tag{1}$$
$$\mu^* = \mu' - j\mu'' \tag{2}$$

The real parts of complex permittivity and permeability (ε', μ') represent the electric and magnetic energy storage, whereas the imaginary parts (ε'', μ'') are associated with the dielectric and magnetic loss or energy dissipated within a material. The ratio of imaginary parts (energy loss) to the real parts

(energy stored) is defined as the loss tangent of the material. The dielectric and magnetic loss [20] is defined by

$$\tan \delta_\varepsilon \ = \ \frac{\varepsilon''}{\varepsilon'} \tag{3}$$

$$\tan \delta_\mu \ = \ \frac{\mu''}{\mu'} \tag{4}$$

where δ is the loss angle of the material.

Usually, agricultural by-products are rich in carbon, and they have no metallic composition. Hence, these materials can be considered as dielectrics, and they have only electrical permittivity [16]. The effectiveness of a material as a microwave absorber can be determined from loss tangent and attenuation coefficient (α) [21] which results in attenuation of EM waves. The attenuation coefficient of a dielectric is given by

$$\alpha = \frac{\sqrt{2}\pi f}{v} \sqrt{\sqrt{(\mu'^2 \varepsilon'^2 + \mu'^2 \varepsilon''^2)} - \mu' \varepsilon'} \tag{5}$$

where "f" and "v" are the frequency and speed of the electromagnetic wave in the medium. The absorptivity or absorption coefficient of a material can be computed from the reflected (S_{11}^2) and transmitted power (S_{21}^2) using the linear power conservation equation [22] as given by Eq. (6):

$$A = 1 - |s_{11}|^2 - |s_{21}|^2 \tag{6}$$

In simple words, the absorption of energy by a material occurs when the incoming wave is scattered or dissipated within the material volume. The higher the amount of scattering or dissipation is, the better the absorption will be. To understand the efficiency of the proposed absorbers in terms of their absorptivity, microscopic level observations are made. Scanning Electron Microscopy (SEM) of CoR and CoRC is done using JOEL JSM-6390-SEM with the same magnification at 20 kV in 100 μm region of the sample. Fig. 3(a) shows the micrograph of CoR, and Fig. 3(b) shows that of CoRC. The presence of carbon is evident in both images, which is expected since both the absorbers contain coconut pith powder. As carbon is a conductive medium, it can act as a very good microwave absorbent. It easily gets heated up when a microwave moves through it, which creates an electric field at the surface of the absorber. During this process, heat is generated at the surface of the absorber due to the presence of electrical energy. This dissipation of energy produces attenuation of the electromagnetic wave moving through the absorber [23]. Thus both CoR and CoRC can act as a radio wave absorber. Since CoRC is made by adding additional carbon, it could provide better absorption characteristics than CoR. This additional amount of carbon in CoRC makes it more porous and is evident from its micrograph. These pores produce multiple reflections when a radio wave enters the absorber. As the wave moves through the absorber, it has to pass through different boundaries continuously. This introduces additional power losses which leads to the improvement in absorption characteristics.

(a)   (b)
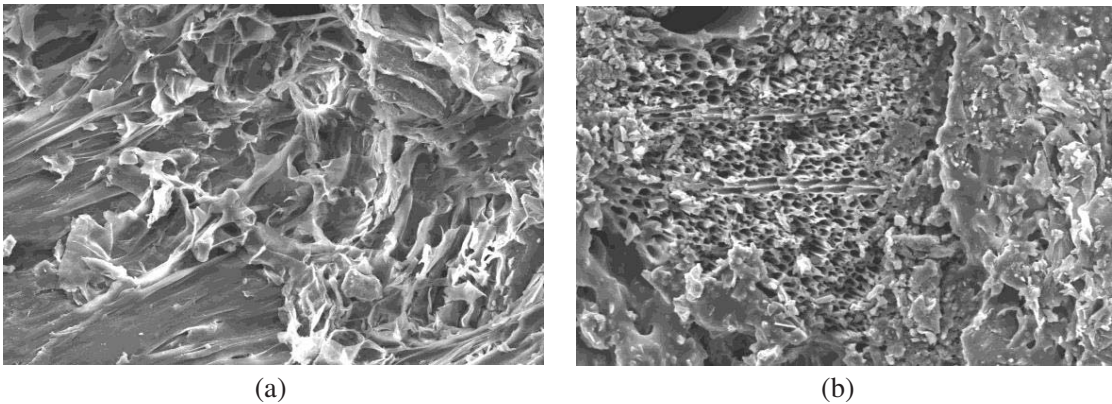
Figure 3. Scanning electron microscopy of (a) CoR and (b) CoRC.

