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# Mechanicaly Reconfigurable Antenna with Ionic-Polymer Metal Composite

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**Abstract—This paper presents the possibility of employing an ionic polymer–metal composite (IPMC) actuator for coplanar waveguide fed antenna reconfiguration. Proposed antenna structure integrates defected ground structure (DGS) into the feeding line, which performs role of the band-reject filters, enhancing selectivity and shaping the frequency response. The IPMC strip acts as an electromechanical tuning element and lifts a separate substrate above the primary radiator. Such replacements alter the electromagnetic field distribution and lead to the operating frequency shift, offering a low-power alternative to conventional methods. With only 5V of bias voltage, operating frequency tuning rage is about 130%, from 2.61 GHz to 6.11 GHz, without bringing additional losses. The results confirm the feasibility of IPMC actuators for frequency tuning applications.**

***Keywords— defected ground structure; filtenna; frequency tuning; IMPC actuator.***

## I. Introduction

Modern wireless communication systems are designed to support numerous digital standards operating in different frequency bands. To meet these requirements within a single device, several approaches are typically employed, such as the use of ultra-wideband antennas, multiband antennas, or reconfigurable antennas. Reconfigurable antennas have some advantages, because they work in a required certain frequency band, which can be changed if needed. At the same time, it helps to reduce the overall system size by using a single antenna, supporting the ongoing trend toward device miniaturization.

The most common way to achieve frequency reconfiguration is to use solid-state devices such as PIN diodes, varactors, or MEMS switches. But each option has its own advantages and limitations. PIN diodes are cheap and straightforward to implement, but they do not allow continuous tuning [1–3]. Varactors solve this problem, but support limited continuous tuning with relatively high bias voltages required [4–6]. Both approaches suffer from restrictions on RF power handling due to intermodulation distortion.

Mechanical reconfiguration offers a wider tuning range and helps to overcome these power limitations. MEMS switches are widely used for this purpose. However, one of the problems with MEMS usage as a control element is the requirement for high driving voltages, above 10 V, which can reduce compatibility with low-power systems [7]. Another way is to use smart materials, like shape memory alloys (SMA). SMA-based actuators consume less energy than MEMS switches and can provide large displacements (up to 40 mm), but they typically need external force to function correctly [8–11]. Electroactive polymers (EAPs) represent another promising direction. Like SMAs, EAPs have low energy consumption and provide large displacements, but without the need for any additional external force [12]. EAPs are classified into two groups: electronic and ionic. Ionic

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EAPs can induce a bending motion at relatively lower voltages than electronic EAPs, though the forces they generate are smaller as well. However, it is still sufficient for practical actuation. For instance, an ionic polymer–metal composite (IPMC) can lift up to 100 g with a displacement of 10 mm under only 4 V [13–14]. While such actuators are typically applied in biomedical devices, they also hold potential to be used for antenna mechanical reconfiguration. In [15], an IPMC actuator was successfully employed to change the operating frequency of an F-shaped antenna.

In order to eliminate the need for multiple separate frequency-selective devices, additional interconnections and reduce hardware complexity and cost, it is profitable to to integrate a frequency-selective filter and an antenna into a single structure, commonly referred as "filtenna". One of the way to do this is to incorporate a defected ground structure (DGS) into the antenna's feeding line [16], [17]. The DGS introduces additional inductive and capacitive effects, allowing the structure to behave as a band filter. By controlling DGS parameters, the resonant frequency and bandwidth of the filtenna can be tuned, enabling frequency selectivity within a compact form factor. In [18], a varactor is used as the controlling element in such a structure. In this paper, a tunable filtenna with DGS is presented. For changing operating frequency of the filtenna, an IPMC actuator is used.

Naturally, the use of an IPMC actuator introduces certain limitations to the practical performance of the proposed design. One notable drawback is the rather slow response time, which may reach seconds. Another issue is the uncertainty of the produced strain under control voltage, which would require some kind of closed-loop control circuit in practical implementations. In contrast to rigid piezoelectric stack-actuators, the bent part of the substrate appears to be a rather long cantilever, making it potentially susceptible to mechanical vibrations.

In this paper, a tunable filtenna with DGS is presented. For changing the operating frequency of the filtenna, an IPMC actuator is used.

