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Development and Performance Enhancement of MEMS Helix Antenna for THz Applications using 3D HFSS-based Efficient Electromagnetic Optimization

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Abstract

Interest of Micro-Electromechanical System (MEMS) antennas in Terahertz (THz) applications has rapidly expanded in recent years due to the advent of accurate Computer Aided Design (CAD) tools. The very special needs of newly proposed MEMS antennas, especially with a wide bandwidth range, require advanced optimization procedures of enhancing already established designs. This paper provides a compact design of a wideband MEMS helix antenna optimized using tree-dimensional High Frequency Structure Simulator (3D-HFSS) based on Quasi-Newton (Q-N) and Sequential Non Linear Programming (SNLP) techniques to modify the antenna structure with a high accuracy for the selective band of frequencies by training the samples and minimizing the error from Finite Element Method- (FEM) based simulation tool. The helix antenna is presented using MEMS technology and shows high performance demonstrated by very low return losses of less than -20 to -65 dB for a wide range of frequencies from 2.5 to 5 THz. High antenna geometry precision and efficient performance are finally achieved by rectifying and synthesizing various tunable parameters embedded in silicon substrate including both helix form and feeding line parameters.

Keywords: *micro-electromechanical systems (MEMS), THz bands, helix antennas, 3D-HFSS, electromagnetic optimization.*

1. Introduction

As new applications for the electromagnetic THz field begin to emerge, a new generation of efficient MEMS antennas [1] is developed to meet the specific requirements of these high frequency systems. Many new processes of MEMS technology are just beginning to stimulate interest in this unique spectral and continue to help manufacturing THz antennas, improving their performance and achieving micro-level precision [2]. Focused Ion Beam (FIB) is one of the important processes used for fabricating MEMS antennas, especially helical antennas [3] by implementing silicon wafers that represent a very good solution to enhance the antenna's radiation and performance. MEMS helix antennas employing silicon substrates, have achieved over the past few years interesting characteristics including compact size, high directional gain, and wide bandwidth, thus their implementation into planar forms seems to become easier due to the advanced micromachining techniques [4]. This has provided a new class of THz antennas with numerous wireless access applications thanks to the use of complex simulation tools to bring the CAD for such high frequency structures to its current state of the art. Accordingly, HFSS-based Q-N and SNLP approaches lead to excellent optimization solutions carrying out by replacing repeated electromagnetic simulations whilst still retaining a good accuracy as compared with finite element modeling to improve the accuracy of the existing design models or develop new design models. This procedure requires acceptable simulation time especially for defining the problem that needs reliable and fully functional approximations.

This paper proposes for the THz frequency access systems a compact geometrical configuration of a wide MEMS Helix antenna using HFSS software. The MEMS antenna geometry is optimized using both Quasi-Newton and Sequential Non Linear Programming algorithms to offer fitness functions for excellent bandwidth learning and fast configuration evaluating. The antenna occupies a very compact volume of 79×80×152 um (0.960 10-3 mm3) including the silicon substrate having a thickness of 9.3 um and a dielectric constant of 11.9.

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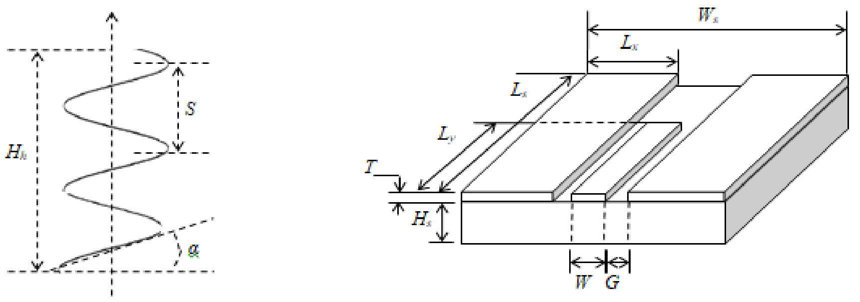
The explored MEMS helix antenna design is validated by demonstrating optimal results in terms of return loss properties in comparison to the previous optimized structures [3, 5]. The antenna with optimized parameters operates in a wide bandwidth from 2.5 to 5 THz and shows very low reflection coefficients with less than -20dB over the entire bandwidth. The compact optimized MEMS antenna is finally simulated by covering an ultra wide range of frequencies of 8.7 THz extending from 1.2 to 9.9 THz and shwos very good performance resulting in a low reflection coefficient of less than -15dB for the entire bandwidth.