From Eq. (5), it is evident that the attenuation constant of dielectric material is directly proportional to frequency. Hence as the frequency of operation increases, more attenuation can be expected in both CoR and CoRC and thereby higher absorption. Another phenomenon is the increase in the imaginary part of the dielectric constant due to the migration of carbon particles [24] from one point to another inside the absorber as a radio wave passes through it. This migration introduces power loss inside the material, which will increase the loss tangent and eventually the absorption. This feature is also directly related to skin depth and frequency, thus better performance can be expected in band 3 than lower frequency bands 1&2 for the same thickness of the sample.

4. EXPERIMENTAL ANALYSIS

4.1. Waveguide Method

The waveguide method [25, 26] is employed to measure the absorption of each composite in three different frequency bands. The method requires two waveguide adapters, a waveguide through/sample holder, and a vector network analyzer as shown in Fig. 4. Line-Reflection-Line (LRL) calibration is done [27, 28] to reduce the effect of waveguide imperfections and other noises due to multiple reflections or scattering of radio waves inside the waveguide. Fig. 4 shows the schematic diagram of the experimental setup. The absorption coefficient or absorptivity of CoR and CoRC is computed from the S_{11} and S_{21} obtained through the waveguide experiment. To validate the industrial feasibility of developed absorbers, their absorptivity is compared with a sample of standard radio wave absorber based on polyurethane developed by SLTL microwave limited (FU-SE-4) having the same dimension as that of CoR and CoRC.
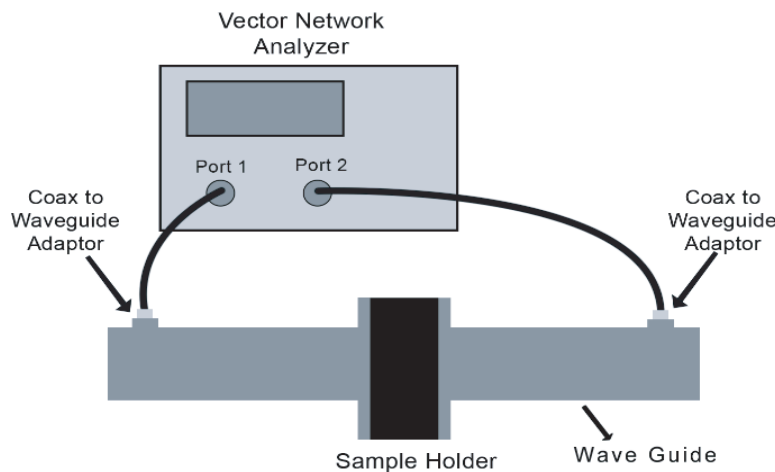
Figure 4. Schematic diagram of experimental setup for measuring absorptivity using Waveguide method.

4.2. VSWR Method

Effect of thickness of absorber is studied through Klystron based microwave test bench method in band 3. The variation in maximum and minimum voltages is used to find out the reflection coefficient, Voltage Standing Wave Ratio (VSWR) and return loss [29, 30]. Fig. 5 demonstrates the schematic arrangement for finding out the return loss of each absorber using the klystron setup. Absorbers with different thicknesses are attached at the end of the slotted line using adhesive metal tapes. Since the absorbers under test are completely covered with metal tape, the effective microwave absorption can be measured using the modified formula given by

