Analysis and Design of Microstrip Antenna Array Using Interdigital Capacitor with CRLH-TL Ground Plane for Multiband Applications

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Abstract—Control and manipulation of electromagnetic waves is at the heart of many industries from wireless communication, Internet and optical data storage to imaging and displays. Progress in these technologies places challenging demands on material properties and therefore structured electromagnetic materials. Metamaterials are a special class of structured materials. Patterning on the sub-wavelength scale allows precise engineering of their electromagnetic properties over a range going far beyond natural media. In this paper, two elements microstrip antenna array using interdigital capacitor with composite right / left handed transmission line (CRLH-TL) ground plane has been introduced. The analysis and design are done by a commercial software. The good agreement between the theoretical expectation and the simulation results is observed. Finally, the proposed optimum multiband microstrip antenna array design structure has been fabricated and the measured S-parameters of the proposed structure can be analyzed with network analyzer to demonstrate the excellent performance and meet the requirement for multiband applications.

Index Terms—microstrip antenna array, interdigital capacitor, CRLH-TL, multiband applications.

I. INTRODUCTION

Metamaterials is a rapidly evolving field of research that covers a vast range of artificial structures and electromagnetic properties. Resulting from this, there is no universally accepted definition of what is meant by a metamaterial [1-5]. It is generally agreed that metamaterials are artificial media with unusual properties not found in their constituent materials. Metamaterials are periodic arrays of artificial structures with a pitch smaller than the wavelength of excitation. Due to their sub-wavelength periodicity, metamaterials do not diffract. Therefore they appear homogeneous to an incident wave and can be described in terms of effective or averaged parameters that are controlled by the geometry of the metamaterial unit cell and its constituent materials. In analogy to natural materials, the elementary building block of a metamaterial, i.e., the metamaterial unit cell is often referred to as a metamolecule. The CRLH metamaterials has been applied to some novel microwave devices [6-9]. The properties of the CRLH metamaterials can be analyzed by the transmission line theory. The analysis and design of the proposed microstrip antenna array and its components by the HFSS simulator [10] based on the finite element method (FEM) has been introduced. The good agreement between the simulation and measured results are observed and the radiation characteristics have been illustrated the performance. Finally, the proposed design structure has been fabricated and the measured S-parameters in dB versus frequency in GHz, of the proposed antenna array structure can be analyzed with network analyzer.

II. SINGLE ELEMENT DESIGN STRUCTURE

A. Interdigital Capacitor

The parasitic resonances caused by the multi-conductor nature of the interdigital capacitor can occur within the desired operational band. The self-resonance frequencies of the interdigital capacitor decrease as the capacitance increases which means an increase in the capacitor’s length if the number of fingers is constant [11-12]. To avoid this problem, parametric studies were carried out to achieve optimum and compact interdigital capacitor structure. The proposed interdigital capacitor structure has been designed using Rogers duroid 6006 substrate with ($\varepsilon_r = 6.15$, $\tan\delta = 0.0019$) and thickness of 0.635 mm at center frequency, $f_c = 2.4\pm0.1$ GHz, as shown in Fig. 1. The characteristics of different varieties for the proposed structure are obtained and analyzed using HFSS simulator [10] to demonstrate the performance. The analysis of interdigital capacitor with respect to the spacing distance between fingers, S, has been shown in Fig. 2. The proposed interdigital capacitor has finger length, $L = \lambda/8$, finger width, $W = 0.94$ mm, and number of fingers, $N = 8$.

![Fig. 1. Microstrip interdigital capacitor design structure.](image-url)
Fig. 2. The proposed interdigital capacitor varieties simulation results (the spacing distance between fingers, \( S \), in mm).

From Fig. 2, it was found that the proposed interdigital capacitor structures have been achieved multiband operational frequencies. In general, all proposed structures concept can be applied to any microwave component to enhance the performance.

B. Antenna Element without CRLH-TL Ground Plane

Fig. 3. The top view and mechanical parameters of the proposed antenna element without CRLH-TL ground plane.

The multiband microstrip patch antenna element with interdigital capacitor has been introduced and analyzed. The proposed antenna is designed on Rogers duroid 6006 substrate. The interdigital capacitors and stub inductors provide the LH and also the RH contributions [12-13]. The top view of the proposed unit cell and its mechanical parameters in mm are shown in Fig. 5. The characteristics of the proposed structure are obtained and analyzed using HFSS simulator to demonstrate the performance, as shown in Fig. 6.

Fig. 4. The simulated \( S_{11} \) [dB] and surface current density, \( J_{\text{sur}} \), of the proposed antenna element without CRLH-TL ground plane.

From Fig. 4, it was found that the proposed antenna element with interdigital capacitor has multiband frequencies with minimum surface current density at the upper portion of the proposed antenna element above the interdigital capacitor. For the best performance of the proposed antenna, the effect of CRLH-TL unit cell on the ground plane must be understood.

C. Antenna Element with CRLH-TL Ground Plane

The proposed multiband CRLH-TL unit cell structure has been designed using Rogers duroid 6006 substrate. The interdigital capacitors and stub inductors provide the LH and also the RH contributions [12-13]. The top view of the proposed unit cell and its mechanical parameters in mm are shown in Fig. 5. The characteristics of the proposed structure are obtained and analyzed using HFSS simulator to demonstrate the performance, as shown in Fig. 6.

Fig. 5. The proposed CRLH-TL Unit cell structure.
The proposed CRLH-TL unit cell simulation results.