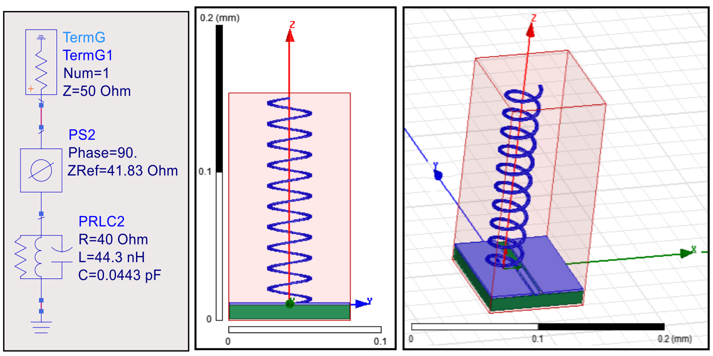
2. Research Method

Electromagnetic THz gap remains one of the least explored regions of the frequency spectrum for diverse applications, for the reason that it claims a deep knowledge of radiofrequency engineering and semiconductor physics. The size of a THz antenna is expected to closely relate to wavelength, which is about 30 um (10 THz) to 3 mm (0.1THz) [6]. Micro-electromechanical systems therefore present a suitable technology for manufacturing compact THz antennas with low profile, wide bandwidth, and large radiation [7]-[9]. Several processes to fabricate THz antennas employing MEMS technology have been reported in recent years, in which the fabrication process is highly precise and antennas with compact size become soft to be integrated with other devices [10]-[11]. FIB process provides a great flexibility to explore such MEMS antennas in micrometer scale and makes possible to fabricate 3D structures with low cost by employing a large irradiation area of FIB on suspended film structures with the advantages of high flexibility, controllability and repeatability [12]-[13].



(a) (b)

Figure 1. Geometric structure of the THz MEMS helix antenna (a) Schematic diagram of the helix (b) 3D model of the CPW feeding



(a) (b) (c)

Figure 2. THz MEMS helix antenna equivalent circuit (a) in ADS, 2D (b) and 3D (c) models in HFSS

The proposed MEMS antenna is realized in a single-crystal silicon substrate and can be fabricated using conventional bulk micromachining relying on available FIB stress-introducing technique [14]. Figure 1 illustrates the geometric structure of the MEMS helix antenna proposed for the optimization and development. Figure 2 shows the equivalent circuit (a) of the optimized MEMS helix antenna implemented using Advanced Design System (ADS) simulator, the two-dimensional cross-section (b) and three-dimensional view (c) of the antenna using HFSS software which clearly indicate that the antenna reaches a high level of precision leading to interesting characteristics including large bandwidth and low reflection coefficient. The proposed structure uses mainly the set of equations demonstrated in [3] to calculate the helix parameters. The antenna is fed with a coplanar waveguide (CPW) and working in transmission mode.

3. Antenna Optimization and Development

The proposed antenna design is firstly simulated by HFSS software which constitutes an interactive tool for computing basic electromagnetic field quantities and analyzing the electromagnetic behavior of the structure within FEM [15] to understand the physical problem to be optimized. Figure 3 presents the simulated return losses of the proposed geometrical configuration for a frequency range from 2.5 to 5 THz. As it is observed, geometric parameters initially proposed for the analysis show acceptable performance which needs to be more enhanced. The structure is then optimized by coupling Q-N and SNLP methods in order to improve the antenna performance, and achieve a high um-level precision of the helix form parameters, CPW feeding characteristics and silicon platform dimensions.

