# Supplementary Materials

The contents of the manuscript are mainly concerned with errors in several recent papers mainly concerning [ 37 – 44]

## 1 The problems in ref. [37, 39]

Equation (1) in [37] is repeated below:

$$A(\omega) = 1 - R(\omega) - T(\omega) \qquad (1)$$

For interface, $R(\omega)$ is not given correctly by Eq. (3) in [37] and needs to be replaced by Eq. (3′) shown below.

$$R(\omega) = |S_{11}|^2 = |R_M|^2 = |\frac{Z_L(\omega) - Z_0(\omega)}{Z_L(\omega) + Z_0(\omega)}|^2 \qquad (3')$$

However, $T(\omega)$ for interface is not "$T(\omega) = |S_{21}|^2 = 0$" as claimed

in [37]. The correct formula should be:

$$T(\omega) = |\frac{Z_0(\omega)}{Z_L(\omega)} S_{21}^2| = |\frac{Z_0(\omega)}{Z_L(\omega)} \gamma_M^2|$$
$$= |\frac{Z_0(\omega)}{Z_L(\omega)} [\frac{2Z_L(\omega)}{Z_L(\omega) + Z_0(\omega)}]^2|$$

Interface does not absorb microwaves at any value of $\omega$. This result can be checked by inserting the formulae of $R(\omega)$ and $T(\omega)$ given above into Eq. (1). Similar errors occur in ref. [39].

[39] Y. Prima Hardianto, R. Nur Iman, A. Hidayat, N. Mufti, N. Hidayat, S. Sunaryono, T. Amrillah, W. Ari Adi, A. Taufiq, A Facile Route Preparation of Fe3O4/MWCNT/ZnO/PANI Nanocomposite and its Characterization for Enhanced Microwave Absorption Properties, ChemistrySelect, 9 (2024) e202304748. (**see Eq. (5) in this paper**)

For metal backed film,

$$R(\omega) = |S_{11}|^2 = |\frac{Z_{in}(\omega) - Z_0(\omega)}{Z_{in}(\omega) + Z_0(\omega)}|^2 \qquad and \qquad T(\omega) = |S_{21}|^2 = 0$$

Thus, ref. [37] has confused film from interface. For more details, please see refs. [34, 45]

[34] Yue Liu, Michael G. B Drew,Ying Liu, A Theoretical Exploration of Impedance Matching Coefficients for Interfaces and Films, Applied Physics A, 2024, 130, 212, Please see Eq. 9 in this paper.

[45] Ying Liu, Yue Liu, Drew M.G.B, A re-evaluation of the mechanism of microwave absorption in film – Part 1: Energy conservation, **Mater. Chem. Phys. 2022, 290**,126576. Please see Eq. 12 - 14 in this paper.

## 2 The problems in ref. [38]

Equation (9) in ref. [38] is listed below as Eqs. (9-1) and (9-2):

$$1+\Phi=T \qquad (9\text{-}1)$$

$$\Phi=\frac{Z_{in}-Z_0}{Z_{in}-Z_0} \qquad (9\text{-}2)$$

But Eq. (9-1) should be used only for an interface and here $\Phi$ is $R_M$ for reflection coefficient of the interface and $T$ is $\gamma_M$ for the transmission coefficient of the interface. These conclusions can be checked by inserting the above formulae for $R_M$ and $\gamma_M$ into Eq. (9-1).

However, $Z_{in}$ in Eq. (9-2) is the input impedance of metal-backed film and $\Phi$ is $RL$ of the film instead of $R_M$ of the interface. Thus Eq. (9) in Ref. [38] is wrong.