The simulated result based on the full wave (FEM) has been shown in Fig. 6 to illustrate the performance of the proposed CRLH-TL unit cell structure. The proposed CRLH-TL structure has been achieved multiband operational frequencies. The multiband microstrip patch antenna element using interdigital capacitor with CRLH-TL ground plane has been introduced and analyzed. The proposed antenna is designed on Rogers duroid 6006 substrate.

Fig. 6. The top, bottom views and mechanical parameters in mm for the proposed modified antenna element.

From Fig. 8, it was found that the proposed antenna element using interdigital capacitor with CRLH-TL unit cell ground plane has more multiband frequencies with minimum surface current density at the lower portion of the proposed antenna element below the interdigital capacitor. To enhance the performance, the proposed antenna has been modified using slots arrangement and matching feed network, as shown in Fig. 9.

Fig. 9. The top, bottom views and mechanical parameters in mm for the proposed modified antenna element.

Thus, simulation was conducted to check the variations of the return loss against the proposed modified antenna element, as shown in Fig. 10.

Fig. 10. The simulated $S_{11}$ [dB] and surface current density, $J_{sur}$, of the proposed modified antenna element with CRLH-TL ground plane.

From Fig. 10, it was found that the proposed modified antenna element has multiband frequencies using slots arrangement and matching feed network whose positions have been chosen after carrying out different parametric analysis.
III. ANTENNA ARRAY DESIGN STRUCTURE

The Wilkinson power divider is such a network, with the useful property of being lossless when the output ports are matched; that is, only reflected power is dissipated [14]. It can be made with arbitrary power division with equally split 3 dB each port. The Wilkinson power divider, as feeding network is designed with matching impedance transformer to adapt the performance, as shown in Fig. 11. Numerical simulation based on the finite element method (FEM) is used to obtain the characteristics of the proposed antenna array feeding structure. Fig. 12 shows the simulated S-parameters in dB versus frequency, $f$, in GHz of the proposed array feeding.

For narrowband antenna arrays, the element spacing should be less than one wavelength $\lambda$ to avoid grating lobes and also to minimize the fading correlation and mutual coupling between elements. But in multiband antenna arrays, which operate at different frequency bandwidths, it is not obvious how the element spacing should be in terms of wavelengths to avoid grating lobes in the most frequency spans [15-17]. Applying parametric studies can be a good solution to satisfy best antenna array performance with compact size. The best choice of the proposed antenna array structure has been introduced in Fig. 13 while Fig. 14 shows the return loss in dB versus frequency in GHz of the proposed antenna array structure to demonstrate the performance.

From Fig. 14, it was found that the proposed antenna array has multiband frequencies with minimum $S_{11} \leq -6$ or -10 dB. The radiation characteristics of the final design, for a sample of frequencies, such as far field 3D polar plot, gain and radiation field patterns are shown in Fig. 15.

![Fig. 11. The proposed array antenna feeding structure and its mechanical parameters in mm.](image1)

![Fig. 12. The simulated S-parameters [dB] of the proposed array antenna feeding.](image2)

![Fig. 13. The top, bottom views and mechanical parameters in mm of the proposed antenna array.](image3)

![Fig. 14. The simulated $S_{11}$ [dB] versus $f$[GHz] of the proposed antenna array.](image4)

From Fig. 14, it was found that the proposed antenna array has multiband frequencies with minimum $S_{11} \leq -6$ or -10 dB. The radiation characteristics of the final design, for a sample of frequencies, such as far field 3D polar plot, gain and radiation field patterns are shown in Fig. 15.

![Fig. 15. The radiation characteristics of the proposed antenna array at the frequencies 2.11 GHz (left) and 3.67 GHz (right).](image5)

(a) 3D polar Far field.

(b) 3D polar Gain.

(c) Radiation field patterns.
IV. THE ANTENNA ARRAY EXPERIMENTAL MEASUREMENTS

Photograph of the proposed antenna array structure has been fabricated using printed circuit technology at antenna laboratory, as shown in Fig. 16.

Fig. 16. The fabricated proposed antenna array at laboratory.

The measured $S_{11}$ in dB and VSWR of the proposed structure can be analyzed with network analyzer HP8719ES, as shown in Fig. 17.

![ measured S11 and VSWR of the proposed array ]

From Fig. 17, it is clear that the measurement results have multiband frequencies in the frequency range 1-10 GHz. The agreement between the simulated and measured results has achieved with frequency band shifted due to the proposed structure fabrication accuracy and complexity. This bandwidth enhancement is due to the balanced behavior of the structure, which has been established by the interpretation of the dispersion characteristics and retrieved effective $e$ and $\mu$ of the interdigital capacitor and CRLH-TL unit cell.

V. CONCLUSIONS

A type of transmission-line resonator based on the concept of composite right/left-handed transmission lines (CRLH-TLs) has been introduced. Generally, resonant frequencies of conventional transmission-line resonators are determined by the length of the lines, whereas those of the CRLH-TLs are independent of the length itself, but are determined by the configuration of the unit cells. The proposed multiband microstrip antenna array using interdigital capacitor with CRLH-TL ground plane has been introduced and analyzed to meet the requirements for multiband applications. A robust analysis has been achieved to demonstrate the practicality of CRLH-TL structures to enhance the performance of the proposed antenna array. The approach of interdigital capacitor and CRLH-TL offer an efficient alternative to the original physical with respect to size and resonant frequency. The proposed design has been fabricated and the S-parameters measured. The measured and simulated characteristics have been introduced to illustrate the proposed microstrip antenna array performance to meet the requirements for desired multiband applications.

REFERENCES