## II. FILTENNA DESIGN

The proposed antenna design consists of a coplanar waveguide (CPW)-fed patch radiator with defected ground structure (DGS) units embedded in the feeding line. The DGS elements perform the role of bandstop filter [19] and are positioned symmetrically with respect to the signal line. The number of DGS units and their geometric parameters determine the frequency characteristic of the DGS-based filter. The topology of the proposed filtenna is shown in Fig. 1. The antenna is fabricated on a Rogers RO3010 dielectric substrate with a thickness ( $h_1$ ) of 1.2 mm and a relative permittivity ( $\varepsilon_{r1}$ ) of 10.2. topological parameters of the CPW feeding were optimized to achieve a characteristic impedance of 50 Ω. Topology parameters of the proposed filtenna are presented in Table I.

Configuration of the second (top) substrate with the metal patches is shown in Fig. 2.

TABLE I. DIMENSIONS OF THE PROPOSED FILTENNA

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *L*, *mm* | *w*, *mm* | $L_g$, *mm* | $w_g$, *mm* | $w_s$, *mm* | *g*, *mm* | $a_1$, *mm* | $a_2$, *mm* |
| 40 | 19 | 20 | 8 | 2 | 0.5 | 16 | 13 |
| $a_3$, *mm* | $a_4$, *mm* | $b_1$, *mm* | $b_2$, *mm* | *b3*, *mm* | $b_4$, *mm* | $b_5$, *mm* | $b_6$, *mm* |
| 12 | 3 | 2.85 | 0.3 | 2 | 1 | 2 | 1 |
| $b_7$, *mm* | $c_1$, *mm* | $c_2$, *mm* | $c_3$, *mm* | $c_4$, *mm* | $c_5$, *mm* | $c_6$, *mm* | |
| 2 | 8.85 | 0.3 | 2 | 1 | 1.5 | 1.5 | |

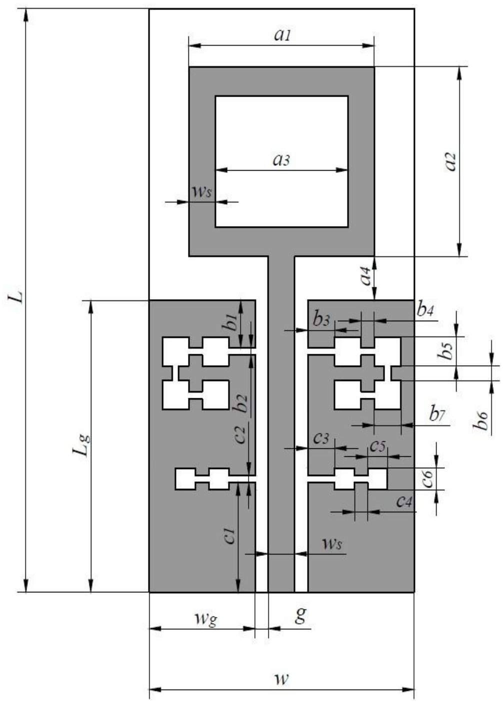


Fig. 1 Topology of the proposed filtenna

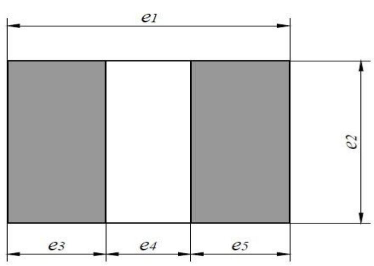


Fig. 2 Topology of the second substrate (grey areas are metal)

