Research Inventy: International Journal of Engineering And Science
Vol.9, Issue 8 (August 2019), PP 17-20
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

A Wearable Metamaterial Microwave Absorber

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Abstract: *A wearable metamaterial microwave absorber (WMMA) for indoor radar clear applications is proposed. The proposed WMMA is composed of two square ring resonators with different sizes, a backing ground plane, and a felt substrate with a 1 mm thickness. All conductive materials were fabricated using conductive textiles. The grid array of different square ring resonators provides a broad absorption band due to two neighboring resonance peaks. The measured results exhibit two absorptivity peaks greater than 90% and a full width at half maximum (FWHM) of 18.9% at 9.475 GHz. Also, the proposed WMMA has a high absorptivity regardless of the polarization angle of the EM waves and the deformation effect.*

Keywords: *Wearable absorber, Textile absorber, metamaterial, microwave absorber, Frequency selective surface (FSS).*

I. Introduction

Research involving electromagnetic absorbers (EMAs) has been extensively conducted for various applications such as anechoic chambers, electromagnetic interference/electromagnetic compatibility (EMI/ EMC) control systems, and concealment applications. EMAs are primarily classified into three types. The most widely used absorber type is the wedge tapered absorber. It usually has a pyramidal-shaped array to absorb and scatter electromagnetic waves in the broadband and is commonly used in anechoic chambers. However, this absorber is bulky and fragile and therefore, is not suitable for portable applications.

Another type of EMAs is the lossy absorber, which uses high-permeability or permittivity-composite materials. It also has high absorptivity in the broadband. However, it is quite expensive because of the scarcity of the materials. Lastly, a metamaterial (MTM) absorber is used for applications requiring flexibility and/or a low profile. MTM is an artificial electromagnetic structure periodically composed of a specific patterned metal structure and dielectric. The initial MTM research addressed the realization of an effective negative permittivity, permeability, and refractive index.

However, the resonance-based MTM absorber has a narrow absorptivity bandwidth. Therefore, a dual-band MTM EMA is required to overcome this problem. Although a dual-band characteristic could be realized using concentric loops, it is difficult to achieve a broadband absorption with neighboring absorption peaks. Because of its low weight, low cost, ease of fabrication, and practicability, microwave components using a textile material for wearable applications have become an attractive research topic. Generally, conductive textiles are used for conductive elements, such as a radiating element or ground of the antenna, while a non-conductive fabric, such as silk, fleece, leather, or felt, is used as a substrate. However, many researches using textile materials have mainly focused on wearable antennas for conformal, flexible, and logo antennas.

A wearable metamaterial microwave absorber (WMMA) for indoor radar clear applications is proposed. To overcome the narrow absorptivity bandwidth of the resonance-based MTM absorber, a unit cell of the proposed WMMA is designed to have dual resonances at 9 GHz and 9.8 GHz. Because the WMMA has polarization- and deformation-insensitive features, it can be integrated on the cloth and used for indoor radar-absorbing materials.

II. Metamaterial antenna and Microwave absorbers

2.1 Metamaterial antenna

Metamaterial antennas are a class of antennas which use metamaterials to increase performance of miniaturized (electrically small) antenna systems. Their purpose, as with any electromagnetic antenna, is to launch energy into free space. However, this class of antenna incorporates metamaterials, which are materials engineered with novel, often microscopic, structures to produce unusual physical properties. Antenna designs incorporating metamaterials can step-up the antenna's radiated power.

