Efficiency Treatment of Composite Right/Left-Handed TL Zeroth-Order Resonator Antenna

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***Abstract*—Antenna efficiency of zeroth-order resonator (ZOR) antenna implemented in composite right/left-handed transmission line (CRLH TL) microstrip structure is treated by method of moment simulator IE3D. Radiation is investigated from individual portions of the antenna structure according to calculated amplitude of surface current density. Dominantly radiating regions are identified, geometrically emphasized, and efficiency improved version of CRLH ZOR antenna is designed, realized, measured and compared with initial design. Improvement of simulation antenna efficiency from 10 to 75 % and 4x increased measured gain at design ZOR frequency has been found.**

I. Introduction

Zeroth-order resonator (ZOR) implemented in right/left-handed (CRLH) transmission line (TL) and other metamaterial (MTM) radiating structures has been developed by several researchers to design electrically small antennas. Radiation and antenna efficiency has not been often studied [1], [2] or relatively low values between approx. 5 to 60 % are presented [3], [4]. Extremely low efficiency values do not enable the structure to work efficiently as an antenna thus methods and techniques enabling to investigate the antenna and radiation efficiency should be subjects of interest.

This paper presents treatment of radiation from individual selected portions of the CRLH TL ZOR antenna structure treated by method of moments (MoM) simulator IE3D. The antenna structure is separated into several regions according to calculated surface current density in order to find the essential radiating parts. These parts - horizontal strips and namely vertical vias forming left-handed (LH) inductor are geometrically emphasized in terms of increasing their size in the next efficiency improved version of the antenna. Gain and directivity of both antennas – initial and improved – is measured and efficiency is evaluated and compared.

II. CRLH TL ZOR Antenna

CRHL TL ZOR antenna with coaxial feeding implemented in microstrip structure with four MTM unit cells (see Fig. 1) has been designed according to presented procedure [5] on substrate GML 1000 with $\varepsilon_r = 3.05$, tg$\delta = 0.003$ and first with height $h = 0.5$ mm for zero-order resonance at frequency $f = 5.64$ GHz.

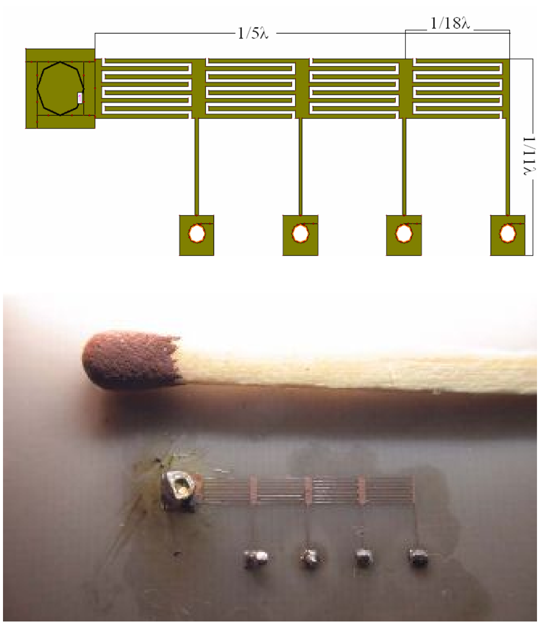


Fig.1 Layout and photograph of four unit cells CRLH TL ZOR antenna.implemented in microstrip technology

The overall length of one basic cell has been set to $\Delta z = 3$ mm ($\Delta z/\lambda \sim 1/18$), length of the fingers of series interdigital capacitors is $l = 2.5$ mm and the width of fingers is w and its the same as width of the gap s, i.e. $w = s = 0.1$ mm. Equivalent circuit model of unit cell is in Fig. 2 and has following parameters: $L_R = 0.92$ nH, $C_L = 0.29$ pF, $C_R = 0.51$ nH, $L_L = 1.32$ pF.

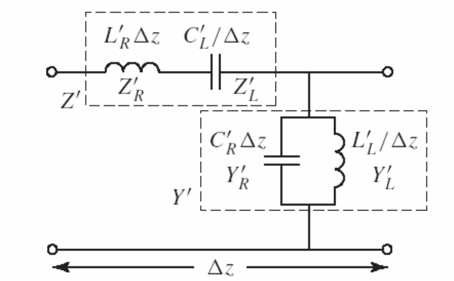


Fig.2 Equivalent circuit model of one unit cell of CRLH TL ZOR antenna

The antenna has been realized and measured. Comparision of simulated and measured reflection coefficient

S_{11} (see Fig. 3) show very good agreement. Simulated antenna and radiation efficiency are presented in Fig. 4.