## 3 The problems in refs. [40 - 44]

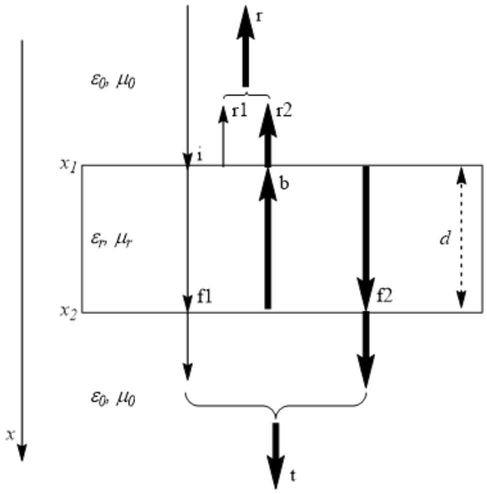
The problems mentioned in section "2.3 Common errors" such as in refs. [40 - 43] are also important since they are common problems which have continued to be expressed in publications though the problems have been identified previously. Thus, corrections are necessary to draw the attention of researchers.

[40] W. Andriyanti, M.A. Choir Hidayati Nur, D.L. Puspitarum, T. Sujitno, H. Suprihatin, S. Purwanto, E. Suharyadi, Microstructures, magnetic properties and microwave absorption of ion-implanted bismuth ferrite thin films, Physica B: Condensed Matter, 676 (2024) 415690. See Fig. 12 in this paper.

[41] D. Zuo, Y. Jia, J. Xu, J. Fu, High-Performance Microwave Absorption Materials: Theory, Fabrication, and Functionalization, Industrial & Engineering Chemistry Research, 62 (2023) 14791-14817. See Fig. 2c in this paper.

[42] A.A. Abu Sanad, M.N. Mahmud, M.F. Ain, M.A.B. Ahmad, N.Z.B. Yahaya, Z. Mohamad Ariff, Theory, Modeling, Measurement, and Testing of Electromagnetic Absorbers: A Review, physica status solidi (a), 221 (2024) 2300828. See page 6.

[43] M. Cao, C. Han, X. Wang, M. Zhang, Y. Zhang, J. Shu, H. Yang, X. Fang, J. Yuan, Graphene nanohybrids: excellent electromagnetic properties for the absorbing and shielding of electromagnetic waves, Journal of Materials Chemistry C, 6 (2018) 4586-4602. See Fig 7.



In refs. [40 - 42] it is stated that maximum absorption is achieved when both beams r1 and r2, shown in the above diagram (Fig. 1 in the manuscript), are vanished out. But as we have shown previously this is not true.

The false conclusion is a consequence of confusing film with material.
The absorptions of film and material are quite different.
The absorption of material originates from the attenuation power of material while the absorption of film originates from the wave cancellation of beams r1 and r2 (the phase difference of th two beams is π) rather than the simultaneous vanishing of the two beams. For more details, please see:

[27] Yue Liu, Ying Liu, Michael G. B Drew, Wave Mechanics of Microwave Absorption in Films - Distinguishing Film from Material, Journal of Magnetism and Magnetic Materials, 2024, 593, 171850