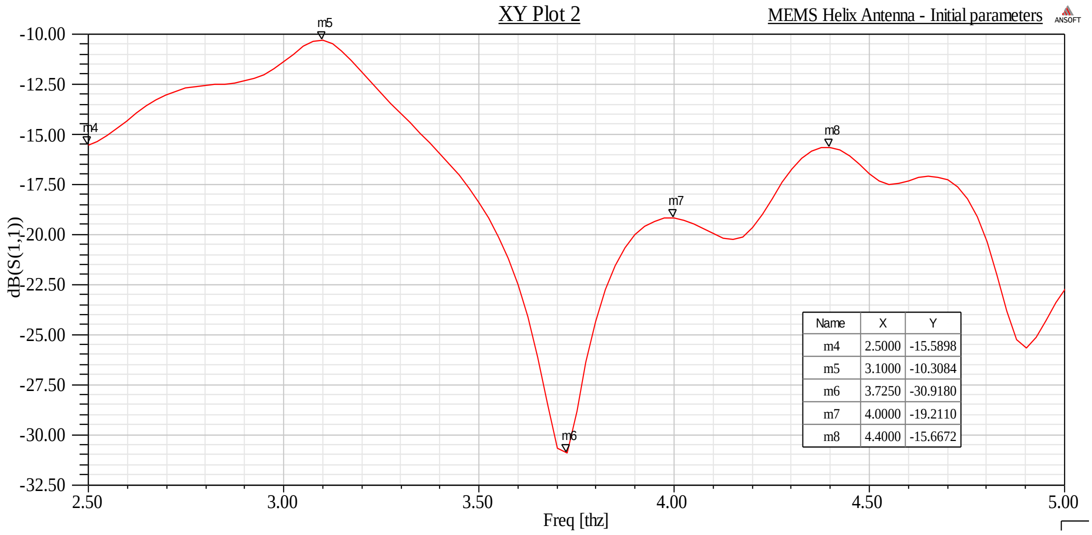


Figure 3. Return loss graph of the proposed MEMS helix antenna with initial parametersin 2.5-5 THz

3.1. Quasi-Newton Optimization

First, Quasi-Newton optimizer is employed to find a minimum or maximum of the cost function which relates three basic parameters in the model, including the helix diameter (D), CPW width (W), and silicon thickness (Hs) to the return loss properties. This choice is mainly based on selecting parameters exhibiting a smooth characteristic and little numerical noise. This technique works to approximate locally the optimization parameter values that will be placed back into the original function and used to calculate a gradient which provides a step direction and size for determining the next best values in the iteration process. However, this approach suffers from two fundamental problems: The first issue is the possible presence of local minima; once the Q-N optimizer has located a minimum, this technique will locate the bottom and will not search further for other possible minima and not a good global solution to the problem. The second issue is numerical noise; the calculation of the parameter values involves taking the differences of numbers that get progressively smaller.

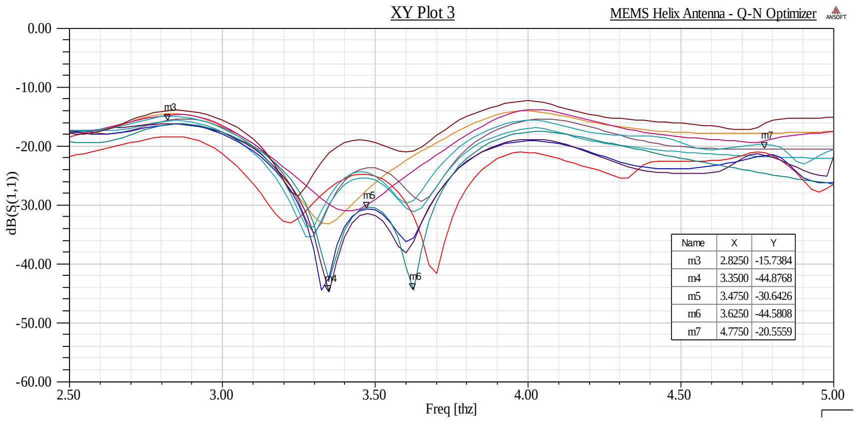


Figure 4. Return loss graph of the optimized MEMS helix antenna using HFSS-based Q-N optimizer in 2.5-5 THz