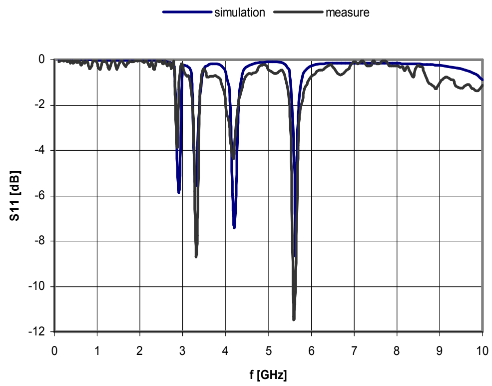


Fig.3. Measured and simulated reflection coefficient of initial CRLH TL ZOR antenna prototype realized on GML 1000 substrate with h = 0.5 mm

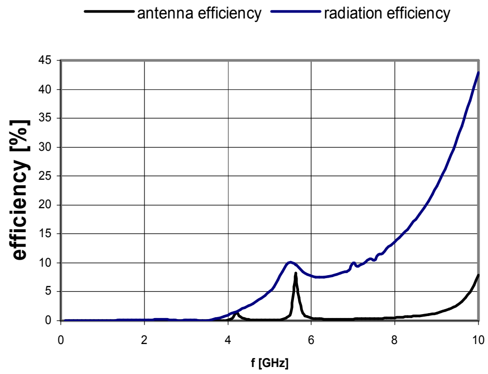
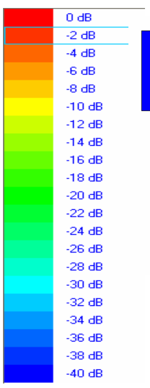


Fig. 4 Simulated antenna and radiation efficiency of initial CRLH TL ZOR antenna prototype realized on GML 1000 substrate with h = 0.5 mm

The current distribution of this CRLH TL ZOR antenna has been calculated by MoM simulator IE3D (see Fig. 5) and regions with dominant magnitude of surface current density has been identified. As it can be seen magnitude of surface current density on shunt inductors is about 10 or more dB higher than on the rest of the structure (series capacitors) and thus significantly contribute to radiation.



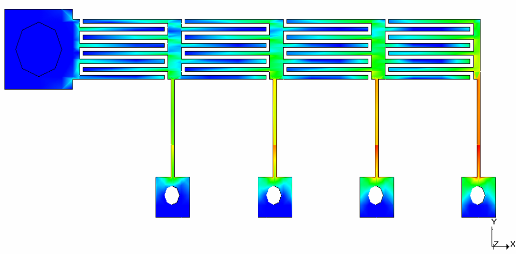
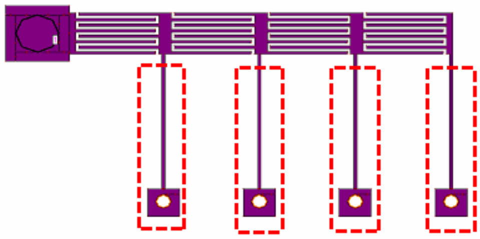


Fig. 5 Surface current distribution of initial CRLH TL ZOR antenna on zero-order resonance (m = 0) at frequency f = 5.64 GHz.

Further radiation of individual parts of the antenna structure has been investigated. This is enabled by simulator IE3D in version 8, where radiation patterns form selected regions can be compared with the radiation patterns of the whole structure. This "separation" of source current areas is done after the full-wave analysis of the structure thus this approach can show their relative contribution to radiation. Three cases of relative level of radiation has been investigated: from area of shunt inductors including horizontal strips and vertical vias (see Fig. 6), from horizontal strips of shunt inductors only (see Fig. 7), from vertical vias of shunt inductors only (see Fig. 8) and for comparison from series capacitors only (see Fig. 9).



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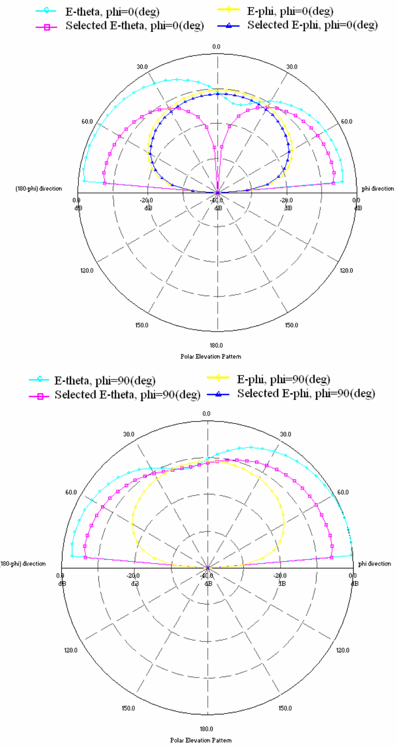
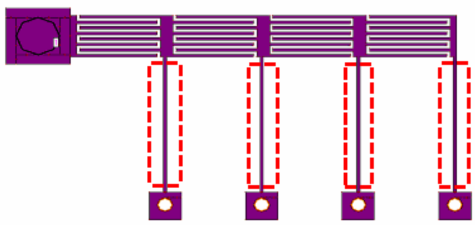


b)