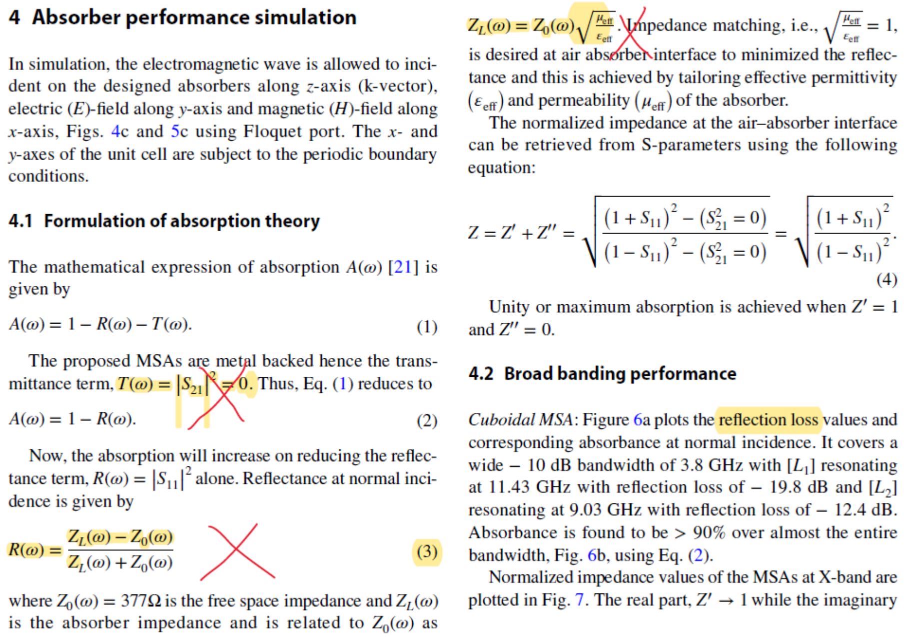
[33] Ying Liu, Yue Liu, Drew M.G.B, A re-evaluation of the mechanism of microwave absorption in film – Part 2: The Real mechanism, **Mater. Chem. Phys,. 2022**, 291, 126601.

[28] Ying Liu, Yi Ding, Yue Liu, Michael G. B. Drew. Unexpected Results in Microwave Absorption – Part 1: Different absorption mechanisms for metal-backed film and for material, **Surfaces and Interfaces**, 2023, 40, 103022

[29] Ying Liu; Xiangbin Yin; M. G. B. Drew; Yue Liu, Microwave absorption of film explained accurately by wave cancellation theory, **Physica B: Condensed Matter**, 2023, 666, 415108

## 4 Related issues quoted from some of the references

[37] S. Saikia, H. Saikia, N.S. Bhattacharyya, Revertible wideband hydrogel-based meta-structure absorber, Applied Physics A, 130 (2024) 189.



## 4 Absorber performance simulation

In simulation, the electromagnetic wave is allowed to incident on the designed absorbers along $z$-axis (k-vector), electric ($E$)-field along $y$-axis and magnetic ($H$)-field along $x$-axis, Figs. 4c and 5c using Floquet port. The $x$- and $y$-axes of the unit cell are subject to the periodic boundary conditions.

### 4.1 Formulation of absorption theory

The mathematical expression of absorption $A(\omega)$ [21] is given by

$$A(\omega) = 1 - R(\omega) - T(\omega). \tag{1}$$

The proposed MSAs are metal backed hence the transmittance term, $T(\omega) = |S_{21}|^2 = 0$. Thus, Eq. (1) reduces to

$$A(\omega) = 1 - R(\omega). \tag{2}$$

Now, the absorption will increase on reducing the reflectance term, $R(\omega) = |S_{11}|^2$ alone. Reflectance at normal incidence is given by

$$R(\omega) = \frac{Z_L(\omega) - Z_0(\omega)}{Z_L(\omega) + Z_0(\omega)} \tag{3}$$

where $Z_0(\omega) = 377\Omega$ is the free space impedance and $Z_L(\omega)$ is the absorber impedance and is related to $Z_0(\omega)$ as $Z_L(\omega) = Z_0(\omega)\sqrt{\frac{\mu_{\text{eff}}}{\varepsilon_{\text{eff}}}}$. Impedance matching, i.e., $\sqrt{\frac{\mu_{\text{eff}}}{\varepsilon_{\text{eff}}}} = 1$, is desired at air absorber interface to minimized the reflectance and this is achieved by tailoring effective permittivity $(\varepsilon_{\text{eff}})$ and permeability $(\mu_{\text{eff}})$ of the absorber.

