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Design and Fabrication of Wide Dual-Band Normal Mode Helical Antenna

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Abstract:

In this paper, a wide dual-band non-uniform Normal Mode Helical (NMHA) is presented at UHF band. Two non-uniform NMHAs with different diameters that nested each other are used for increasing wideband. The proposed method can be lead to design wideband antenna and dual-band antenna with small frequency ratio. A sample antenna has been simulated and fabricated. Simulation results are shown that 7.6% and 9.95% fractional bandwidth (FBW) have obtained at center frequencies of 462 MHz and 905 MHz, respectively. There is a good agreement between simulation and measurement results.

Keywords — **Dual-band, Nested non-uniform Normal Mode Helical (NMHA).**

I. INTRODUCTION

Normal mode helical antenna (NMHA) is a proper choice of military handsets and recreational wireless devices because of the small dimensions compared to dipole [1]. From important characteristics of NMHA can mention to its narrow bandwidth and reproducibility of radiation characteristic in 2.5 times of operation frequency [2]. The first listed characteristic (narrow bandwidth) is considered as the NMHA disadvantage, but reproducibility of the radiation characteristic of the NMHA can be used for the design of the dual-band antenna. Dual- or multi-band antennas have numerous applications in wireless communication systems that use from frequency-division duplexing (FDD) in transmitter/receiver or support multi-standard band simultaneously [3-4]. In the FDD method, two separate radio frequency band are selected for transmitting and receiving. Usually, the choice of the band has considerations besides the design of the antenna. Therefore, the wide-band antenna design that its second band is in control is of great importance for the designer. Unfortunately, the second band of the NMHA isn't in control of the designer. Using the non-uniform pitch is proposed to control second band [2,5]. In [6], the author used this method and designed wide single- and dual-band NMHA. Using lumped loading inductors and continuously varying radius has been achieved to reduce the size and increase the bandwidth of the NMHA in [7]. The optimized HF and VHF non-uniform NMHA has been investigated in [8] to improve antenna bandwidth and efficiency.

In this paper, wide single- and dual-band NMHA is presented by using two nested non-uniform pitch-NMHA. The paper is organized into five sections. Design stages of NMHA with uniform and the non-uniform pitch is given in section II. Proposed antenna configuration is presented in section III. Section IV indicates results simulation. Finally, a conclusion is given in section V.

II. DESIGN OF NMHA

A: *Uniform Pitch NMHA*

Fig. 1(a) shows uniform pitch NMHA. As demonstrated, antenna design parameters are the number of terns (N), the distance between terns (S) or the angle between turns (α), and antenna diameter (D). Antenna operating modes are divided into axial- and normal- modes. In normal mode, dimensions are small in compared to operating wavelength $(S, D << \lambda)$ so that the current distribution is supposedly fixed in antenna length. For simplicity of the analysis and design of the antenna, the antenna can be considered as a combination of multi- small dipoles and loop antennas [9]. Finally, the model of NMHA fed in the center is a dipole with length 2N×S and 2N loops antenna, as shown Fig.2. The input impedance of the dipole and loops antenna are capacitive and inductive [9], respectively. So, the proper combination of them leads to pure resistance. Mentioned property is named "self-resonance" condition of the NHMA. This means that antenna dimensions must be chosen so that the imaginary part of the input impedance is zero at operating frequency. For the antenna shown in Fig. 2, "self-resonance" condition is given by [10]:

$$600\pi \frac{19.7(2N)\left(\frac{D}{\lambda}\right)^2}{9\frac{D}{\lambda}+20\frac{2N\times S}{\lambda}} = \frac{279\frac{2N\times S}{\lambda}}{2N\pi\left(0.92\frac{2N\times S}{\lambda}+\frac{D}{\lambda}\right)^2} \quad (1)$$

On the other, it is necessary that the resistance part of input impedance approaches 50 ohms. According to Fig. 1(c), the resistance part of NMHA is equal to [8]:

$$R_{in} = 80\pi^2(2N)^2\left(\frac{S}{\lambda_0}\right)^2 + 20\pi^2\left(\frac{\pi D}{\lambda_0}\right)^4(2N)^2 \quad (2)$$

So, antenna parameters are determined in such a way that the given goal function in (3) is minimized.

$$OF = |50 - R_{in}| + \left| 600\pi \frac{19.7(2N)\left(\frac{D}{\lambda}\right)^2}{9\frac{D}{\lambda}+20\frac{2N\times S}{\lambda}} - \frac{279\frac{2N\times S}{\lambda}}{2N\pi\left(0.92\frac{2N\times S}{\lambda}+\frac{D}{\lambda}\right)^2} \right| \quad (3)$$

Now, if the antenna is a monopole, by using of image theorem, the above relations can be re-used.