2.2 Microwave absorbers

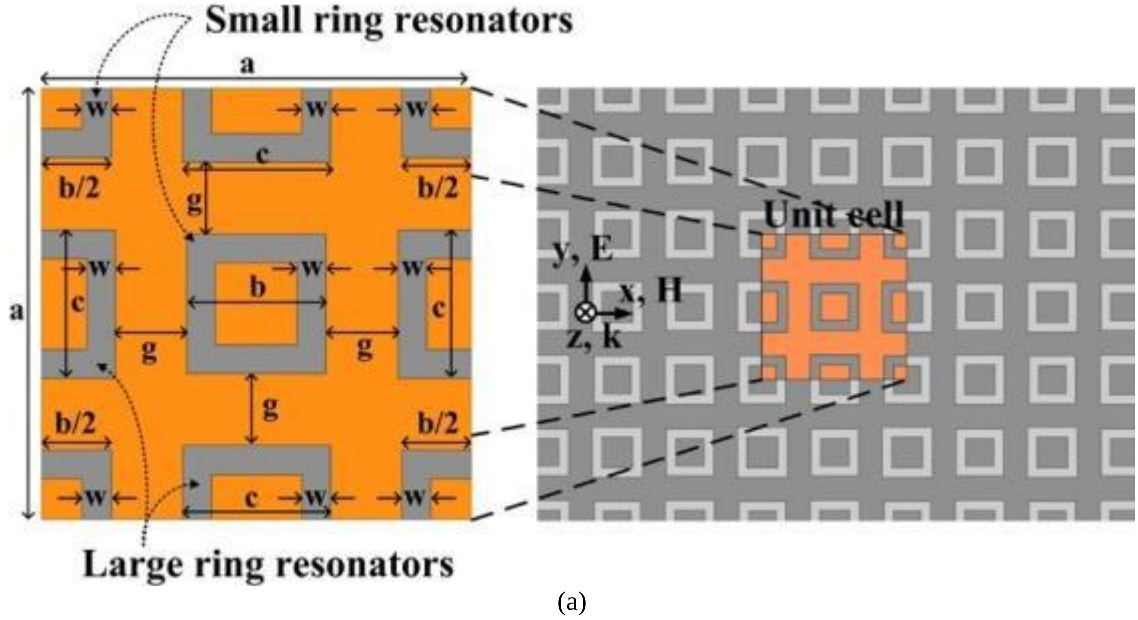
Microwave absorbers have been used in military applications for several decades. They have been traditionally used for EMI reduction, antenna pattern shaping and radar cross reduction. More recently with the rise of wireless electronics and the movement to higher frequencies microwave absorbers or “noise suppression sheets" (NSS) are used to reduce electromagnetic interference (EMI) inside of the wireless electronics assemblies.Skin depth engineering can be used in metamaterial absorbers in photovoltaic applications as well as other optoelectronic devices, where optimizing the device performance demands minimizing resistive losses and power consumption, such as photodetectors, laser diodes, and light emitting diode.

III. Absorber Design And Characteristics

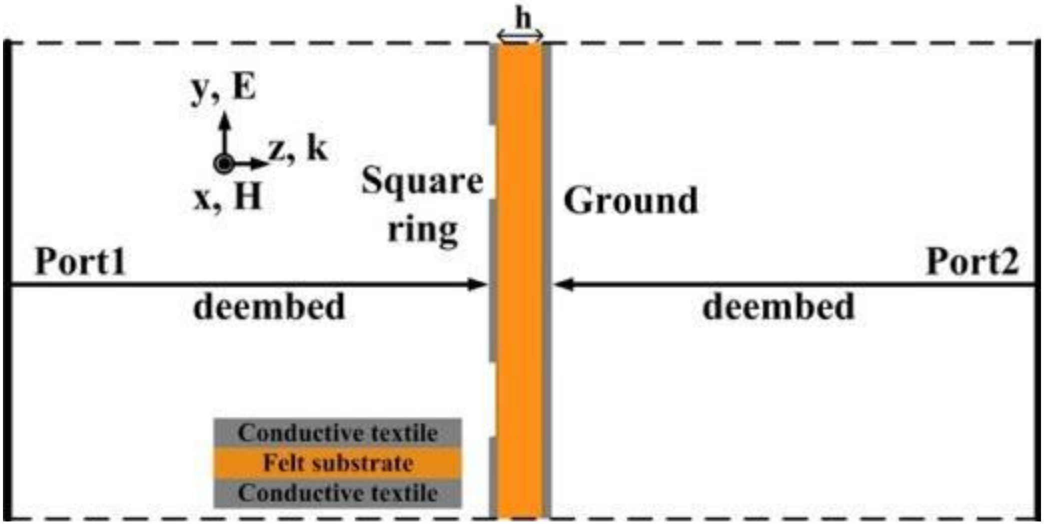
The unit cell of the absorber consists of square ring resonator backing ground plate, and a felt (εr=1.2; tanδ=0.02) substrate with a thickness of 1 mm. On the top of the substrate, a square ring grid array consisting of smaller square rings and larger square rings is used. Employing the grid array with two types of resonators generating different resonances is utilized to achieve the broadband absorptivity. The full ground is placed on the bottom of the substrate. To analyze the performance of an infinite array of the proposed WMMA shown in Fig. 1(a), the unit cell is simulated with periodic boundary conditions and Floquet-port excitations using ANSYS HFSS. To determine the absorptivity values, the incident electromagnetic wave is excited along the z-axis. To describe the characteristics of MTMs, the effective medium parameters, the complex electric permittivity ε(ω) = ε1 + jε2, and the magnetic permeability μ(ω) = μ1 + jμ2 can be used. The real parts of the permittivity and permeability determine the negative refractive index of the material. Their imaginary parts account for losses and they must have high values to achieve a high absorptivity at the required frequency.