The normalized impedance at the air–absorber interface can be retrieved from S-parameters using the following equation:

$$Z = Z' + Z'' = \sqrt{\frac{(1+S_{11})^2 - (S_{21}^2 = 0)}{(1-S_{11})^2 - (S_{21}^2 = 0)}} = \sqrt{\frac{(1+S_{11})^2}{(1-S_{11})^2}}. \tag{4}$$

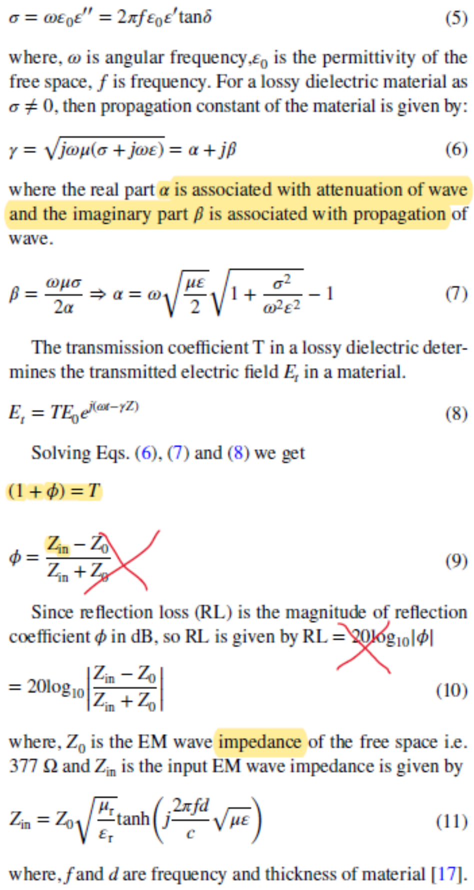
Unity or maximum absorption is achieved when $Z' = 1$ and $Z'' = 0$.

### 4.2 Broad banding performance

*Cuboidal MSA*: Figure 6a plots the reflection loss values and corresponding absorbance at normal incidence. It covers a wide $-$ 10 dB bandwidth of 3.8 GHz with $[L_1]$ resonating at 11.43 GHz with reflection loss of $-$ 19.8 dB and $[L_2]$ resonating at 9.03 GHz with reflection loss of $-$ 12.4 dB. Absorbance is found to be $>$ 90% over almost the entire bandwidth, Fig. 6b, using Eq. (2).

Normalized impedance values of the MSAs at X-band are plotted in Fig. 7. The real part, $Z' \rightarrow 1$ while the imaginary

[38] P.P. Singh, A.K. Dash, G. Nath, Dielectric characterization analysis of natural fiber based hybrid composite for microwave absorption in X-band frequency, Applied Physics A, 130 (2024) 171.



$$\sigma = \omega\varepsilon_0\varepsilon'' = 2\pi f\varepsilon_0\varepsilon'\tan\delta \tag{5}$$

where, $\omega$ is angular frequency,$\varepsilon_0$ is the permittivity of the free space, $f$ is frequency. For a lossy dielectric material as $\sigma \neq 0$, then propagation constant of the material is given by:

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} = \alpha + j\beta \tag{6}$$

where the real part $\alpha$ is associated with attenuation of wave and the imaginary part $\beta$ is associated with propagation of wave.

$$\beta = \frac{\omega\mu\sigma}{2\alpha} \Rightarrow \alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{1 + \frac{\sigma^2}{\omega^2\varepsilon^2}} - 1 \tag{7}$$

The transmission coefficient T in a lossy dielectric determines the transmitted electric field $E_t$ in a material.

$$E_t = TE_0e^{j(\omega t - \gamma Z)} \tag{8}$$

Solving Eqs. (6), (7) and (8) we get

$$(1 + \phi) = T$$

$$\phi = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} \tag{9}$$

Since reflection loss (RL) is the magnitude of reflection coefficient $\phi$ in dB, so RL is given by RL $= 20\log_{10}|\phi|$