B: ***Non-Uniform Pitch NMHA***

Using the non-uniform pitch idea instead of the uniform pitch was presented to control second band [2]. Fig. 1(b) shows a non-uniform pitch NMHA. The operation mechanism of this antenna has been given in [5]. Indeed, this method causes that distributed inductor and capacitor of the antenna change that leads to control of the second band.

III. PROPOSED ANTENNA CONFIGURATION

The proposed antenna configuration is observed in Fig. 2. As observed, antenna consists of two non-uniform pitch NMHAs nested each otherthat they are named Ant.1 and Ant.2in the following paper. The design parameters and operating frequencies of the proposed antenna are given in Table I. Columns 2 and 3 of Table I show the physical and electrical features of each antenna alone. Simple calculation dedicated that total length of used wires is $0.5766\lambda_1$ and $0.6591\lambda_1$ (λ_1 is waveguide at 462MHz), respectively. While height antenna is $0.1414\ \lambda_1$ that

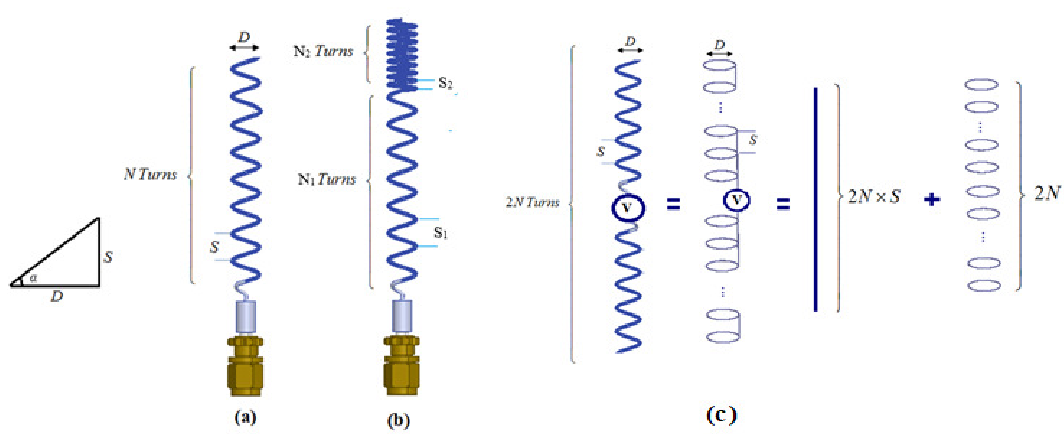

Fig. 1. The sample of NMHA and its design parameters, (a) uniform pitch NMHA (b) non-uniform NMHA(c) The sample of NMHA that fed in the center and its equivalent models.

is less than $\lambda_1/4$. The diameter of the used wire for the fabricated antenna is 1 millimeter. The diameter of Ant.1 and Ant.2 are 10 mm and 7.5 mm, respectively. This method (using nested two non-uniform NMHA antennas) can help us to design dual-band with frequency approximate ratio and the wideband antenna.

IV. SIMULATION RESULTS OF THE DESIGN ANTENNA

Proposed antennas have been simulated by CST commercial software. The simulation of the reflection coefficient of the antenna is shown in Fig.3. More minor results of the simulation that features have been given in Table I, show that the first resonance frequency of Ant.1 and Ant.2 are 392 MHz and 380 MHz, respectively. While the first resonance frequency of the proposed antenna is 462 MHz. Therefore, it can be said that when two antennas lie nested, "self-resonance"condition changes because distributed inductor and capacitor of structure modify.

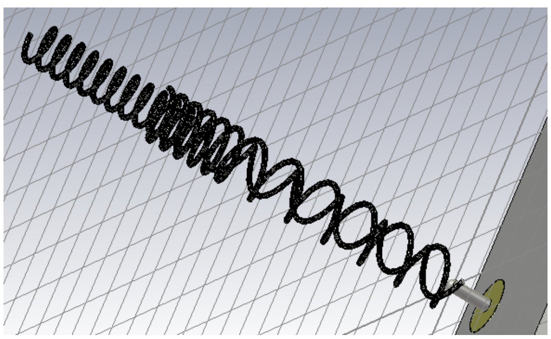

Fig. 2. The proposed antenna configuration that consists of two non-uniform pitch NMHAs nested each other.

