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A Gain-Enhanced 60 GHz Yagi Antenna based on Zero-Index Metamaterial

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***Abstract*-Metamaterial (MTM) unit-cells with a zero refractive index was developed, characterized and employed for gain enhancement of a Yagi antenna operating at 60 GHz. The unique property of the MTM gathers the wave radiated from the antenna and collimates it towards the normal direction when used as director. The proposed design provides a gain enhancement of 2.3 dB when the nearing zero-refractive-index MTM director is utilized. Simulation results show that the conventional Yagi antenna's director replaced by the proposed MTM directors can achieve a maximum gain of 8.18 dBi at 60 GHz.**

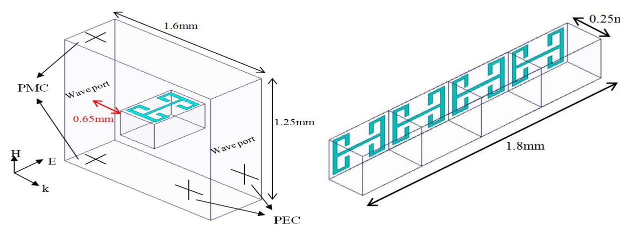
I. INTRODUCTION

Veselago [1] explored in 1968 various electromagnetic properties of the MTMs which did not exist in nature with both negative permeability and permittivity. The first produced MTMs was only achieved in 2001, when Shelby et al. [2] proposed a structure based on split-ring resonator (SRR) and thin wire (TW) that presented a behavior resembled a double negative material. Since then MTM has become a popular subject. The computation method of retrieving the constitutive effective parameter, including permittivity, permeability and refractive index of MTM was discussed [3] and nearing-zero index of refraction was used to enhance the gain of antenna [4]. Zero or low index materials (ZIM/LIM) are materials for which the index of refraction is less than unity. According to Snell's law of refraction, a material with an index of refraction less than unity will focus incident waves over a wide range of incidence angles into a small range of refracted angles (nearly parallel to the surface normal).

In this paper, we propose a novel Yagi antenna which loaded with the zero-index MTM directors. From the simulation results, it can be seen that the gain enhanced by replacing conventional metal strip directors for Yagi antennas with nearing zero-index MTM director.

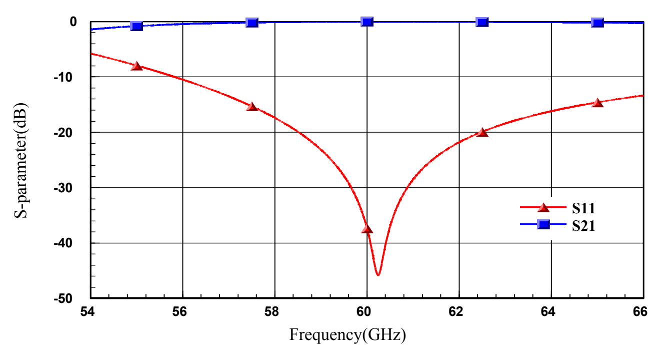
II. CONFIGURATION AND CHARACTERIZATION OF METAMATERIAL UNIT-CELL

In order to construct a gain-enhanced performance, we consider a MTM director with nearing zero refractive index. With the characteristic of nearing zero refractive index, the angle of refraction will be close to zero based on Snell's law of refraction, hence this property can be used to enhance the gain. The configuration of the nearing zero-index MTM unit-cell is displayed in Fig. 1. Ansoft HFSS, an FEM-based solver, is used to calculate S-parameters of the unit-cell in PEC-PMC waveguides. The method in [3] is used to retrieve constitutive parameters of the unit-cell. The unit cell strip lines are printed on a Rogers RO3210 substrate with relative permittivity ε_r =10.2 and dimension of 0.45×0.3×0.25mm³. The simulated S-parameters and refractive index of the unit-cell are shown in Fig. 2. It is clear from Fig. 2 that the effective refractive index of the unit-cell is close to zero at 60 GHz.

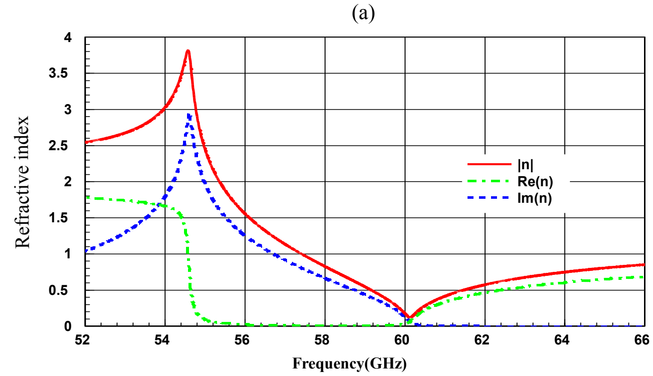


(a) (b)

Figure 1. (a) The simulation setup in HFSS for the analysis of unit-cell. (b) The proposed 1×4 director



(a)