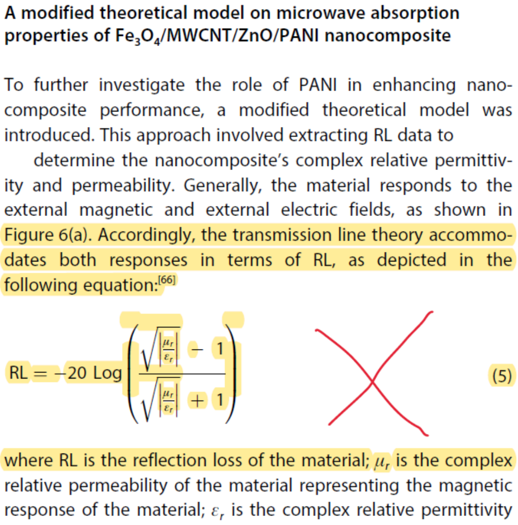
$$= 20\log_{10}\left|\frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0}\right| \tag{10}$$

where, $Z_0$ is the EM wave impedance of the free space i.e. 377 $\Omega$ and $Z_{\text{in}}$ is the input EM wave impedance is given by

$$Z_{\text{in}} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi fd}{c}\sqrt{\mu\varepsilon}\right) \tag{11}$$

where, $f$ and $d$ are frequency and thickness of material [17].

[39] Y. Prima Hardianto, R. Nur Iman, A. Hidayat, N. Mufti, N. Hidayat, S. Sunaryono, T. Amrillah, W. Ari Adi, A. Taufiq, A Facile Route Preparation of Fe3O4/MWCNT/ZnO/PANI Nanocomposite and its Characterization for Enhanced Microwave Absorption Properties, ChemistrySelect, 9 (2024) e202304748.



**A modified theoretical model on microwave absorption properties of $Fe_3O_4$/MWCNT/ZnO/PANI nanocomposite**

To further investigate the role of PANI in enhancing nanocomposite performance, a modified theoretical model was introduced. This approach involved extracting RL data to

determine the nanocomposite's complex relative permittivity and permeability. Generally, the material responds to the external magnetic and external electric fields, as shown in Figure 6(a). Accordingly, the transmission line theory accommodates both responses in terms of RL, as depicted in the following equation:[66]

$$\mathrm{RL} = -20\ \mathrm{Log}\left(\frac{\sqrt{\left|\frac{\mu_r}{\varepsilon_r}\right|} - 1}{\sqrt{\left|\frac{\mu_r}{\varepsilon_r}\right|} + 1}\right) \quad (5)$$

where RL is the reflection loss of the material; $\mu_r$ is the complex relative permeability of the material representing the magnetic response of the material; $\varepsilon_r$ is the complex relative permittivity

[40] W. Andriyanti, M.A. Choir Hidayati Nur, D.L. Puspitarum, T. Sujitno, H. Suprihatin, S. Purwanto, E. Suharyadi, Microstructures, magnetic properties and microwave absorption of ion-implanted bismuth ferrite thin films, Physica B: Condensed Matter, 676 (2024) 415690.

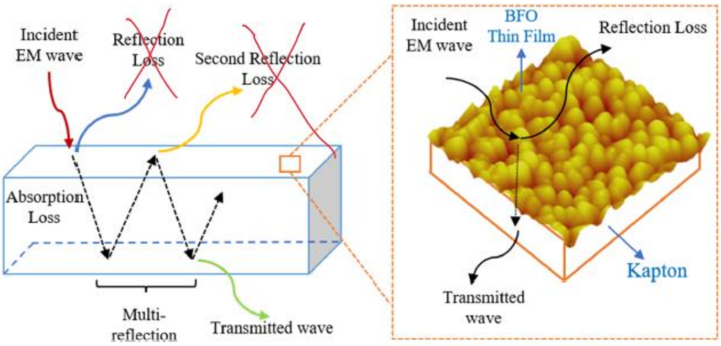
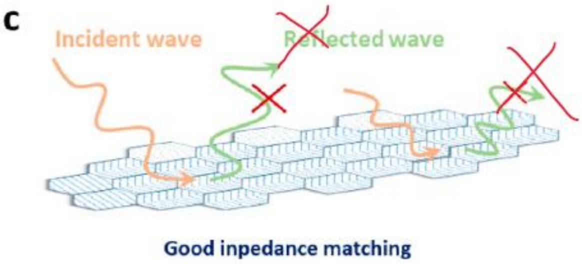
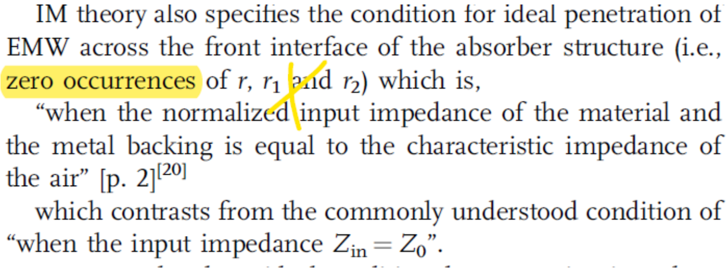


