Performance enhancement of cut–wire–based metamaterial absorbers

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Abstract

This study shows how performance of conductively lossy cut–wire–based (CW–based) metamaterial absorbers can be effectively improved with minor geometrical modifications. First, the reason for absorptance reductions found in short CW pairs is explained. Two approaches, i.e. restoration of the geometrical symmetry and increase of the CW width, are then used for the enhancement of the absorbing behaviour.

1. Introduction

Metamaterial absorbers [1] have some advantages over traditional absorbers. For example, the physical thickness can be markedly reduced [2]. Also, it has been reported in our previous work [3] that absorptance characteristics become more customisable for arbitrary polarisation in multiple bands by using carefully designed cut–wire (CW) pairs deployed near to a perfect electric conductor (PEC) wall. For instance, use of conductively lossy three CW pairs led to three absorptance peaks, and thereby broadband absorption was obtained for both polarisations. In addition, deploying lossless CW pairs enabled also reduction of the absorptance performance. In this paper the enhancement of this performance is numerically studied.

2. Method

The basic configuration of the CW metamaterial absorbers studied here (in this study we use *metamaterial* to describe this structure partly because of consistency with past related works e.g. [4]) was described in our previous work [3]. The brief introduction to the models is found from the left of Fig. 1, where four CW pairs were deployed close to a PEC wall with an incident electric field (x axis) and magnetic field (y axis). In the following simulations some of the CWs were removed and the CW(s) left was/were modified for the improvement to the absorption. For simplicity the relative permittivity and permeability of the substrate were set to the values of vacuum. The CWs had ohmic loss as the only source of absorption. In this paper the absorptance A was calculated from $A = 1 - |\Gamma_{xx}|^2 - |\Gamma_{yx}|^2$, where $|\Gamma_{xx}|$ and $|\Gamma_{yx}|$ are the magnitudes of, respectively, the x–polarised and y–polarised reflection coefficients from the x–polarised incidence. More details of the calculation conditions are found in [3, 5]

3. Calculation results

The eight figures on the right of Fig. 1 show absorptance of different lengths of one CW (top) or one CW pair (bottom). The CW length was changed from 5.1 (left) to 3.3 mm (right) in 0.6 mm steps, and the vertical and horizontal axes respectively represent the frequency (GHz) and sheet resistance ($\Omega\Box^{-1}$). As found from these results, the absorptance peak was shifted to higher frequency by decreasing the CW length(s). It also turned out that the use of the short CW pairs resulted in relatively weak maximum absorptances (e.g. $\sim$ 0.95 for 3.3 mm CW pair).

These reductions are assumed to be due to the geometrical asymmetry. The left and centre of Fig. 2 show the conduction current profile of, respectively, the 5.1 mm and 3.3 mm CW pair of the metamaterial absorber at each absorptance peak frequency. For the 5.1 mm CW pair, relatively weak conduction current was found in the CW deployed along the incident magnetic field (i.e. y axis). However, this horizontal current became more significant in the 3.3 mm CW pair. For the longer CW structure, the