At some point, the numerical imprecision in the parameter calculations becomes greater and the solution will oscillate and may never reach convergence. For this, to use the Q-N optimizer effectively, the starting point of each parameter optimization is chosen close to the expected minimum displayed by the primary simulation based on the understanding of the physical problem being optimized. The Q-N optimizer begins then to vary the value of the selected parameters on the basis of getting a minimum or maximum of the cost function to overall simulation goals. Figure 4 shows the simulated return losses of the optimized antenna design using Q-N technique which shows that the antenna configuration begins to present good performance for the same frequency range with low return losses of less than -15 to -44dB.

3.2. Sequential Non Linear Programming Optimization

Next, in order to achieve a high level of performance of the antenna design, Sequential Non Linear Programming optimizer is further added to analyze four additional parameters including the helix pitch (S), helix turn number (N), CPW gap (G), and CPW thickness (T). The antenna height (HA) and the substrate width (Ws) will be automatically optimized relating into these parameters.

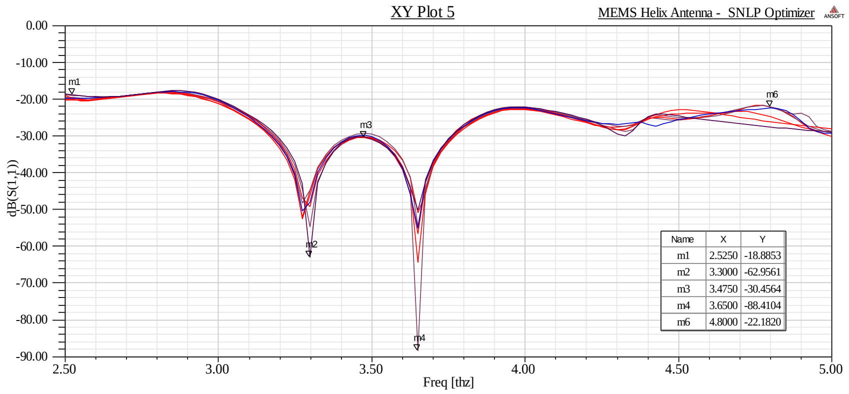


Figure 5. Return loss graph of the optimized MEMS helix antenna using HFSS-based SNLP optimizer in 2.5-5 THz

The main advantage of SNLP optimizer over Q-N optimizer is that it handles the optimization problem in more depth, and assumes that the optimization variables span a continuous space and take any value within the allowable constraints and within the numerical precision limits of the simulator. The SNLP optimizer estimates the location of improving points with an accurate Finite Element Approximation (FEA) with Response Surfaces (RS) and light evaluation of the cost function. This allows a faster practical convergence speed than that of Q-N optimizer. Another advantage is that SNLP optimizer allows the use of nonlinear constraints, making it much more general than Q-N optimizer. The SNLP optimizer creates the response surface using a polynomial approximation from the FEA simulation results available from past solutions. The response surface is most accurate in the local vicinity. The response surface is used in the optimization loop to determine the gradients and calculate the next step direction and distance. The response surface acts as a surrogate for the FEA simulation, reducing the number of FEA simulations required and greatly speeding the problem. Convergence improves as more FEA solutions are created and the response surface approximation improves. As illustrated in Figure 5, the antenna geometry obtained from the SNLP technique presents very low reflection coefficients with less than -18dB to -88dB, resulting in a significantly high performance for the selected band of frequencies.