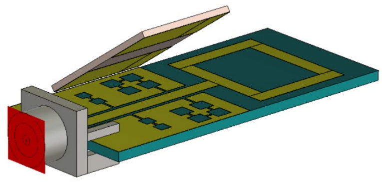

Fig. 3 Principle of the resonant frequency tuning by moving the second substrate

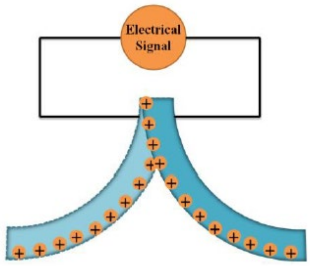


Fig. 4 Schematic representation of an IPMC actuator

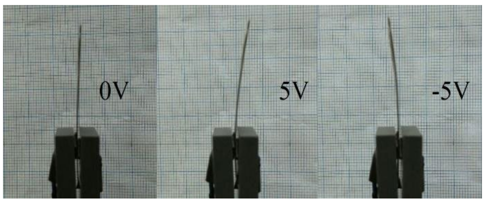


Fig. 5 Displacement of the IPMC strip under different applied voltage

TABLE II DIMENSIONS OF THE SECOND SUBSTRATE

| Parameter | $e_1$ | $e_2$ | $e_3$ | $e_4$ | $e_5$ |
|---|---|---|---|---|---|
| Size, mm | 19 | 13 | 7 | 5 | 7 |

The dimensions of the second substrate are listed in Table II. It is fabricated on a Rogers RT/duroid 5880 substrate with a thickness ( $h_2$ ) of 0.75 mm and a relative permittivity ( $\varepsilon_{r2}$ ) of 2.2. The permittivity of this substrate was selected to be lower than that of the primary layer in order to minimize its influence on the antenna's electromagnetic characteristics.

Frequency tuning is achieved by vertically displacing the second substrate metal patches above the main substrate. The metal patches on the second substrate are positioned directly above the DGS units of the main substrate, ensuring strong electromagnetic coupling. The operating principle of this tuning mechanism is shown in Fig. 3.

The second substrate moves at an angle relative to the main substrate, and the distance between them is therefore defined by the tilt angle α. In the down position, when α ≈ 0°, the second substrate lies almost directly on top of the main substrate. However, it is practically impossible to achieve zero spacing between the two substrates due to fabrication tolerances, and a small gap of approximately 50 μm remains. As a result, the DGS units are not completely short-circuited.

As the distance increases, the capacitive coupling between the metal patches on the top substrate and the ground planes of the main substrate decreases sharply. This leads to a change in the operating frequency. When the angle α exceeds approximately 30°, this coupling will be so low that the second substrate will no longer have any influence on the antenna's frequency response.

## III. IPMC ACTUATOR

The moving of the top substrate, as described above, can be realized by using an IPMC actuator. Briefly, an IPMC is a structure based on ionic electroactive polymers that bends in response to an electrical activation or generates an electromotive voltage when under mechanical stress. IPMCs usually consist of a thin ionomeric membrane (usually Nafion, or Flemion) with a typical thickness of approximately 100 µm. Two thin layers of noble metal electrodes, such as platinum or gold, are coated on the two sides of the ionomeric membrane. Due to the fixed anions on the backbone of the polymer membrane, the same amount of cations also exists in the membrane and they can move freely with the existence of the polyelectrolyte. In Fig. 4 a schematic representation of the IPMC electromechanical and mechano-eletrical process is depicted.

During the actuation process, an applied electrical signal leads to the attraction and repulsion of ions toward and away from electrodes of opposite and alike charge, respectively. Accumulation of mobile ions at the cathode and anode of the IPMC causes a mechanical imbalance which in turn results in an actuation response [20].

The IPMC actuator can be used in the topology of Fig. 3 by connecting the second substrate at one end and applying a voltage at the other end.

The produced samples of the IPMC strip were provided by Environmental Robots Inc. The length of the strip is 40 mm, the width of the strip is 10 mm, and the thickness of the sample is 0.4 mm. Such sizes of the IPMC strip provide the capability to lift the weight of the second substrate to the desired height. Displacements of the IPMC sample under different values of applied voltage are shown in Fig. 5. As shown, 5V is enough to achieve a displacement of about 5 mm.

## IV. SIMULATION AND MEASUREMENTS

CST Microwave Studio was employed to simulate the proposed filtenna design. The main substrate was modeled as an anisotropic material, since the dielectric

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constant of the Rogers RO3010 substrate differs along different planes [21]. The Z-axis of the substrate is a thickness axis, and the X-Y-axes are related to the length and width of the substrate. Dielectric constant over the Z-axis was set to 11.0, and over the X-Y axes was set to 12.1. The fabricated filtenna and the second (top) substrate are shown in Fig. 6.