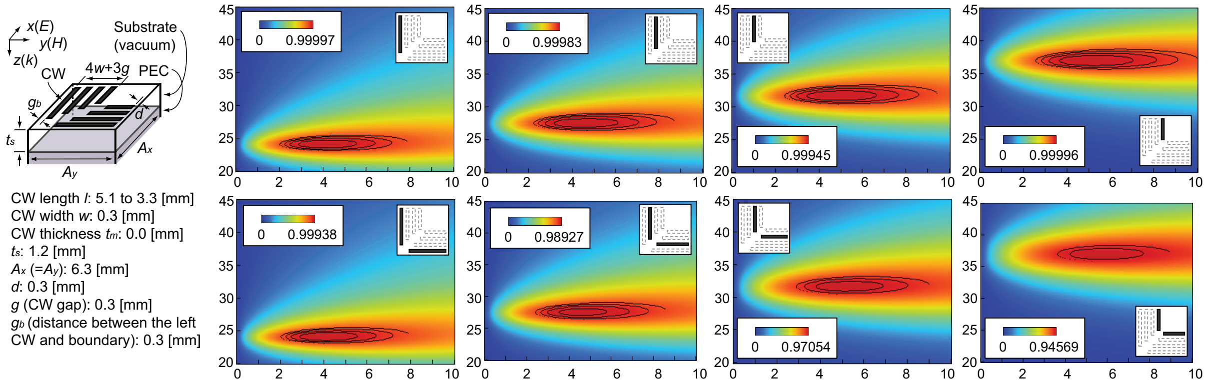

Fig. 1: Example of calculation model (left) and absorptance of various CW metamaterial absorber configurations for one polarisation (top) and both polarisations (bottom). In the calculation results the CW length(s) was/were changed from 5.1 to 3.3 mm in 0.6 mm steps. The horizontal and vertical axes respectively represent the sheet resistance ($\Omega\square^{-1}$) and frequency (GHz). The contour lines for absorptance are marked from 0.9 in 0.025 steps.

horizontal CWs (including the ones in the next periodic units) exist almost symmetrically toward the vertical CW parallel to x axis. However, as the CW length decreases, this symmetry is gradually broken with the configuration shown in the left of Fig. 1 and the whole shape approaches a cut–L–shape. As shown in the right of Fig. 2 the resonance induced by the L–shape–like structure changes the polarisation of the reflected wave and interferes strong absorptance.

Restoring the total geometrical symmetry (i.e. the distance between the 3.3 mm CW pair) increased the absorptance value, which is summarised in the top left of Fig. 3. It is found from a simple calculation that this symmetry is satisfied for the CW pair whose CW length l is $l = A_y - w - 2(g_b + d)$ (see the left of Fig. 1 for each symbol). Note that this symmetry is broken again, when an additional CW pair is used for another absorptance peak, so that slight decrease happens. This can be confirmed from the bottom left of Fig. 3, where a 5.1 mm CW pair (4.0 $\Omega\square^{-1}$) was additionally deployed in the structure used in the top left of Fig. 3. The optimised value is compared to the result of the 5.1 and 3.3 mm CW pair absorber without the distance modification in the centre of Fig. 3. This figure shows the enhancement of the absorptance. Also, this figure describes that in this approach the improved characteristics tend to be narrow band. This is assumed to be due to the inductive coupling with the 5.1 mm CW, which results to an increase of the quality (Q) factor ($= \sqrt{L/C}/R$, where L, C and R are respectively the effective total inductance, capacitance and resistance), i.e. the decrease of the half band width.

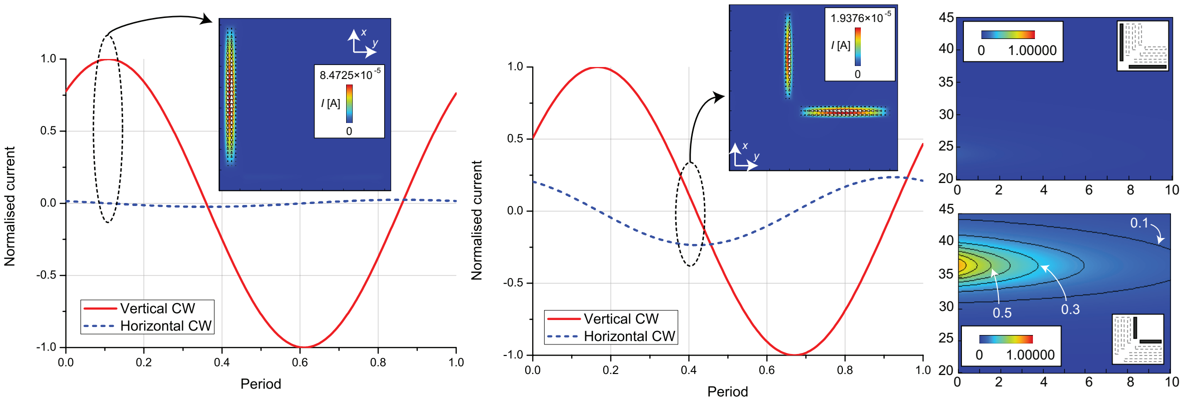

Fig. 2: Conduction current in 5.1 mm CW pair (left) and 3.3 mm CW pair (centre) in time domain. The surface current distribution can be confirmed from each inset. The right figures show the y–polarised reflection coefficient magnitude $|\Gamma_{yx}|$ of 5.1 mm CW pair (top) and 3.3 mm CW pair (bottom).