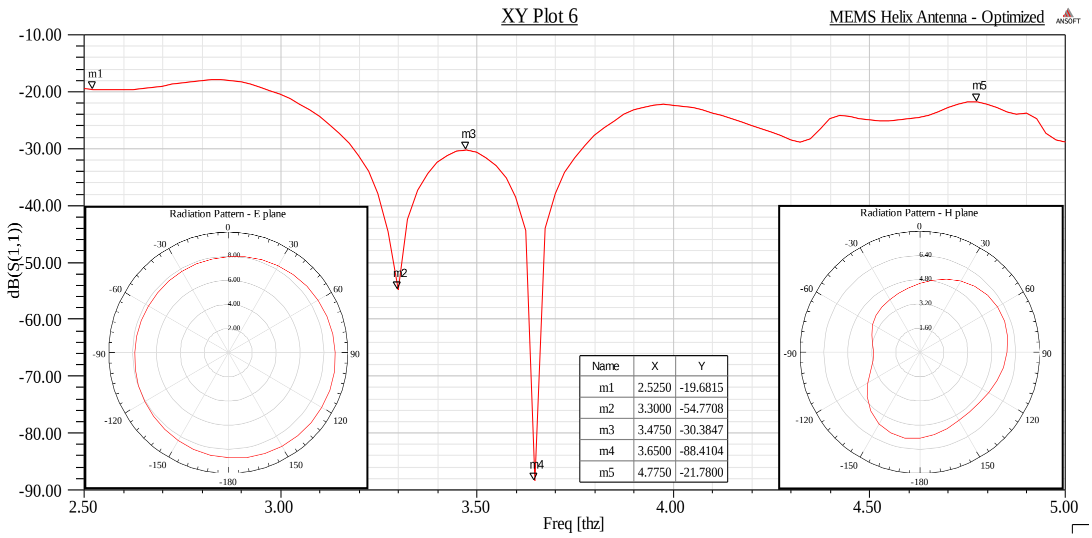


Figure 6. Return loss and radiation pattern graphs of the optimized THz MEMS helix antenna using HFSS-based efficient electromagnetic optimization

Figure 6 shows the simulated return losses (a) and radiation patterns (b) of the optimized antenna design finally obtained using HFSS based on Q-N and SNLP solvers that indicates excellent performance for the developed antenna design interpreted by very low return losses of less than -30 over the central frequency band. Thus, the radiation patterns, both in E-plane (xoz-plane) and H-plane (yoz-plane) of the antenna transmission mode at the central frequency (3.5 THz), keeps good directivity with slightly bending in the side lobes of yoz-plane due to the fine modeling process. This demonstrates the high efficiency of the applied optimization strategy to provide a good geometrical accuracy and excellent electromagnetic response for the developed antenna design for a very wide THz comparing to previous research works. The promising results obtained from the efficient electromagnetic optimization are then compared to the results previously achieved in [3, 5]. As shown in figure 7, it is clearly observed that the new THz MEMS helix antenna geometric characterization developed by HFSS based on efficient electromagnetic optimization comes with very low return losses with closely less than -20dB over the entire frequency band, and less than -30dB over the central frequencies from 3.2 to 3.7 THz, and approximately -55dB and -89dB at 3.20 THz and 3.80 THz respectively, this significantly validates the excellent performance for the proposed THz MEMS helix antenna design improved by Q-N and SNLP optimizers comparing to the previous attempts. Details of geometrical configuration of the THz MEMS helix antenna optimized in HFSS-based Q-N and SNLP optimizers are presented in Table 1.