TABLE I
DESIGN PARAMETERS AND OPERATION FREQUENCIES OF THE PROPOSED ANTENNA

	Ant.1	Ant.2	Nested 1 & 2
D *(mm)*	10	7.5	-
S_1 *(mm)*	8	9.5	-
N_1	6	6	-
S_2 *(mm)*	3	3	-
N_2	5.7	11.6	-
f_{r1} *(MHz)*	392	380	462
FBW* (First band)	-	-	7.6%
f_{r2} *(MHz)*	780	820	905
FWB (Second band)	-	-	9.95%
f_2 / f_1	1.98	2.15	1.95

*FBW: Fractional Bandwidth

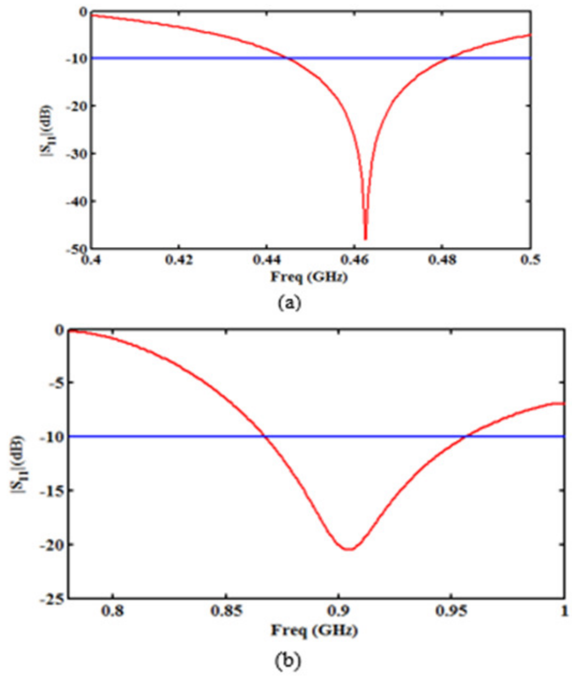

Fig. 3. The simulation of the reflection coefficientof the proposed antenna (a) the first band (b) the second band.

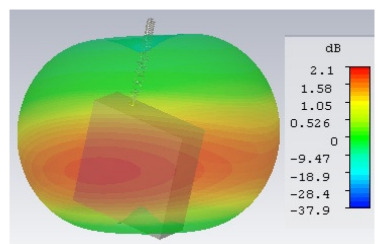

Fig. 4. 3-D of the radiation pattern

In this state, the obtaining of "self-resonance" condition is complex because the calculation of the mutual coupling between antenna is related to different factors and its calculation is not easy. Therefore, for the design of the desired antenna, first non-uniform pitch NMHAs are synthesized separately, then, antennas are set nested together and re-simulated and optimized. As known, the radiation pattern of the NMHA is omnidirectional in the perpendicular plane on antenna axis. Here, 3-D of the radiation pattern of the antenna at 900 MHz is shown in Fig.4, too. As expected, the radiation pattern is normal on the antenna axis.

TABLE II
DESIGN PARAMETERS AND OPERATION FREQUENCIES OF OTHER THREE PROPOSED ANTENNAS

		Ant.1	Ant. 2			
Physical parameters of antennas	D*(mm)*	10	7	Operation frequencies of antennas Nested 1 & 2	f_{r1} *(MHz)*	615
		10	7			660
		10	7			450
	S_1*(mm)*	7.75	9.5		FBW (First band)	8.3%
		7.75	8			19.7%
		10	8			8.9%
	N_1	6	6		f_{r2} *(MHz)*	763
		6	6			-
		5	6			880
	S_2*(mm)*	3	2		FBW (Second band	8%
		3	2			-
		3	2			12.3%
	N_2	4.25	11.6		f_2 / f_1	1.24
		6.75	10.5			-
		3	10.5			1.95

As told previously, using of nested two non-uniform NMHA antennas can be lead to dual-band with frequency approximate ratio and the wideband antenna. Here, to illustrate this claim, the other three designs are introduced. Physical parameters and operating frequencies of these antennas are given in Table II. In all of these designs, diameters of both antennas are fixed and equal to 10 mm and 7 mm, respectively. First, second and third rows of each parameter are related to the first, second and third designs, respectively. It is clear from data given in Table II and depicted VSWR in Fig. 5, the first design is dual-band with frequency ratio 1.24. In the second design, two bands were so close together that leads to wide-band. Fractional bandwidth of this antenna is 19.7%. In facts, the range of operation frequencies of the antenna is between 600 MHz and 730 MHz. Third design shows a wide-dual-band antenna.

