Frequency and Impedance Reconfigurable Antennas for Terahertz Photomixers

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Abstract

We present, for the first time, the design of two antennas for the terahertz photomixers that have reconfigurable operation frequency or reconfigurable input impedance as an alternative to the state-of-the-art high-impedance, narrow band or low-impedance, wide-band antennas. Both antennas have folded-dipole structures, which inherently have high radiation resistances, and the dimensions of the antennas are modified in the horizontal and vertical dimensions by means of ideal switches, changing the operation frequency of the antenna or the input impedance of the antenna at a given operation frequency. We also propose a real-life solution for the ideal switches for the antennas, namely miniature Micro-Electro-Mechanical Systems (MEMS) switches, which have an area of 10 um x 10 um and is, to the best of our knowledge, the smallest MEMS switch reported in the literature. The first antenna is capable of operating at three different frequencies of 200, 400, and 600 GHz, whereas the input impedance of the second antenna can be adjusted between 4 kΩ and 7.5 kΩ at an operation frequency of 385 GHz. The proposed antennas can also be used as a photoconductive antenna for the terahertz frequency band.

1. Introduction

Terahertz frequency band has been investigated by several researchers due to its potential in imaging, spectroscopy, and communication applications [1-4]. The increasing demand in the terahertz band also has developed the need for high performance components that operate within this band. The terahertz sources and detectors require a special attention, as they are crucial for any terahertz system; moreover, the sources and detectors that have been developed using RF and optical approaches cannot provide the desired power level, efficiency, and bandwidth at the same time [1].

Optical-to-terahertz generation through photoconduction has been one of the promising methods for terahertz generation and detection in the last decade [5-8]. Continuous-wave (CW) [5, 6] and pulsed [7, 8] terahertz generation can be obtained by photoexcitation of the semiconductor substrates such as low-temperature grown gallium arsenide (LT-GaAs) or radiation-damaged silicon-on-sapphire (RD-SOS). In both cases, an antenna is integrated with the system in order to radiate the generated terahertz signal, the performance of which strongly influences the total generated power and efficiency. The antennas employed in the pulsed generation systems, so called as the photoconductive antennas, and the antennas employed in the CW photomixing generation systems both require a wide operational bandwidth and a high radiation resistance for preserving the bandwidth of the generated signal or tunability and for maximizing the generated power, respectively. However, the antennas presented in the literature are either resonant type structures that can provide a high radiation resistance in a narrow band [9], such as dipoles, or can provide a wider bandwidth with low radiation resistance, such as spiral antennas [10]. No antenna solutions are presented that can offer wide bandwidth together with high radiation resistance.

In this paper, we present the design of two folded dipole antennas which can have either reconfigurable operation frequency or reconfigurable input impedance. The first antenna is capable of having three different instantaneous operation frequencies together with a high radiation resistance, whereas the second antenna can is capable of having two different levels of radiation resistance at a given operation frequency. The antennas are reconfigured by means of ideal switches; nevertheless, a real-life solution is also proposed using miniature MEMS switches, which is, to the best of our knowledge, the smallest reported MEMS switch in the literature.

2. Antenna Design

Figure 1 shows the layout of the proposed frequency reconfigurable folded dipole antenna, and Table 1 presents its dimensions. The antenna is designed on gallium arsenide (GaAs) substrate with $\varepsilon_r = 11.9$ and $\tan \delta = 0.0009$ using the design equations given in [11] and verified using ANSYS HFSS [12]. The conductors of the antenna are assumed as perfect electric conductors (PEC) in order to see the maximum achievable levels of the radiation resistances. The antenna is fed by current source which models the photoconduction mechanism, and the perfectly matched layer (PML)

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boundary conditions are used in order to compensate the radiation due to the edges of the substrate and observe the antenna performance more clearly. The antenna has three modes of operation, which are centered at 200, 400, 600 GHz, respectively, and the modes are formed by optimizing the positions of the 12 MEMS switches on the antenna, which effectively changes the electrical length of the antenna. For the antenna simulations, the MEMS switches are assumed as PEC on/off switches, but a MEMS switch design is proposed for the design of the real-life antenna, which is discussed in the following sections. Considering the simulation results given in Fig. 2, one can conclude that the antenna operation frequency can be successfully reconfigured with a minimal change in the radiation resistance.