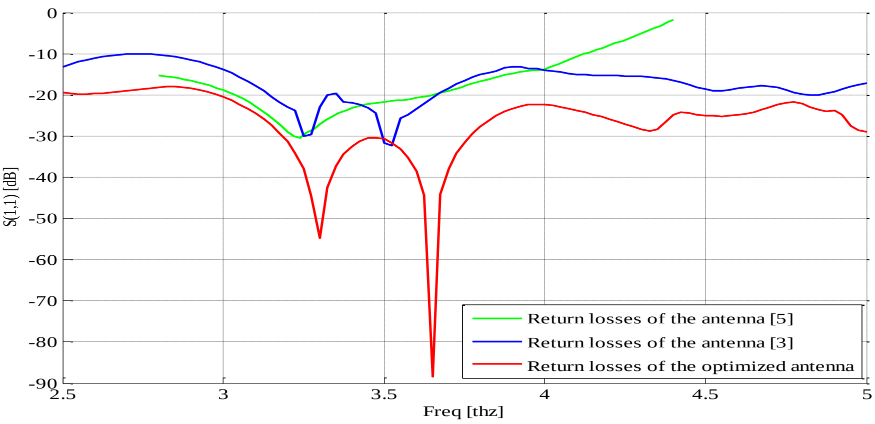


Figure 7. Comparison of the return losses of the optimized antenna to the return losses of the antennas [3,5]

Table1. Characterization of te THz MEMS Helix Antenna Optimized in HFSS

Section	Parameter	Value (um)	Specification
Helix	Diameter (*D*)	27.3661	Q-N optimization
	Pitch (*S*)	14.1409	SNLP optimization
	Turn number (*N*)	10	SNLP optimization
	Height (H_h)	141.409	$H_h = S.N$
	Slent angle (α)	9.340°	$S = \pi.D.\tan\alpha$
CPW	Width (*W*)	4.8659	Q-N optimization
	Gap (*G*)	2.0937	SNLP optimization
	Width (L_x)	35	/
	Longer (L_y)	40	/
	Thickness (*T*)	1.5674	SNLP optimization
Silicon substrate	Thickness (H_s)	9.2952	Q-N optimization
	Longer (L_s)	80	/
	Width (W_s)	79.0533	$W_s = W + 2(L_x + G)$
Antenna	Height (H_A)	152.2721	$H_A = H_s + T + H_h$

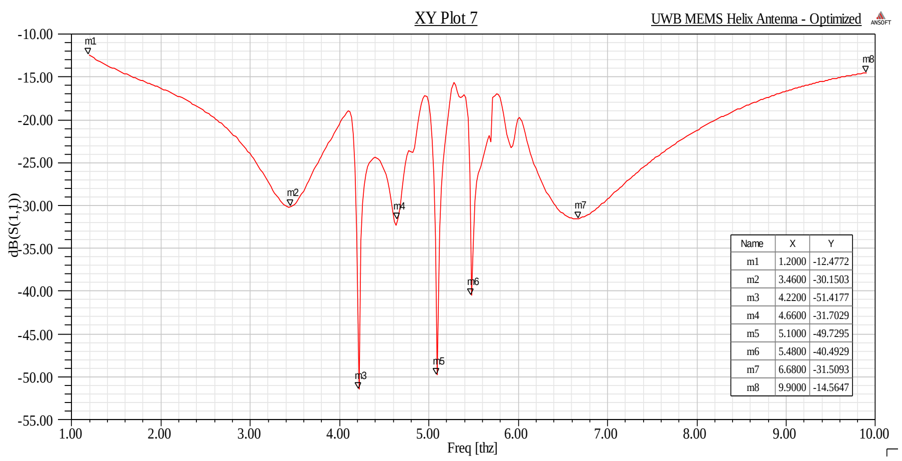


Figure 8. Return losses graph of the proposed UWB THz MEMS helix antenna optimized by HFSS-based Q-N and SNLP in 1.2 to 9.9 THz

Finally, the compact THz antenna design optimized using Q-N and SNLP methods has been tested and simulated covering an ultra wide range of frequencies of 8.7 THz extending from 1.2 to 9.9 THz as presented in Figure 8. The antenna shows very low return losses of closely less than -20dB for the entire bandwidth presenting a great success in finding useful design with very good performance for UWB wireless products. This demonstrates the advantage of HFSS optimization techniques in offering a more degree of freedom in developing new structures, supporting multiple resonance modes distributed across a large THz spectrum, based on the proposed MEMS helix antenna design which presents a potential candidate for different wireless communication applications.