The constants can be manipulated to create high absorption over various frequency ranges. The absorption of an incident electric field **E** or magnetic field **H** by MTMs is possible by controlling the resonance of ε and/or μ. The values of ε and μ can be obtained from the scattering parameters. To achieve low reflection from the MTM absorber, the impedance 11 as A(ω) = 1 − R(ω) because the transmission is diminished by the full ground on the bottom of the substrate. The retrieved effective permittivity and permeability, respectively. It is observed that the real parts of both parameters become zero at the absorptivity frequencies, which indicates zero reflectance. Also, the signs of the real parts of the permittivity and permeability are always different, which indicates that zero transmission occurs. The simulated impedance normalized by the free space impedance. The real part of the impedance is near unity at the dual resonance frequencies and simultaneously, the imaginary part crosses zero. Clearly, the reflectance is near zero at the corresponding frequencies because of impedance matching to free space. The simulated absorptivity and reflectance of a unit cell of the WMMA.

Peak absorptivities of approximately 96.7% and 97.2% were obtained at 9 GHz and GHz, respectively. Since the neighboring dual absorption peaks are close to each other, the lower valley absorptivity between the two absorption peaks is higher than 60%. Therefore, the proposed WMMA provides an enhanced bandwidth with a full width at half maximum (FWHM) of 15.7% at 9.5 GHz. The FWHM is defined as a range of frequency between the two neighboring 50% absorption points. It is used as a figure of merit for absorption bandwidth.



(a)



(b)

Fig. 1. Geometry of the proposed WMMA (a = 30 mm, b = 9.7 mm, w = 2 mm, g = 5 mm, and h = 1 mm): (a) magnified view of the unit cell and periodic structure, and the (b) side view indicating the direction of the incident waves.

As b increases, the high frequency absorptivity band shifts toward the low frequency side, while the low frequency absorptivity band is stationary. On the other hand, as c increases, the low frequency absorptivity band shifts toward the low frequency side, whereas the high frequency band is not changed. The requiredabsorptivity band can be attained by adjusting the design parameters. To demonstrate the operating principle of the proposed absorber structure at each resonance frequency, the simulated current distributions on the unit cell. The current is formed along the lager square rings at 9 GHz and along the smaller ones at 9.8 GHz. To verify the polarization behavior of the proposed WMMA, parametric analysis was performed under different polarization angles ranging from 0° to 90° with a 10° angular step size. Because of the symmetric structure, the WMMA has polarization-insensitive characteristics.