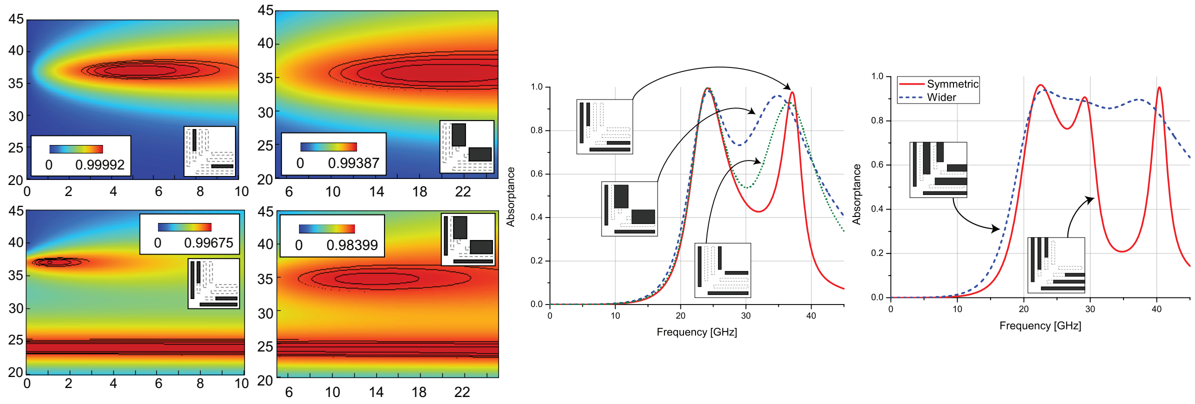

Fig. 3: Improvement of maximum absorptance of 3.3 mm CW pair by restoration of the geometrical symmetry (top left) and increase of the CW width (top centre). In each bottom figure a 5.1 mm CW pair $(4.0\ \Omega\square^{-1})$ was added for extra absorptance peak. The centre figure compares the improved absorptances of 5.1 and 3.3 mm CW pairs to the result before using these modifications. The right figure shows the results applying these two geometrical modifications to three CW pairs of 5.4, 4.2 and 3.0 mm. For the improvement method by widening the CW width, only the two short CW pairs had 0.6 mm width (double) and instead of maximising each absorptance peak, the dips between the three peaks were reduced so that the strong absorptance is maintained at broad range.

Another solution for the absorptance reduction may be increasing the CW width. This geometrical change enhances the capacitive coupling with the image of the CW beyond the PEC wall. For the CW absorbers the mutual capacitance is a dominant factor for the determination of the total capacitance [5]. Therefore, this increase can contribute to the decrease of the Q factor, thus the increase of the band width. This improvement can be seen from the next to the top left of Fig. 3, where the absorptance of the quadruple width of the 3.3 mm CW pair was calculated, resulting in the increase of the absorptance and band width. This broadband behaviour was still maintained, when the 5.1 mm CW pair was deployed as shown in the bottom figure. Also, the comparison of the band width to the first approach (the restoration of the symmetry) can be confirmed from the centre of Fig. 3. These band width trends for the two geometrical modifications were demonstrated in the three CW pair case (5.4, 4.2 and 3.0 mm CW pairs) as shown in the right of Fig. 3.

The simulated CW metamaterial absorbers have some advantages over traditional absorbers. For example, the substrate thickness is shorter than a quarter of the wavelength at operating frequencies. Using multiple resonant CW elements may produce absorption as well as enhancement at specified frequency. Moreover, the simulated structures can combine other types of CW elements to manipulate not only absorption but also other scattering parameters in specified frequency bands [6].

4. Conclusion

Performance enhancement of CW metamaterial absorbers has been numerically studied. Firstly the reason for absorptance reductions found in short CW pairs was investigated from the conduction current profile. Two approaches for improvement, i.e. restoration of the geometrical observations of symmetry and increase of the CW width, were introduced and found to enhance the absorptance value. In the first case, the improved absorbing performance tended to be narrow band, while in the second case broad band. This study contributes to better customised design of CW–based metamaterial absorbers.

References

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