

Ivane Javakhishvili Tbilisi State University, Georgia
Pidstryhach Institute for Applied Problems of Mechanics and
Mathematics, NASU, Ukraine

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Chapter

**2025 IEEE 30th International Seminar/Workshop
Direct and Inverse Problems of
Electromagnetic and Acoustic Wave
Theory (DIPED)**

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Tbilisi, September 8-10, 2025



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ELECTRON DEVICES SOCIETY



**XXXth International Seminar/Workshop on
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ACOUSTIC WAVE THEORY
DIPED-2025**

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Prof. Revaz S. Zaridze
Ivane Javakhishvili Tbilisi State University
3, Tchavtchavadze Ave.
Tbilisi, 0179, Georgia
Tel: +995 599 965 825
E-mail: revaz.zaridze@tsu.ge

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Assist. Prof. Tamar Nozadze
Ivane Javakhishvili Tbilisi State University
1, Tchavtchavadze Ave.
Tbilisi, 0179, Georgia
Tel: +995 322 250 484 / +995 591 220 646
E-mail: tamar.nozadze@tsu.ge

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Prof. Mykhaylo Andriychuk
Pidstryhach Institute for Applied Problems of Mechanics and
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3rd Bnd Naukova St., Lviv, 79060, Ukraine
Tel: +38 032 258 96 46 / Fax: +38 032 263 72 70
E-mail: andr@iapmm.lviv.ua

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Pidstryhach Institute for Applied Problems of Mechanics and
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3rd Bnd Naukova St., Lviv, 79060, Ukraine
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jaszcz@ire.pw.edu.pl

<i>Nadezhda Yeliseyeva and Serhii Berdnyk</i> , Input Impedance of Arbitrarily Oriented Hertz Dipole with Infinite Sized Plane or Corner Screens	244
<i>Nadezhda Yeliseyeva, Nikolay Gorobets and Serhii Berdnyk</i> , The Features of Radiation Patterns of Dipole with Plane or Corner Screens depending on Wavelength	249
<i>Serhii Berdnyk, Victor Katrych, Valerii Zozulia, Dmytro Havrylenko and Mikhail Nesterenko</i> , Radiation Characteristics of a Clavin-Type Radiator with a Transverse Slot in a Rectangular Waveguide	254
<i>Sergey Sheleg, Ihor Sliusar and Vadym Slyusar</i> , Study of a Metamaterial Unit Cell with a Flat Möbius Strip: Frequency Characteristics and DNG Bands	259
<i>Leonid Filinsky</i> , Reflection Coefficient of Liquid Foams with a Layer Thickness of about 100 mm in the Range of 38-52 GHz	265
 <i>RF Components</i>	
<i>Sergii Litvintsev and Alexander Zakharov</i> , Synthesis of Resonators for Bandpass Filters with Quarter-Wave Couplings and Wide Rejection Band	273
<i>Sergii Litvintsev and Alexander Zakharov</i> , Synthesis of Nonuniform Transmission Line Resonators for Filters with Finite Number of Passbands	278
<i>Mikhail Andreev, Oleg Drobakhin, Dmitry Saltykov, Nikolai Gorev and Inna Kodzhespirova</i> , On the Calculation of Biconical Cavity Parameters to Provide Up-To-Date Material Characterization	282
<i>Bohdan Karkulovskiy</i> , Electrodynamic Modeling of Magnetic Forces of a Spring-Type Microactuator	288
<i>Andrii Perov</i> , A High Selective Frequency Selective Surface for 5G mm-Wave Communication Radome	292
 <i>Acoustics and Applications</i>	
<i>Dariia Rebot, Serhiy Shcherbovskykh, Tetyana Stefanovych, Olena Stankevych and Volodymyr Topilnytskyy</i> , Mathematical Modeling of Oscillatory Processes in Printed Circuit Boards Under the Influence of External Disturbances	299
<i>Olena Stankevych and Volodymyr Stankevych</i> , Analysis of the Acoustic Stress Field in an Array of Collinear Structural Inhomogeneities with Angular Periodicity	303

Study of a Metamaterial Unit Cell with a Flat Möbius Strip: Frequency Characteristics and DNG Bands

Sergey Sheleg

ENIT, Inc.

Scottsdale, USA

ORCID 0000-0002-1378-2617

Ihor Sliusar

Department of information systems and
technologies Poltava State Agrarian
University

Poltava, Ukraine

islyusar2007@ukr.net

Vadym Slyusar

Central Research Institute of
Armaments and Military Equipment of
Armed Forces of Ukraine
Kyiv, Ukraine
swadim@ukr.net

Abstract - This work reports the results obtained for a novel metamaterial unit cell architecture developed using the concept of a flat Möbius strip. The modeling was performed using the Ansys HFSS software package. The influence of various structural modifications and substrate materials on the frequency bands with simultaneous negative values of magnetic and dielectric permeabilities (Double Negative, DNG bands) was analyzed. It is shown that changes in the dimensions of the connecting elements and the use of different materials significantly affect the position and width of the DNG bands. A controllable shift of the DNG region spanning 180–1300 MHz was identified through variations in the geometry and relative permittivity of the substrate. The obtained results may be useful for the design of metamaterials for microwave devices, including antennas and filters.