Fig.6 Relative level of radiation evaluated from a) selected regions – horizontal strips and vertical vias of shunt inductors of initial CRLH TL ZOR antenna, and corresponding b) radiation pattern from both selected regions and total structure



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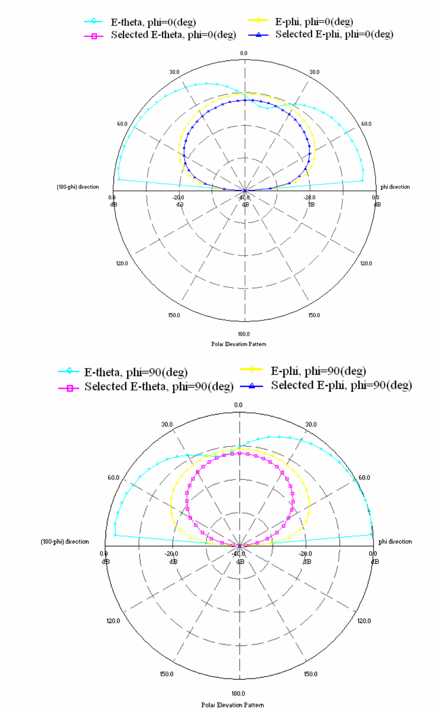
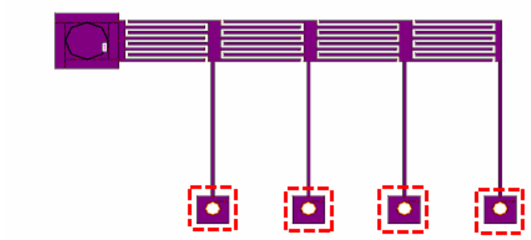


b)

Fig.7 Relative level of radiation evaluated from a) selected regions – <u>horizontal strips only</u> of shunt inductors of <u>initial</u> CRLH TL ZOR antenna, and corresponding b) radiation pattern from both selected regions and total structure



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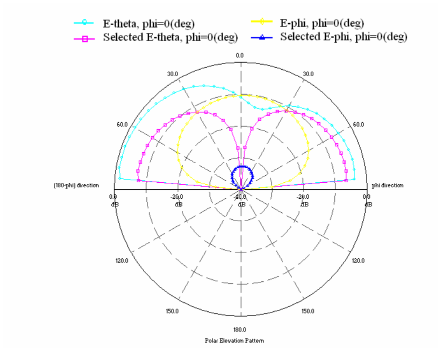
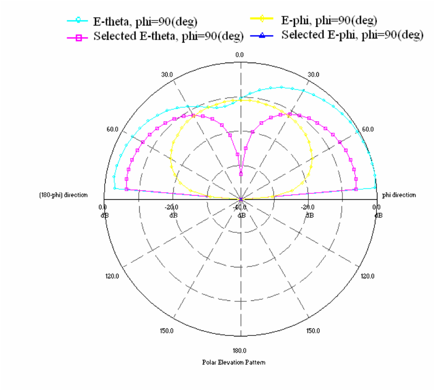
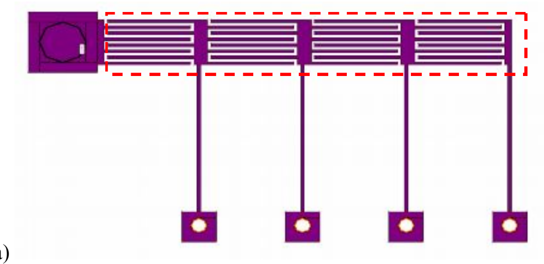




b)

Fig.8 Relative level of radiation evaluated from a) selected regions – <u>vertical vias only</u> of shunt inductors of <u>initial</u> CRLH TL ZOR antenna, and corresponding b) radiation pattern from both selected regions and total structure