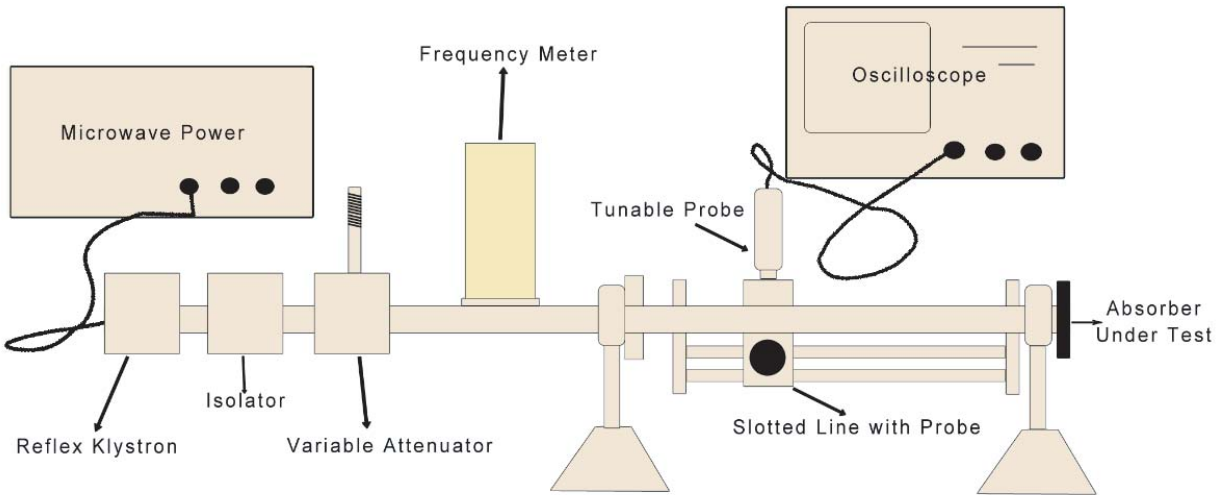$$A_{Effective} = 1 - \Gamma^2 = 1 - |RL|^2 = 1|S_{11}|^2 \tag{7}$$

Figure 5. Schematic diagram of experimental setup for measuring absorptivity using VSWR method.

5. RESULTS AND DISCUSSION

5.1. Waveguide Method

To get an overall idea about the effectiveness of CoR and CoRC in terms of radio wave absorption, their absorption curves are compared with that of a standard absorber and a normal sponge material. The introduction of the sponge is to state that not all normal materials possess the capability to absorb radio waves. Fig. 6 shows reflection, transmission, and the absorption characteristics of these four materials in band 1.

From Fig. 6, it is clear that at lower frequencies, none of the absorbers have a significant amount of absorption. This may be because at lower frequencies, the skin depth of the absorber is high, and the surface dissipation of radio wave power is low. But the industrial absorber based on polyurethane (FU-SE 4) has a noticeable edge compared with CoR and CoRC composites.
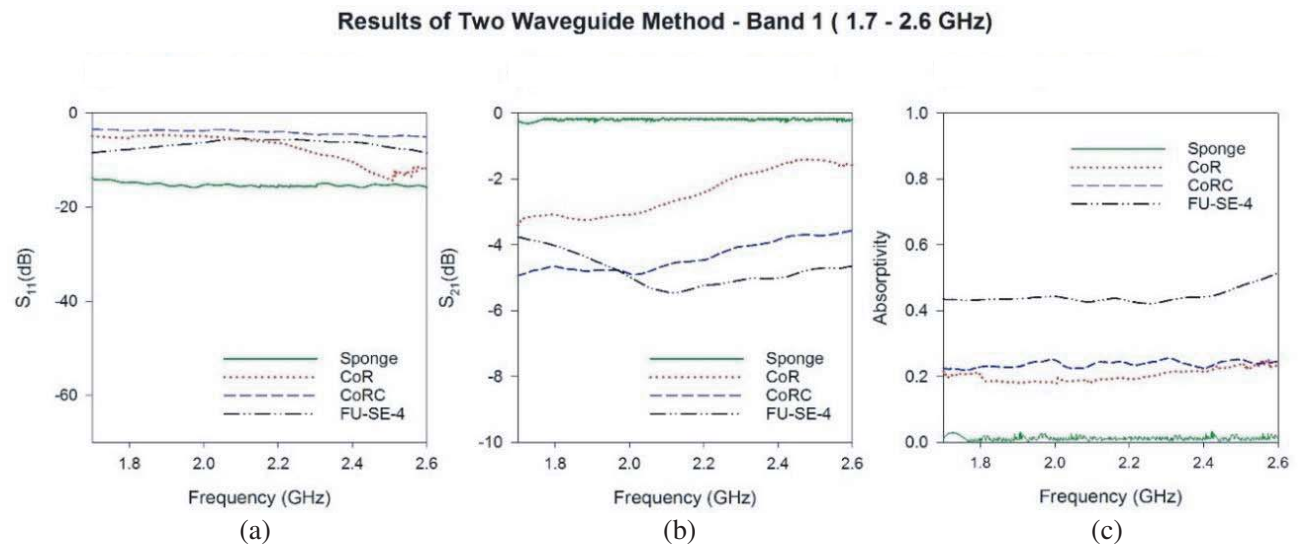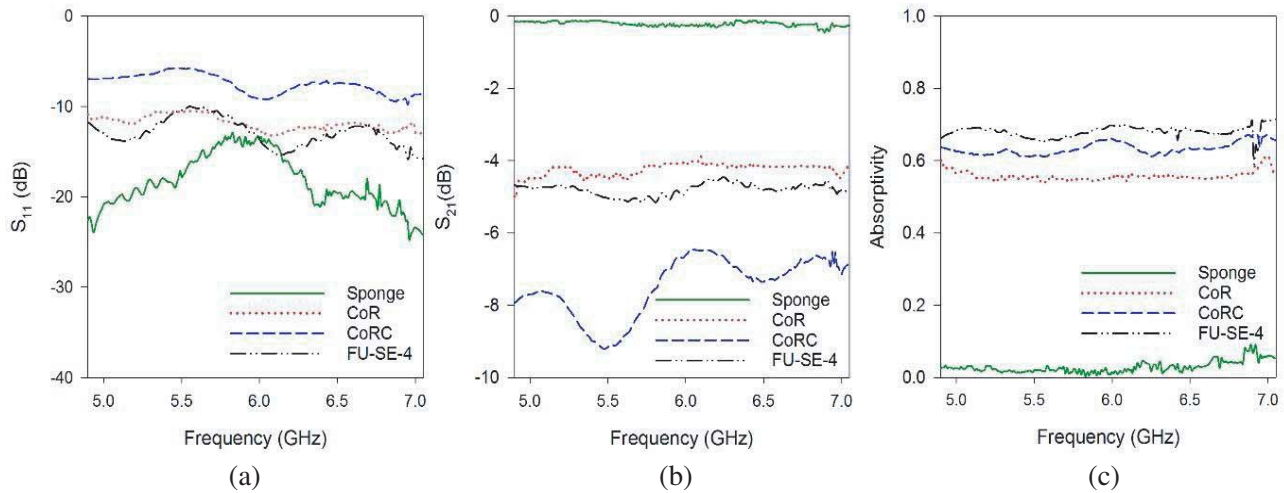