Fig. 12. Schematic representation of the EM absorber mechanism.

[41] D. Zuo, Y. Jia, J. Xu, J. Fu, High-Performance Microwave Absorption Materials: Theory, Fabrication, and Functionalization, Industrial & Engineering Chemistry Research, 62 (2023) 14791-14817. Fig. 2c



[42] A.A. Abu Sanad, M.N. Mahmud, M.F. Ain, M.A.B. Ahmad, N.Z.B. Yahaya, Z. Mohamad Ariff, Theory, Modeling, Measurement, and Testing of Electromagnetic Absorbers: A Review, physica status solidi (a), 221 (2024) 2300828.

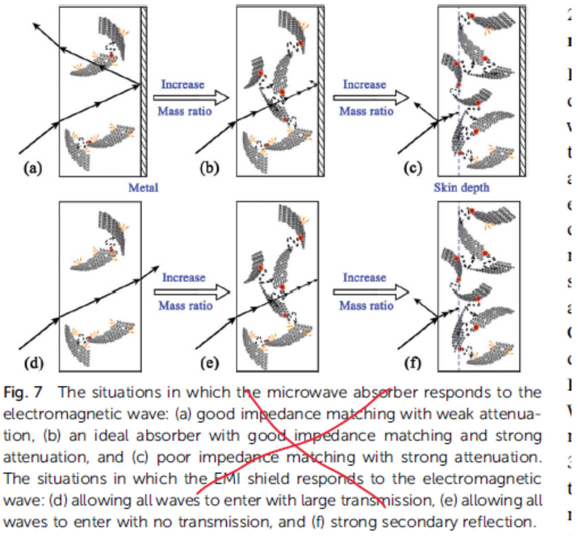


IM theory also specifies the condition for ideal penetration of EMW across the front interface of the absorber structure (i.e., zero occurrences of $r$, $r_1$ ~~and~~ $r_2$) which is,

"when the normalized input impedance of the material and the metal backing is equal to the characteristic impedance of the air" [p. 2][20]

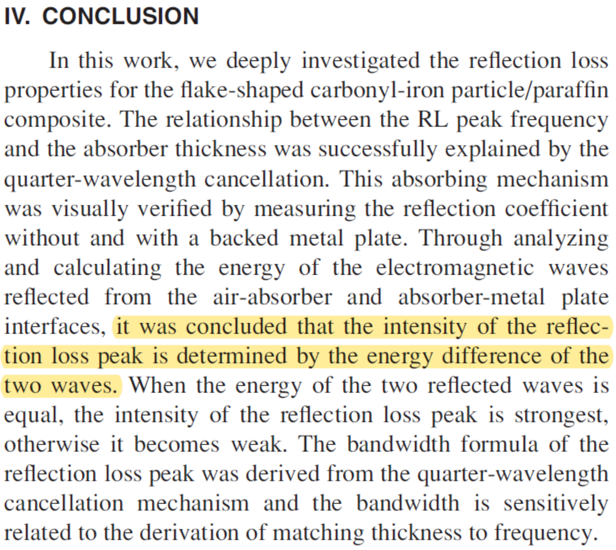
which contrasts from the commonly understood condition of "when the input impedance $Z_{in} = Z_0$".