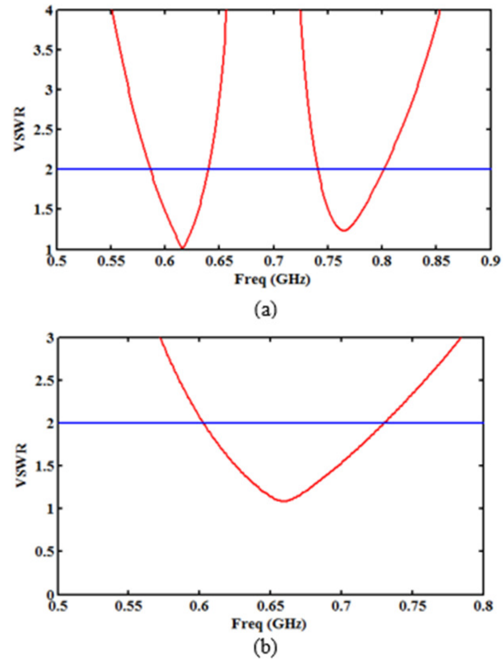

Fig.5. The simulation VSWR of the antenna(a) the first design 1, (b) the second design.

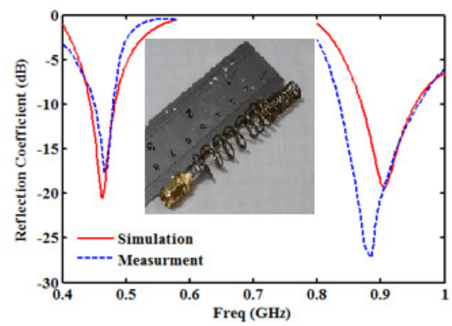

Fig. 6. Compression between simulation and measurement reflection coefficient of antenna.

V. FABRICATION AND MEASUREMENTS RESULTS

A prototype antenna is fabricated and its operating parameters are measured in an antenna measurement chamber. The fabricated antenna with parameters given in Table I is shown in Fig. 6. Compression between the simulation and measurement reflection coefficient of the antenna is depicted in Fig. 6. The simulation and measurement results of 2-D co-polarization components of the radiation pattern of the antenna (at normal plane) are plotted in Fig. 7 at 460 MHz and 900 MHz frequencies. As observed, there is a good agreement between the simulation and measurement results. Measurement of the peak gain of the proposed antenna has been achieved, also. Unfortunately, starting operating frequency of available antenna measurement chamber was 650 MHz. Simulation and measurement antenna realized gain has been plotted in Fig.8. As expected, there isn't agreement between simulation and measurement results in the first band. As shown, the maximum realized gain at 460 MHz and 900 MHz frequencies (in xy-plane) are 0 dB and 2.5 dB, respectively.

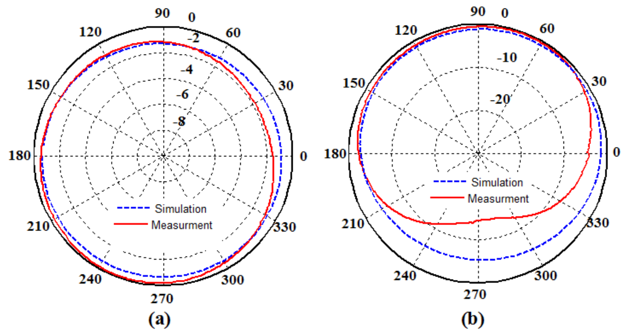

Fig. 7. Simulation and measurement results of co-polarization components of the 2-D radiation pattern of the antenna in normal plane (xy-plane) (a) 460 MHz (b) 900 MHz.

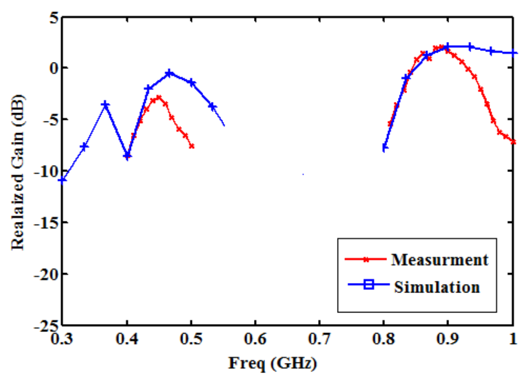

Fig. 8. Simulation and measurement antenna realized gain at normal plane of antenna ($\theta = 90^\circ$).

CONCLUSIONS

In this paper, two non-uniform NMHA that stay on nested together and are fed from one point, were designed, simulated and fabricated for UHF applications. Because of mutual coupling between two antennas, inductor and capacitor of the nested structure and its electrical features modify so that the proposed method leads to wide-dual-band, dual-band with frequency approximate ratio and wideband antenna. Porotype designed antennas have a frequency ratio (in dual-band state) and fractional bandwidth (in the wideband state) equal to 1.24 and 19.7%, respectively in this paper.

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