The complete experimental setup is shown in Fig. 7. The IPMC strip serves as the actuator and is fixed at one end using a clamp with integrated electrodes. Controlling voltage is applied to the electrodes in the clam. The opposite end of the IPMC strip is attached to the top substrate using clue. The second substrate is positioned above the main substrate. When the applied voltage is equal to zero, the second substrate remains in the down position, as shown, Fig. 7a. When the applied voltage is equal to 5V, the top position of the second substrate is observed, Fig. 7b.

The frequency characteristics in both cases are shown in Fig. 8. As show in Fig. 8, when $\alpha$=0° (down-position) the filtenna operates at 2.61 GHz with a return losses of approximately 25 dB. When $\alpha$ > 30°, the operating frequency shifs to 6.11 GHz, while maintaining a similar return loss level of about 25 dB. The frequency tuning range is 3.46 GHz, corresponding to approximately 130% of the original first operating frequency. The simulated and measured results demonstrate good agreement.

The electric current distribution for the 2 operating frequencies (2.61 GHz and 6.11 GHz) for both states are shown in Fig. 9 and Fig. 10, respectively

## Conclusion

A reconfigurable CPW-fed filtenna with a defected ground structure is proposed. Frequency tuning is

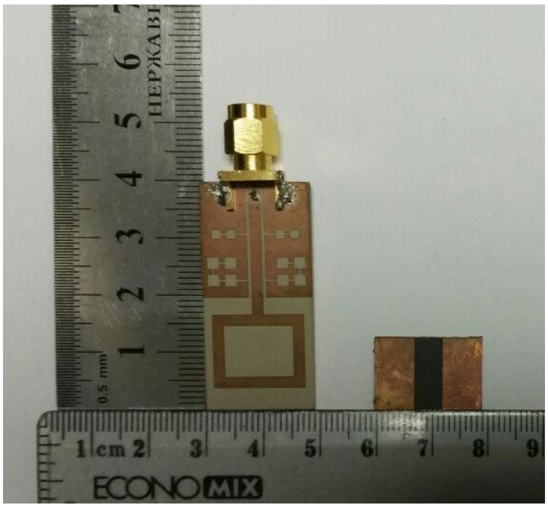
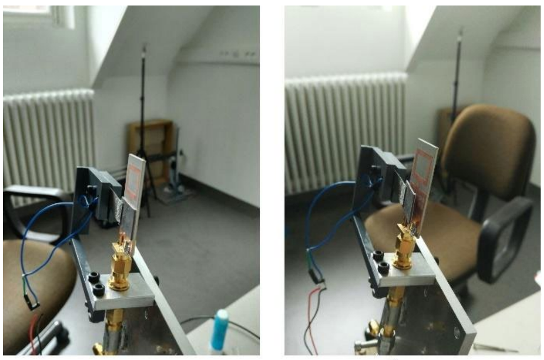



Fig. 6 The produced filtenna and top substrate



a b

Fig. 7 Experimental setup: a) down position of the second substrate; b) top position of the second substrate

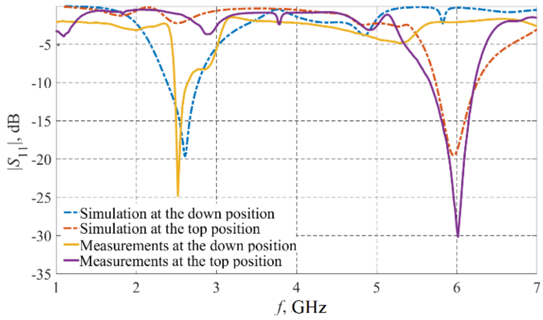



Fig. 8 Simulated and measured S-parameters of the filtenna for the two extreme states of the second substrate

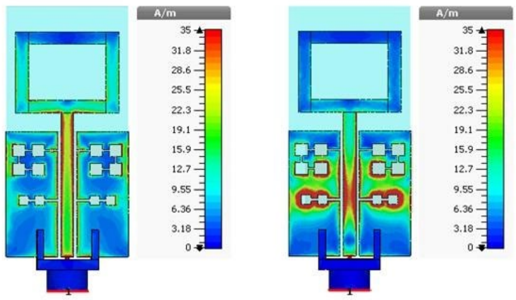



Fig. 9 Electric current distribution at 2.61 GHz: a) down-position of the second substrate; b) top position of the second substrate