[43] M. Cao, C. Han, X. Wang, M. Zhang, Y. Zhang, J. Shu, H. Yang, X. Fang, J. Yuan, Graphene nanohybrids: excellent electromagnetic properties for the absorbing and shielding of electromagnetic waves, Journal of Materials Chemistry C, 6 (2018) 4586-4602.



~~**Fig. 7** The situations in which the microwave absorber responds to the electromagnetic wave: (a) good impedance matching with weak attenuation, (b) an ideal absorber with good impedance matching and strong attenuation, and (c) poor impedance matching with strong attenuation. The situations in which the EMI shield responds to the electromagnetic wave: (d) allowing all waves to enter with large transmission, (e) allowing all waves to enter with no transmission, and (f) strong secondary reflection.~~

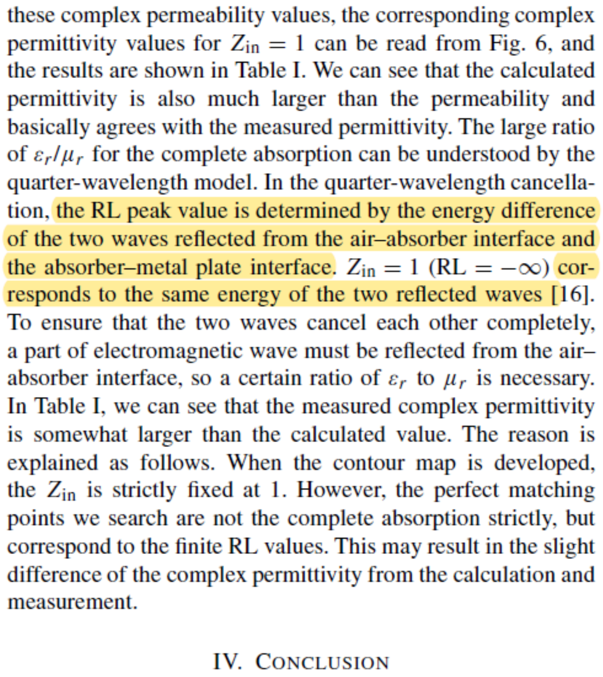
[44] T. Wang, R. Han, G. Tan, J. Wei, L. Qiao, F. Li, Reflection loss mechanism of single layer absorber for flake-shaped carbonyl-iron particle composite, Journal of Applied Physics, 112 (2012) 104903.



### IV. CONCLUSION

In this work, we deeply investigated the reflection loss properties for the flake-shaped carbonyl-iron particle/paraffin composite. The relationship between the RL peak frequency and the absorber thickness was successfully explained by the quarter-wavelength cancellation. This absorbing mechanism was visually verified by measuring the reflection coefficient without and with a backed metal plate. Through analyzing and calculating the energy of the electromagnetic waves reflected from the air-absorber and absorber-metal plate interfaces, it was concluded that the intensity of the reflection loss peak is determined by the energy difference of the two waves. When the energy of the two reflected waves is equal, the intensity of the reflection loss peak is strongest, otherwise it becomes weak. The bandwidth formula of the reflection loss peak was derived from the quarter-wavelength cancellation mechanism and the bandwidth is sensitively related to the derivation of matching thickness to frequency.