4. Conclusion

In this paper, a new geometrical configuration of a THz MEMS helix antenna design is developed using HFSS-based Quasi-Newton and Sequential Non Linear Programming optimizers which demonstrate high efficiency and accuracy in achieving excellent performance and high um-level precision. The proposed THz antenna design can be easily developed using micromachining technology based on MEMS processing, and offers very good applications for a wide range of frequencies from 2.5 to 5 THz. These characteristics make the proposed MEMS helix antenna design highly attractive to support several THz systems such as radar, biomedical, sensing, imaging, space, radio astronomy, and spectroscopy systems [16].

References

[1] Gauthier G. P, Courtay A, and Rebeiz G. M. Microstrip antennas on synthesized low dielectric-constant substrates. *IEEE Transactions on Antennas Propagation.* Jun. 1997; Vol. 45 (8): 1310–1314.
[2] Pan B et al. *A W-band surface micromachined monopole for low-cost wireless communication systems*. Microwave Symposium Digest, IEEE MTT-S International. Fort Worth, TX. USA. Jun. 2004; 1935–1938.
[3] Guo L, Huang F, and Tang X. A novel integrated MEMS helix antenna for terahertz applications. *Optik*. 2013; Vol. 125 (1): 101-103.
[4] Ko W. H, Suminto J. T, and Yeh. Bonding techniques for microsensors. *Studies in Electrical and Electronic Engineering.* 1985; Vol. 20: 41-61.
[5] Guo L, Huang F, and Tang X. *Design of MEMS On-chip helical antenna for THz application*. IEEE Conferences. Chengdu, China. 2016; Vol. 56(8): 15-18.
[6] Siegel P.H at al. *Antennas for terahertz applications*. IEEE Antennas and Propagation Society International Symposium. Albuquerque, NM. 2006; 2383–2386.
[7] Rebeiz G. M. *Millimeter-wave and terahertz integrated circuit antennas*. Proceedings of the IEEE. 1992; Vol. 80 (11): 1748-1770.
[8] Morabito A. F, Lagana A. R, and Isernia T. Isophoric array antennas with a low number of control points: a 'size tapered' solution. *Progress in Electromagnetics Research Letters*. 2013; Vol. 36: 121-131.
[9] Morabito A. F, Laganà A. R, Sorbello G, and Isernia T. Mask-constrained power synthesis of maximally sparse linear arrays through a compressive-sensing-driven strategy. *Journal of Electromagnetic Waves and Applications*. 2015; Vol. 29 (10): 1384-1396.
[10] Zheng M, Chen Q, Hell P. S, and Fusco V. F. Broadband microstrip patch antenna on micromachined silicon substrates. *Electronics letters*. 1998. Vol. 34 (1): 3-4.
[11] Biber S et al. *Design and Measurement of a 600 GHz Micromachined Hom Antenna Manufactured by Combined DRIE and KOH-Etching of Silicon*. 16th International Symposium on Space Terahertz Technology. 2005; 507-512.
[12] Lai X.H et al. *Suspended nanoscalesolenoid metal inductor with tens-nH level inductance*. IEEE 21st International Conference on MEMSYS. Wuhan, China. 2008; 1000–1003.
[13] Li C, Ding K, Wu W.G, and Xu J. *Ultra-fine nanofabrication by hybrid of energeticion induced fluidization and stress*. IEEE 24th International Conference on MEMSYS. Cancun, Mexico. Mar. 2011; 340–343.
[14] Kovacs G. T. A, Maluf N. L, and Petersen K. E. *Bulk micromachining of Silicon*. Proceedings of IEEE. Aug. 1998; Vol. 86(8): 1536-1551.
[15] HFSS online help. Ansoft Corporation, 2007.
[16] Drouin B, Yu S, Pearson J, and Gupta H. Terahertz spectroscopy for space applications: 2.5–2.7 THz spectra of HD, H2O and NH3. *Journal of Molecular Structure*. Dec. 2011; Vol.1006 (1-3): 2-12.