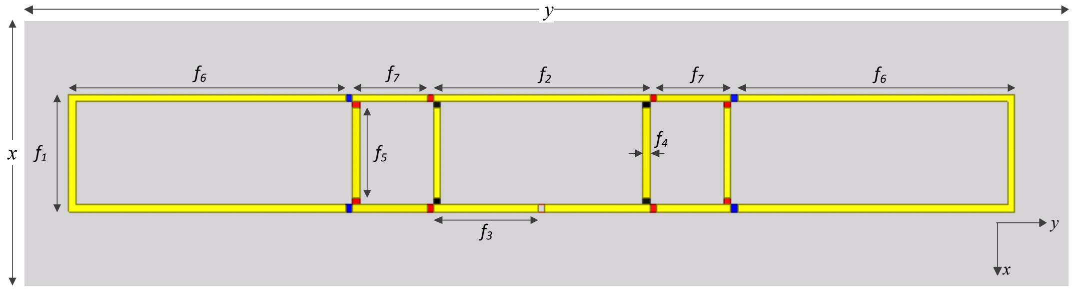


Fig. 1. The layout of the frequency reconfigurable folded dipole antenna. The antenna has three modes of operation: Case 1: Black switches on, red switches off, blue switches off; Case 2: Black switches off, red switches on, blue switches off; Case 3: Black switches off, red switches off, blue switches on.

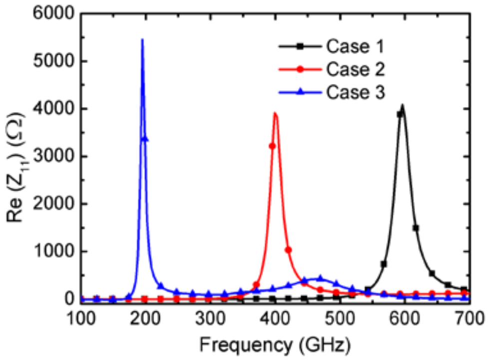


Fig. 2. The simulated input impedance for the frequency reconfigurable folded dipole antenna. The colors of the traces correspond to the switch states in Fig. 1.

Table 1.
The design parameters for the frequency reconfigurable folded dipole antenna.

Antenna parameters			
Parameter	Value (μm)	Parameter	Value (μm)
f_1	17	f_5	13
f_2	32	f_6	42
f_3	15.5	f_7	11
f_4	1		
x	600	y	400

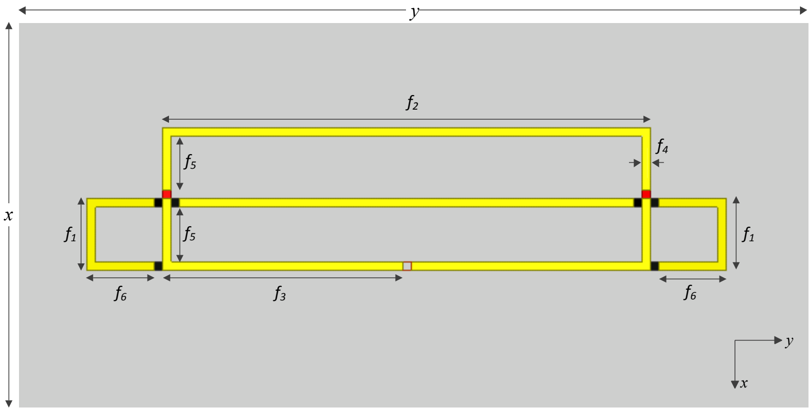


Fig. 3. The layout of the impedance reconfigurable folded dipole antenna. The antenna has two modes of operation: Case 1: Red switches off, black switches on; Case 2: Red switches on, black switches off.

The second antenna, which is presented in Fig. 3, is designed to demonstrate the ability of tuning the input impedance, and hence, the radiation resistance of the antenna. The idea here is improve the impedance matching between the photomixer and antenna in case of a change in the photomixer impedance under different optical excitation and DC bias conditions. The antenna is designed using the same conditions and assumptions with that of the previous antenna. Moreover, the antenna dimensions are reconfigured in both horizontal and vertical dimensions. The vertical direction is used for tuning the input impedance by changing the coupling between dipole elements, whereas the horizontal direction is used for compensating the shift in the operation frequency. Table 2 gives the dimensions used in the design, and Fig. 4 presents the simulations results of the antenna. The simulation results show that the input impedance of the antenna, which has a very low imaginary part, can be adjusted by almost a factor of two with a small amount of shift in the operation frequency.

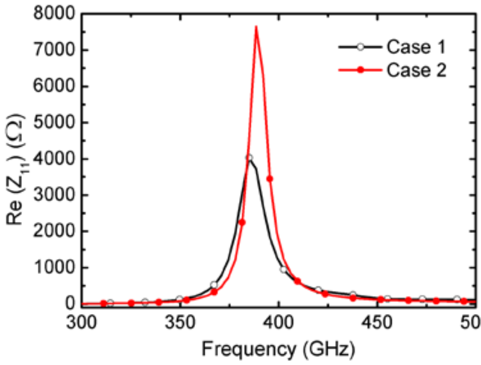


Fig. 4. The simulated input impedance for the impedance reconfigurable folded dipole antenna. The colors of the traces correspond to the switch states in Fig. 3.