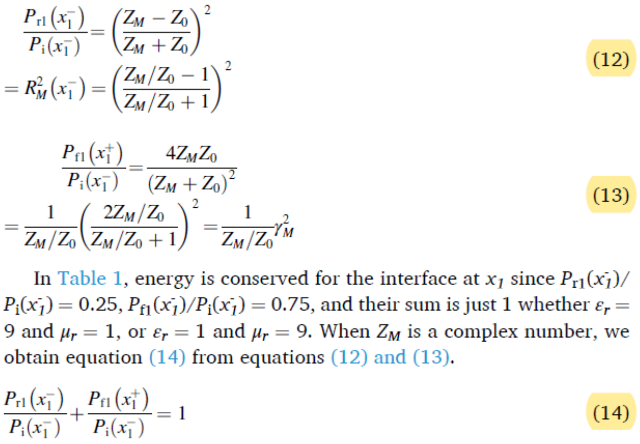
[61] T. Wang, H. Wang, G. Tan, L. Wang, L. Qiao, The Relationship of Permeability and Permittivity at the Perfect Matching Point of Electromagnetic Wave Absorption for the Absorber Filled by Metallic Magnetic Particles, IEEE Transactions on Magnetics, 51 (2015) 2800405.



these complex permeability values, the corresponding complex permittivity values for $Z_{\text{in}} = 1$ can be read from Fig. 6, and the results are shown in Table I. We can see that the calculated permittivity is also much larger than the permeability and basically agrees with the measured permittivity. The large ratio of $\varepsilon_r/\mu_r$ for the complete absorption can be understood by the quarter-wavelength model. In the quarter-wavelength cancellation, the RL peak value is determined by the energy difference of the two waves reflected from the air–absorber interface and the absorber–metal plate interface. $Z_{\text{in}} = 1$ (RL $= -\infty$) corresponds to the same energy of the two reflected waves [16]. To ensure that the two waves cancel each other completely, a part of electromagnetic wave must be reflected from the air–absorber interface, so a certain ratio of $\varepsilon_r$ to $\mu_r$ is necessary. In Table I, we can see that the measured complex permittivity is somewhat larger than the calculated value. The reason is explained as follows. When the contour map is developed, the $Z_{\text{in}}$ is strictly fixed at 1. However, the perfect matching points we search are not the complete absorption strictly, but correspond to the finite RL values. This may result in the slight difference of the complex permittivity from the calculation and measurement.

### IV. CONCLUSION

[45] Y. Liu, Y. Liu, M.G.B. Drew, A Re-evaluation of the mechanism of microwave absorption in film – Part 1: Energy conservation, Materials Chemistry and Physics, 290 (2022) 126576.



$$\frac{P_{\text{r1}}(x_1^-)}{P_{\text{i}}(x_1^-)} = \left(\frac{Z_M - Z_0}{Z_M + Z_0}\right)^2 = R_M^2(x_1^-) = \left(\frac{Z_M/Z_0 - 1}{Z_M/Z_0 + 1}\right)^2 \tag{12}$$

$$\frac{P_{\text{f1}}(x_1^+)}{P_{\text{i}}(x_1^-)} = \frac{4Z_M Z_0}{(Z_M + Z_0)^2} = \frac{1}{Z_M/Z_0}\left(\frac{2Z_M/Z_0}{Z_M/Z_0 + 1}\right)^2 = \frac{1}{Z_M/Z_0}\gamma_M^2 \tag{13}$$

In Table 1, energy is conserved for the interface at $x_1$ since $P_{\text{r1}}(x_1^-)/P_{\text{i}}(x_1^-) = 0.25$, $P_{\text{f1}}(x_1^-)/P_{\text{i}}(x_1^-) = 0.75$, and their sum is just 1 whether $\varepsilon_r = 9$ and $\mu_r = 1$, or $\varepsilon_r = 1$ and $\mu_r = 9$. When $Z_M$ is a complex number, we obtain equation (14) from equations (12) and (13).

$$\frac{P_{\text{r1}}(x_1^-)}{P_{\text{i}}(x_1^-)} + \frac{P_{\text{f1}}(x_1^+)}{P_{\text{i}}(x_1^-)} = 1 \tag{14}$$

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