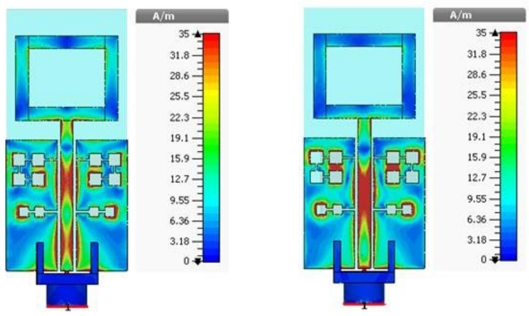



Fig. 10 Electric current distribution at 6.11 GHz: a) down position of the second substrate; b) top position of the second substrate

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achieved through the controlled mechanical displacement of a dielectric substrate carrying metallic patches placed above the CPW-fed line. This displacement is driven by a electroactive actuator based on an ionic polymer–metal composite (IPMC). The IPMC actuator provides smooth and reversible bending motion when a low bias voltage of approximately 5 V is applied, ensuring energy-efficient operation. By changing the position of the movable dielectric substrate, the resonant frequency of the filtenna shifts significantly—from 2.61 GHz in the down position to 6.11 GHz in the up position. The proposed design demonstrates the potential of IPMC-based actuators as a novel and flexible approach to mechanical frequency reconfiguration in compact microwave systems.

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# Механічно перелаштовувана антена з іонно-полімерним металевим композитом

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**Анотація—Розглядається актуальна задача створення антен для сучасних бездротових систем, здатних до роботи у різних частотних діапазонах. Зазвичай для перелаштування частоти використовують PIN-діоди, варактори або MEMS структури, однак ці методи мають суттєві обмеження: обмежений діапазон перелаштування, підвищене енергоспоживання, необхідність високої напруги або складність реалізації неперервного перелаштування. Однією з альтернатив є механічне перелаштування, зокрема із застосуванням розумних матеріалів. Деякі з них, наприклад, іонно-полімерні металеві композити (ІПМК) створюють великі переміщення за порівняно низьких керуючих напруг. Це дозволяє створювати енергоефективні та компактні пристрої. Запропоновано конструкцію фільтени — антени з інтегрованим фільтром на основі копланарної лінії передачі, у якій нижній електрод може відхилятися від основи. Ця частина виконує роль смугового фільтра, а його параметри визначають частотні властивості пристрою. Для перелаштування частоти використовується ІПМК-актюатор, який змінює положення додаткової діелектричної пластинки з металевими елементами над основною антеною. Переміщення пластинки збурює розподіл електромагнітного поля, внаслідок чого відбувається також зміна резонансної частоти. Конструкція дозволяє плавно змінювати кут нахилу рухомої пластинки, що забезпечує перелаштування частоти у широкому діапазоні, від 2,61 ГГц у нижньому положенні до 6,11 ГГц у верхньому положенні, що становить близько 130% від початкової частоти, а рівень відбивання залишається стабільним близько –25 дБ. При цьому для роботи актюатора достатньо прикладати напругу до 5 В. Вимірювання S-параметрів прототипа підтвердили ефективність запропонованої конструкції. В експериментальній установці ІПМК-актуатор був закріплений з одного боку, а з іншого – приєднаний до рухомої пластинки. Експериментальні вимірювання добре узгоджуються з результатами моделювання. Перевагами запропонованої конструкції є енергоефективність, широкий діапазон перелаштування робочої частоти та відсутність додаткових внесених втрат. Основними обмеженнями є відносно повільна реакція ІПМК (секунди) та необхідність замкненого контуру керування для точного позиціонування. Конструкція чутлива до механічних вібрацій, що слід враховувати при практичному застосуванні. Разом з тим, використання ІПМК-актюатора дозволяє уникнути використання високих напруг і складних електронних схем. Запропонована конструкція може бути використана для створення сучасних антен з розширеними функціональними можливостями.**

***Ключові слова — структура з відхиленням електрода; фільтена; перелаштування частоти; актюатор ІМПК***