Figure 6. (a) Reflection, (b) transmission and (c) absorption Characteristics of absorbers with thickness = 6 mm.

Results of Two Waveguide Method - Band 2 (4.9 - 7.05 GHz)

(a)   (b)   (c)

Figure 7. (a) Reflection, (b) transmission and (c) absorption Characteristics of absorbers with thickness = 6 mm.

Figure 7 shows the absorption characteristics in band 2. By comparing it with Fig. 6, it is evident that the absorptivity of CoR and CoRC gets increased as the frequency of operation increases. This is a direct implication of Eq. (5) which states that as the frequency increases, the attenuation factor also increases. Higher amount of attenuation will lead to a higher amount of radio wave power dissipation in the surface of the absorber, which causes the absorptivity to increase. The absorption curve of the sponge remains almost the same. This indicates the inefficiency of normal materials in terms of microwave absorption.

Figure 8 shows the suitability of CoR and CoRC for absorbing microwave power in band 3. The level of absorption is comparable with that of industrial standard absorbers. Table 1 summarises the absorptivity of CoR, CoRC, and FU-SE-4 in various bands obtained by performing the waveguide method. From Table 1, it is evident that the performance of CoRC is almost comparable with that of the FU-SE-4 in band 3. The properties of CoRC have also been tested many times within a span of four months to evaluate the stability of the absorption properties. The repeated measurements have given similar results for absorptivity, which indicates the suitability of the absorber for long term applications. This result extends the possibility of employing these absorbers for radar stealth applications.

Table 1. Average absorptivity of various absorbers in different frequency bands using the waveguide method.

Frequency Band	Average Value of Absorptivity		
	CoR (%)	CoRC (%)	Industrial Absorber (FU-SE-4) (%)
Band 1 (1.7–2.60 GHz)	20.48	23.61	48.46
Band 2 (4.9–7.05 GHz)	55.79	63.38	68.03
Band 3 (8.2–12.0 GHz)	62.87	74.06	80.19

5.2. VSWR Method

Table 2 depicts the measurements obtained by performing klystron based absorption analysis in band 3. The absorptivities of CoR and CoRC absorbers are measured from their return loss. The effect of

Results of Two Waveguide Method - Band 3 (8.2 - 12 GHz)