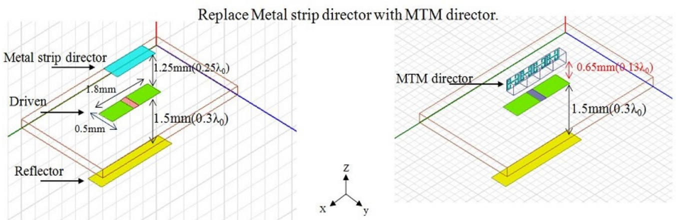


(b)

Figure 2. The simulated results of unit-cell.
(a) S-parameters (b) refractive index

III. ANTENNA WITH PROPOSED MTM DIRECTOR AND RESULT

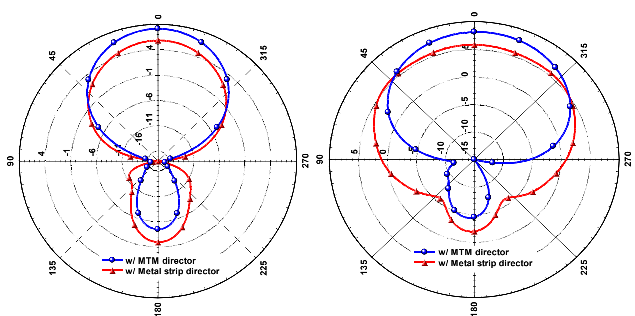
Figure 3(a) shows the structure of the conventional Yagi antenna. The metal strip director was replaced by the proposed MTM director which is described in Section II. The final arrangement of the antenna loading with the proposed MTM director is shown in Fig. 3(b). The comparison of the simulated radiation patterns of the conventional antenna and the MTM based antenna are shown in Fig. 4, where only the results at 60 GHz are presented. It can be seen that peak gain increases from 5.84 dBi to 8.14 dBi, an improvement of 2.3 dB, after metal strip director is substituted by the MTM one. In addition to gain-enhanced performance, it is noticed that the proposed MTM based antenna has more compact size by comparing the structure of antenna as shown in Fig. 3.



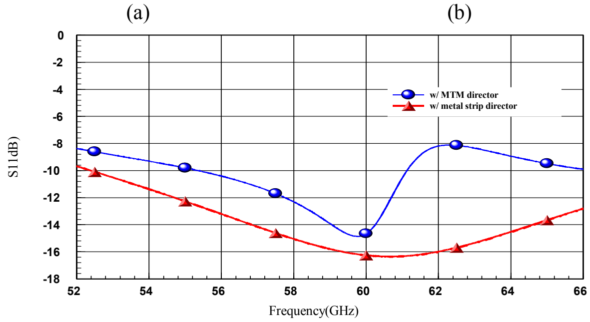
(a) (b)

Figure 3. The structure of antenna

(a) Conventional Yagi antenna (b) MTM based antenna



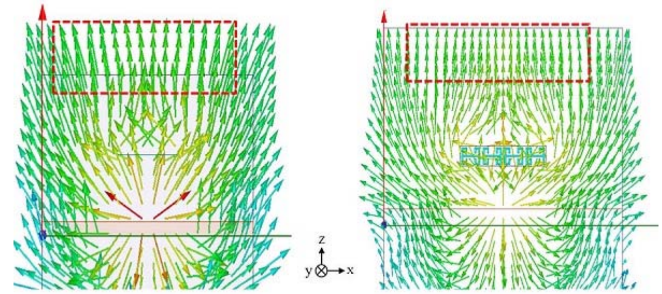
(a) (b)



(c)

Figure 4. The comparison of the simulation results. (a) radiation pattern of xz plane (b) radiation pattern of yz plane (c) S-parameter

The mechanism for gain-enhanced can be verified from distribution of Poynting vector. As shown in Fig. 5(a) and Fig. 5(b), it can be realized by observing distribution of Poynting vector that the radiated energy will be collimated after replacing metal strip director with MTM director which provides gain enhancement (as indicated by square dash line). The simulation results of the design for gain-enhanced and return loss are shown in Fig. 4 and given in Table I. For comparison, the results are presented for conventional antenna and MTM based antenna.



(a) (b)

Figure 5. Comparison of Poynting vector distribution.

(a) Conventional Yagi antenna (b) MTM based antenna

TABLE I COMPARISON OF PEAK GAIN IMPROVEMENT

	Peak Gain(dBi)	Improvement (dB)
Conventional Yagi antenna	5.84	
Yagi with MTM director	8.18	2.3

IV. CONCLUSION

A zero-index MTM based unit-cell operating at 60 GHz has been designed for gain enhancement. Effective constitutive parameters are extracted through full wave simulation. The gain enhancement is achieved by replacing the conventional metal strip director with MTM director at 60GHz. The proposed antenna loaded with zero-index MTM directors can enhance the gain by about 2.3 dB which achieves a maximum gain of 8.18 dBi and also has more compact size than conventional antenna.

V. ACKNOWLEDGMENT

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