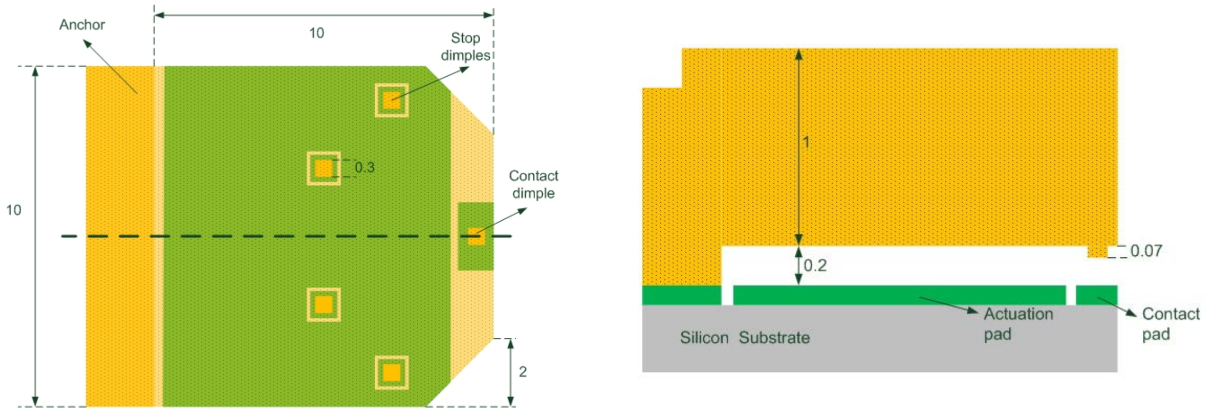
Table 2.
The design parameters for the impedance reconfigurable folded dipole antenna.

Antenna parameters			
Parameter	Value (µm)	Parameter	Value (µm)
f_1	8.5	f_4	1
f_2	58	f_5	6.5
f_3	28.5	f_6	8
x	600	y	400

3. MEMS Switch Design

We propose a MEMS switch design instead of the ideal switches that are utilized in the designed folded-dipole antennas. The switch is a miniature, cantilever type, metal contact, series MEMS switch that has dimensions of 10 µm x 10 µm x 1 µm. The switch is designed for a previously designed fabrication process, the details of which can be found in [13]. The dimensions of the switch are given in Fig. 5. The switch is designed and simulated using Coventorware, and the simulation results show that the switch has a mechanical resonance frequency of 2.32 MHz, an actuation voltage of 36 V, an operation voltage of 80 V for a contact force of 82 µN, and a switching speed of 0.25 µs. The practical switching speed of the switch is expected to be higher than the simulated value, but lower than 1 µs is expected depending on the past experience. Fig. 6 also shows a snapshot from the Coventorware simulation results.

We, as the authors, are aware of the fact that although the proposed miniature MEMS switch is, to the best of our knowledge, the smallest switch reported up to date, its dimensions are still big for the proposed antennas and can distort the antennas performances. However, we still believe that performances close to the ones reported within the frame of this study can be achieved by careful and parallel design iterations of the switch and antennas.



(a) **(b)**

Fig. 5. The top (a) and side (b) views of the proposed MEMS switch.

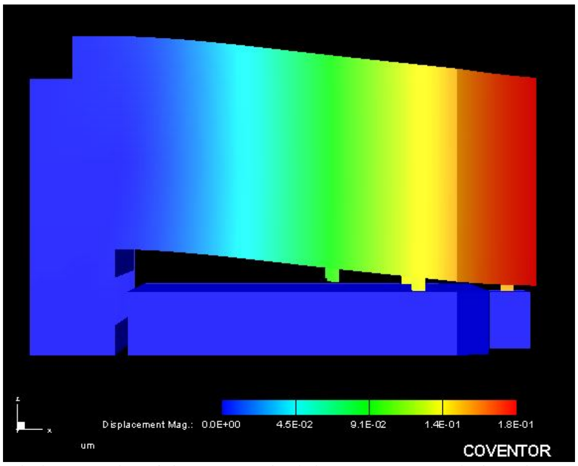


Fig. 6. Coventorware simulations results of the proposed miniature MEMS switch under an applied voltage of 80 V.

6. Acknowledgments

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