(a)   (b)   (c)
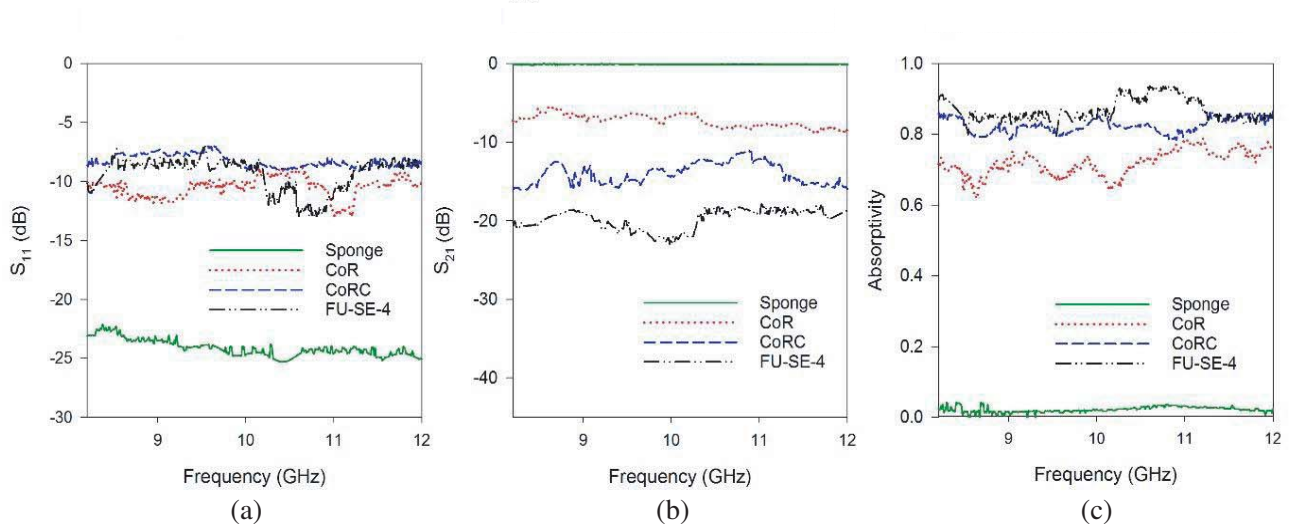
Figure 8. (a) Reflection, (b) transmission and (c) absorption characteristics of absorbers with thickness = 6 mm.

**Table 2.** Results of peak absorptivity calculation using VSWR method in band 3.

Name of the Absorber	Thickness (mm)	$V_{\max}$ (mV)	$V_{\min}$ (mV)	Reflection Coefficient Γ	(S_{11}) dB	VSWR	Absorptivity (%)
CoRC	1 mm $(\lambda_0/30)$	256	93	0.47	-6.56	2.77	77.91
	2 mm $(\lambda_0/15)$	248	98	0.43	-7.33	2.5	81.51
	3 mm $(\lambda_0/10)$	244	102	0.41	-7.74	2.39	83.19
	4 mm $(2\lambda_0/15)$	241	106	0.39	-8.18	2.28	84.79
	5 mm $(\lambda_0/6)$	237	109	0.37	-8.64	2.17	86.31
	6 mm $(\lambda_0/5)$	234	112	0.35	-9.11	2.08	87.75
CoR	1 mm $(\lambda_0/30)$	274	56	0.67	-3.48	5.06	55.11
	2 mm $(\lambda_0/15)$	272	59	0.64	-3.88	4.56	59.04
	3 mm $(\lambda_0/10)$	271	63	0.62	-4.15	4.26	61.56
	4 mm $(2\lambda_0/15)$	268	68	0.6	-4.44	4	64
	5 mm $(\lambda_0/6)$	264	71	0.58	-4.73	3.76	66.36
	6 mm $(\lambda_0/5)$	258	76	0.54	-5.35	3.35	70.84

thickness in absorptivity is studied by varying the thickness of the absorbers physically from 1 mm to 6 mm. Based on the results obtained from Table 2, an absorption characteristic is plotted to understand the effectiveness of CoR and CoRC absorbers in band 3.