Keywords - metamaterial, Möbius strip, unit cell, Double Negative (DNG), electromagnetic properties, HFSS modeling, relative permittivity, substrate materials, microwave devices, frequency tuning

I. INTRODUCTION

Over the past several decades, the field of metamaterials has witnessed intensive and systematic development, primarily stimulated by their remarkable and unconventional electromagnetic responses [1–6], which fundamentally distinguish them from the properties inherent to naturally occurring materials. A significant research focus has been directed toward the development of periodic structures incorporating topological elements, which can generate targeted electromagnetic responses even in the relatively low-frequency range. Within this framework, special attention is given to the implementation of nontraditional geometric shapes in the unit cells of metamaterials. In particular, one promising structure is the Möbius strip, which possesses unique topological properties [7 – 14].

The authors have previously conducted an extensive set of studies on similar metamaterial cells based on double Möbius strips [15 – 19]. The motivation for investigating this type of structure was provided by two-tape split-ring resonators [20]. The investigations reported in [16 – 19] confirmed that certain frequency bands exist in which the dielectric parameter ϵ_r , describing polarization behavior, and the magnetic parameter μ , reflecting magnetic response, both acquire negative values concurrently. These spectral regions are conventionally referred to as double negative (DNG) [4].

As a further development in this direction, the transition to using a flat analog of the double Möbius strip is proposed, with a design patented in [21]. The advantage of this new unit cell geometry lies in its compactness and simplified

fabrication process.

This paper addresses the analysis of the electromagnetic characteristics of different configurations of metamaterial structure constructed from the aforementioned flat Möbius strip in a square geometry. It should be noted that square topologies of unit cells have long attracted the attention of researchers [3 – 5]. Among recent works of this kind, one can cite, for instance, [22]. At the same time, the proposed new variants of square-topology unit cells go beyond existing approaches and offer a fresh perspective on the capabilities of metamaterial technologies.

The corresponding studies were carried out using the Ansys HFSS software environment [23, 24] with Floquet boundary conditions applied for the analysis of periodic structures. This allowed for high-precision modeling of electromagnetic processes and identification of wave propagation characteristics. Special attention, in line with [25 – 29], was paid to evaluating the values of ϵ_r , μ , and the refractive index n calculated from them, as well as to examining the DNG band shift under various cell configurations.

II. KEY RESULTS OF THE INVESTIGATION

A. Description of the baseline model

At the initial stage of the study, a baseline model of the flat Möbius strip was created in the form of two square loops interconnected by a special coupling pad (Fig. 1). All conductive materials were modelled using Perfect Electric Conductor (PEC). A 1.5-mm-thick Plexiglas layer was employed as the substrate separating the loops. The outer side length of each square loop is 23.55 mm, and the width of the conductive strip forming the loop is 4.5 mm. Both loops include gaps with a width of 1.5 mm. In Fig. 2, the additional geometric ratios are presented, and the overall dimensions of the unit cell were scaled to correspond to those of the cell based on the double Möbius strip, the design and properties of which were investigated in [16–19].

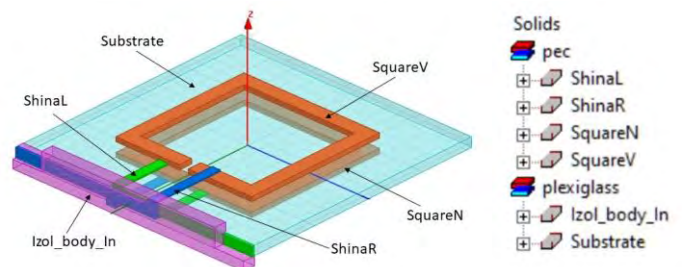


Fig. 1. The baseline model of the flat Möbius strip.

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Rybin O.	32	Topilnytskyym V.	299
		Tsakmakidis K.	239
Salo Yu.	323	Tsitsas N. L.	123
Saltykov D.	282	Tsitskishvili N.	161
Şanlı A.	36	Tuan A. L.	313
Savenko P.	67	Tuchkin Y. A.	36
Shcherbovskykh S.	299		
Sheleg S.	259	Vanin V.	142, 146
Shevchenko A.	32	Vediakovi D.	59
Shtoda D.	216	Vovk S.	72
Shulga S.	32		
Sliusar I.	259	Yeliseyeva N.	244, 249
Slyusar V.	177, 259	Yevstyhneiev B.	329
Stankevych O.	299, 303		
Stankevych V.	303, 319	Zakharov A.	273, 278
Stefanovych T.	299	Zaridze R.	8, 40, 188
Steshenko S.	100, 104	Zhbadynskyi I.	319
		Zhyla O.	173
Tabatadze V.	14, 59, 111, 117, 137	Zouros G.	3, 91, 239
Thi H. C. N.	307	Zozulia V.	254
Tkachuk V.	211		