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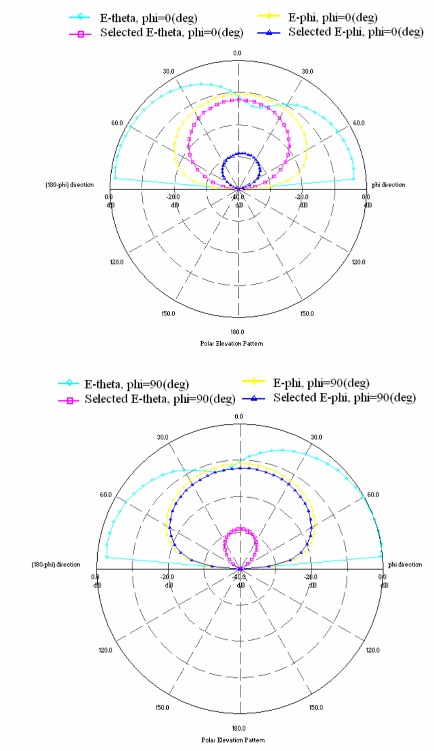

b)

Fig.9 Relative level of radiation evaluated from a) selected regions – <u>series capacitors</u> of <u>initial</u> CRLH TL ZOR antenna, and corresponding b) radiation pattern from both selected regions and total structure

As mirror currents on the ground (GND) plane below horizontal strip have opposite orientation (phase) to currents on strip significant radiation cancelling can be supposed for very low substrate height. On the other hand increasing of strip distance over GND plane is supposed to enhance the radiation from these areas. To verify this idea new CRLH TL ZOR antenna with increased height over GND plane has been designed (see Fig. 10).

III. Improved CRLH TL ZOR Antenna

The difference between initial and improved antenna is namely in increased substrate height that comprises additional air layer of width h = 6.4 mm so that total antenna height over the ground plane is h = 6.9 mm (~1/8 λ). Corresponding reflection coefficient and simulated efficiencies are in Fig. 11 and 12.

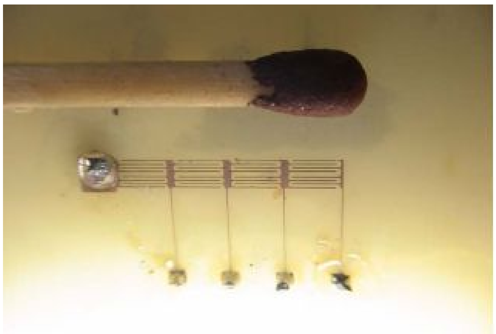

Fig. 10 Photograph of improved CRLH TL ZOR antenna

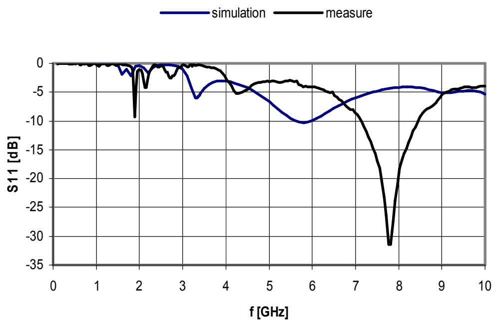

Fig.11 Measured and simulated reflection coefficient of improved CRLH TL ZOR antenna prototype realized on GML 1000 substrate with air layer of total height h = 6.9 mm.

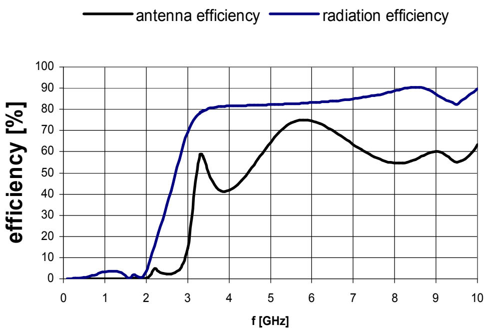

Fig. 12 Simulated antenna and radiation efficiency of improved CRLH TL ZOR antenna prototype realized on GML 1000 substrate with air layer of total height h = 6.9 mm.

Measured gain G and calculated efficiency η (for measured zero-order resonances are presented in table 1.

TABLE I
MEASURED VALUES OF GAIN AND CALCULATED EFFICIENCY FOR INITIAL AND IMPROVED CRLH TL ZOR ANTENNAS

	CRLH TL ZOR Antenna	
	h = 0.5 mm	h = 6.9 mm
f [GHz]	5,58	7,79
G [dBi]	-6,89	-0,52
η_{ant} [%]	6	25

IV. Conclusion

Radiation of CRLH TL ZOR antenna implemented in microstrip line technology has been investigated from selected regions of the antenna to find dominantly radiating source areas. It has been found that these areas are formed by vertical vias of inductive stubs of LH inductors. Based on these findings an efficiency improved antenna with increased vertical height from 0.5 to 6.9 mm has been designed and measured. Simulated radiation efficiency has been increased from 10 to 75 %. Simulated increase of radiation efficiency has been confirmed by increase of measured gain of improved antenna. Although measured values of efficiency are lower then simulated efficiency of improved antenna has been increased by factor 4. It can be concluded that radiation efficiency dominantly depends on the vertical size of the antenna structure.

Acknowledgment

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