The absorptivities of both CoR and CoRC absorbers are plotted against their thickness to analyse the importance of the parameter. From Fig. 9, it is clear that as the thickness of the absorber increases from 1 mm to 6 mm, the peak absorptivity is also increased. The absorptivity of CoRC is always greater than that of CoR due to the additional polarisation effect provided by the additional carbon present in it. The value of absorptivity obtained through VSWR method is in good agreement with that obtained from the waveguide measurement in band 3 by considering the fact that VSWR measurement only takes the reflection coefficient for measuring the absorptivity.
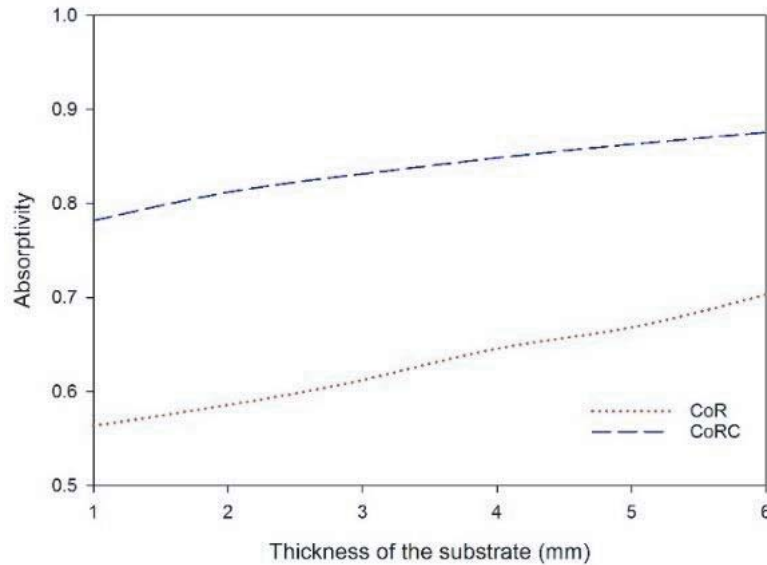
Figure 9. Peak absorption characteristics of CoR and CoRC in band 3 using VSWR method.

Table 3. Various industrial absorbers with their absorptivities.

Name of the producer and model number of the absorber	Shape of the absorber with thickness	Frequency band of operation (GHz)	Reflection Parameter (dB)	Transmission Parameter (dB)	Absorptivity (%)
Cuming Microwave — Ceramic ferrite [31]	Tile Absorber Thickness = 6.3 mm	1.5	−9	0	87.41
Laird — HR-10 [32]	Sheet Absorber Thickness = 10 mm	5 8 12	−2.5 −5 −7	0 0 0	43.76 68.37 80.04
Murata Manufacturing — EA1075A270 [33]	Planar Absorber Thickness = 2.733 mm	2.5 5–12	−24 −5	0 0	99.6 68.3
Mast Technologies — MF11-0002-00 [34]	Planar Absorber Thickness = 12.8 mm	4 8–13	−5 −29	0 0	68.30 99.89
CoR — With metal backing	Planar Absorber Thickness = 6 mm	8–12	−5.27	0	70.31
CoRC — With metal backing	Planar Absorber Thickness = 6 mm	8–12	−9.05	0	87.56
CoR — Without metal backing	Planar Absorber Thickness = 6 mm	8–12.04	−13.02	−7.94	62.87
CoRC — Without metal backing	Planar Absorber Thickness = 6 mm	8–12.04	−10.27	−13.71	74.06

Table 3 demonstrates the absorption capability of popular industrial standard absorbers in various frequency bands. The absorptivities of these absorbers are calculated using Eq. (6) based on the reflection parameter sited in their data sheet. The results in Table 3 points out that CoR and CoRC absorbers are competent enough compared with other planar absorbers of similar thicknesses in terms of their absorptivities. They also possess wide absorption bandwidths compared with the industrial absorbers. From Fig. 9, it is evident that the dependence of thickness in regulating the absorption capability is less in CoR and CoRC absorbers than the industrial absorbers. For CoRC absorber, there is only a 9% variation in the absorptivity as the thickness is increased by 6 times.

6. CONCLUSION

Two types of eco-friendly radio wave absorbers, namely CoR and CoRC, using coconut pith powder, charcoal powder, and natural rubber latex are proposed in this paper. The suitability of using CoR and CoRC as absorbers in 3 different application bands is experimentally verified. The analysis based on the waveguide method shows that CoR and CoRC have average absorptions of 63% and 74% in band 3 which are very close to the absorbance possessed by industrial absorber based on polyurethane. The results are also verified using the slotted line VSWR method and found in good agreement with the result obtained from the waveguide method. This paper also gives an experimental validation to the fact that as the frequency of operation increases, attenuation in a dielectric material increases which will eventually lead to an increase in absorption. The absorptivity of CoRC is greater than CoR in every band due to the additional presence of Carbon which will introduce additional losses to the radio wave when it passes through the absorber. The absorption provided by CoRC is in the range of 64% in band 2 and the range of 24% in band 1. The amount of absorption can be improved by adding certain chemicals to the absorbers. This paper opens up the possibility of using eco-friendly absorbers for radio wave absorbing applications like stealth, creation of radiation free zone, etc.

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