The proposed WMMA was also simulated for different oblique incident angles up to 60° under TE polarization. The simulated absorptivity indicates that the absorptivity gradually decreases after a 45° incident angle in the higher frequency band. Since the textile absorber can be deformed due to bending in a wearable situation, the effects of such phenomena on the absorber performance should be investigated. The unit cell of the WMMA attached on a circular cylinder with a radius of r. The antenna is bent around the cylinder along the yz-plane. The cylinder can be considered to be an arm, leg, forearm, or chest. Cylinders with various radii (r = 30 mm, 60 mm, and 100 mm) were designed by considering the curvatures of the wrist, forearm, and chest. A comparison of the simulated absorptivity characteristics for the various deformations. The frequency shift among various bent absorber situations is minimal. Because the absorptivity performance of the WMMA is insensitive to the bending effect, it can be applied to wearable applications.

IV. Measurements And Results

The proposed absorber was fabricated with conductive textile materials and non-conductive textile material. Square rings and the ground were made of Shieldex conductive metallized nylon fabric (Zell) with a thickness of 0.1 mm (surface resistance = 0.02 Ω/sq.). Felt with a thickness of 1 mm was used as the substrate. The fabricated WMMA prototype has 4 × 4 unit cells (9 × 9 square rings) with overall dimensions of 135 mm × 135 mm × 1 mm. To realize the bending effect, the bent absorber was attached on a truncated circular cylinder fixture fabricated using a 3D printer. To experimentally verify the performance of the WMMA for both the normal incidence and oblique incidence, monostatic and bistatic measurements were performed. A network analyzer (Rodhe&Shwarz ZVB20) was used to measure the S-parameters, and WR 90 standard gain horn antennas were used. Pyramidal-shaped microwave-absorbing materials surround the device under test (DUT) to eliminate the scattered waves from the edges. The reflectance measurement was calibrated using a copper plate identical in size to the WMMA sample. In the monostatic measurement, the sample was rotated from 0° to 90° in 30° steps to realize different polarization angles. In the bistatic measurement, two standard horn antennas are focused on the DUT with the same incident angles for absorptivity characteristics at different oblique incidence angles.

The absorptivity was calculated using the measured magnitudes of S11 and S21. The measured absorptivity characteristics of the WMMA for various polarization and incident angles. The measured results agree reasonably with the simulation results. At normal incidence, the measured results exhibit two absorptivity peaks of 90.1% at 9 GHz and 92.8% at 9.85 GHz. The FWHM of the measured WMMA is 18.9% at 9.475 GHz. As previously stated in the simulation results, the measured WMMA has a high absorptivity, regardless of the polarization angle (peak in the lower freq. band: 82.7%−90.1%, peak in the higher freq. band: 92.8%−97.3%). The measured FWHM gradually decreases as the incident angle increases and becomes less than 12.6% beyond an incident angle of 60°. The fabricated WMMA under various bending conditions has good absorption characteristics (absorptivity peak, FWHM: 97.4% and 29.5% for r = 60 mm and 91.7% and 25.7% for r = 100 mm) in the required frequency band. Discrepancies between simulation and measurement for the deformation effect may be due to the following two reasons. Firstly, the manufacturing error can be caused since the prototype of the WMMA was handmade. Secondly, a truncated dielectric cylinder fixture (which is not included in simulation) made by 3D printing (PLA; εr=2.4) used for realizing the bending effect in measurement could affect the measurement results. However, the overall absorption trend of measurement is very similar to simulation result.

V. Conclusions

In this letter, a WMMA for indoor radar clear applications is proposed. The absorber consists of square ring resonators, a backing ground plate, and a textile substrate with a 1 mm thickness. By using effective medium parameters, the EM behavior was clarified to describe the operating mechanism. For practical wearable utilization, the proposed WMMA was fabricated using a conductive textile and felt substrate. Also, the effect of absorber deformations such as bending was investigated. The simulated and measured results exhibit two absorptivity peaks above 90% and a FWHM of 18.9% at 9.475 GHz. Also, a high absorptivity was achieved regardless of the polarization angles of the EM waves and the bending effect. The proposed WMMA operates well as a broadband microwave absorber. It can easily be extended to an absorber design for multiband applications and can be integrated onto clothes. Thus, the proposed WMMA is a good candidate as an electromagnetic wave absorbing material for indoor radar clear applications.

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