Helical Antenna to Measure Radiated Power Density Around a BTS; Design and Implementation

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Abstract— **A helical antenna is a helical shaped conductor winded around a cylinder. This antenna can radiate in different modes but the axial mode is one of the most commonly used ones since in this mode, it gives the maximum radiation power. This paper presents a novel, simple and inexpensive method to measure the radiated power density around base transceiver stations (BTS). We design an optimized helical antenna for this application. Our simulation results show that it is possible to measure the power density with about 10% error, which is acceptable for this application. Furthermore, we implement the designed antenna based on our analytical results and calibrate it. Experimental tests have been carried out to examine the performance of the designed antenna.**

I. INTRODUCTION

Wireless communication systems have become an inseparable part of human life in recent decades. Despite various advantages of these systems, many harmful effects on human health are being reported which are assumed to be caused by electromagnetic (EM) waves.

BTSs are very widespread in our populated urban areas and close to our bodies. Hence, it is essential to check out the radiated power density of the EM waves around a BTS not to exceed the standards for human health.

There exists a number of researches to measure cumulative cell tower radiation values besides quality of services (QoS) parameters to analyze power density [1]. Some theoretical ways are also used to estimate the radiation level from an array of dipole antennas. These antennas are used in cellular base stations such as FM, UHF or WiMAX [2]. Some expensive devices such as selective radiation meter (SRM), e.g., "Narda 3-Axes-Antenna; 27MHz-3GHz" are also available to measure power density near a BTS and for high frequencies [3].

Helical antennas have been used in many applications and for different frequency bands. For instance, in higher gain uses, a helical antenna can be used as a feed in parabolic dishes [4]. A 400 MHz helical antenna is also designed for high power RF applications [5]. We can also mention monofilar helical antennas in satellite radio channel [6]. Dual-band quadirfilar helix antenna which is used in satellite uplink and downlink frequency bands [7] and thin helical antennas with conducting cores in a lossy medium Non-insulated antenna are other uses of helical antenna [8].

Some of the advantages of the helix antennas include their wide bandwidths, easy implementation, real input impedances and circularly polarized fields which are utilized in this paper. We design an optimized helix antenna which works for the center frequency of 900 MHz.

The paper is organized as follows. Section II explains the operation principles and the design procedure of the antenna. Section III presents some numerical simulations of the designed antenna in HFSS environment. In the last section, some experimental tests which are performed on the constructed antenna and their results are provided.

II. OPERATION PRINCIPLES

A) Analytical Model

Consider an axial-mode helical antenna that produces radiation along the axis of the antenna. The geometry of the antenna is shown in Fig. 1.

The helix-antenna parameters are defined as follows [9] (see Fig. 1):

D = diameter of helix (center to center)
C = circumference of helix = π D
S = Spacing between turns (center to center)
a = pitch angle = $\tan^{-1}(\frac{S}{\pi D})$
N = number of turns
L = axial length of helix = NS
d = diameter of helix conductor
l = length of one turn = $\sqrt{(\pi \mathrm{D})^2 + (SD)^2}$

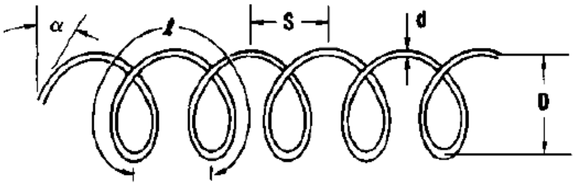


Fig.1. Helix geometry [1].

We have the following formulas for the helical antenna

$$D = 12 \times \left(\frac{C}{\lambda}\right)^2 \times N \times \left(\frac{S}{\lambda}\right) \tag{1}$$

$$\frac{3\lambda}{4} \le C \le \frac{4\lambda}{3} \tag{2}$$

$$\alpha = \tan^{-1}\frac{S}{C} \tag{3}$$

$$\text{correction factor} = \mathrm{K} = \frac{P_2}{P_1} = \frac{8\pi}{\lambda_0^2 \times D \times (1-\Gamma^2)} \tag{4}$$

where D is the directivity of the helix antenna, P_1 is the power which is read on the spectrum analyzer, P_2 is the exact power density on the antenna, S is the spacing between turns (center to center), C is the circumference of helix, λ is the wavelength and Γ is the reflection coefficient given by

$$\Gamma = \frac{R-50}{R+50} \tag{5}$$

Furthermore, the input impedance (Z_{in}), the gain (G) and the half power beam width (HPBW) of the antenna are expressed respectively as:

$$Z_{in} = 140\frac{C}{\lambda} \tag{6}$$

$$G = \frac{6.2C^2NS}{\lambda^3} = \frac{6.2C^2NSf^3}{c^3} \tag{7}$$

$$HPBW = \frac{52}{\frac{C}{\lambda}\sqrt{N\frac{S}{\lambda}}} \tag{8}$$

Where f is frequency, S is the spacing between turns (center to center) and N is the number of turns.

B) Antenna Design

By experiment, it was concluded that setting the parameters ∝=12.5, N=3 and C/λ=0.65, results in the optimum result.

Using (3) and the fact that λ=33.3 cm, we can conclude that S=4.88cm.

Now, we can easily find the antenna length as:

$$L = N \times S = 15cm.$$

Furthermore, from (8) we find its half power beam width:

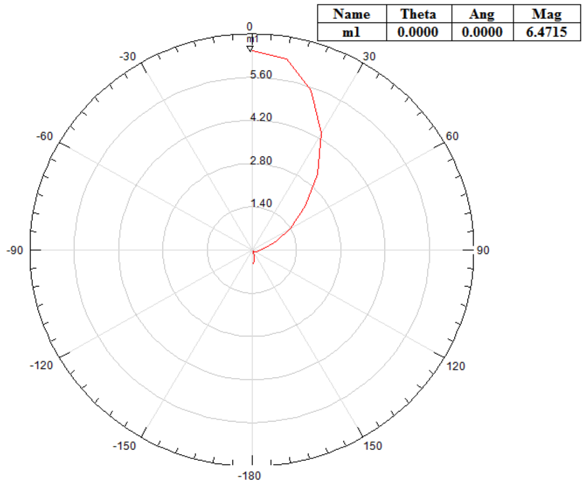
HPBW=120 degree .

Finally, (4) gives us the correction factor (K) 112.48.

III. NUMERICAL SIMULATION

Based on the designed parameters, the resulted helical antenna has been investigated through simulations in HFSS. As shown in Fig. 2, the maximum achievable gain is 6.47 dB.

The three dimension pattern of the antenna is also shown in figure 3.



Name	Theta	Ang	Mag
m1	0.0000	0.0000	6.4715

Fig.2. Helical antenna gain in HFSS.

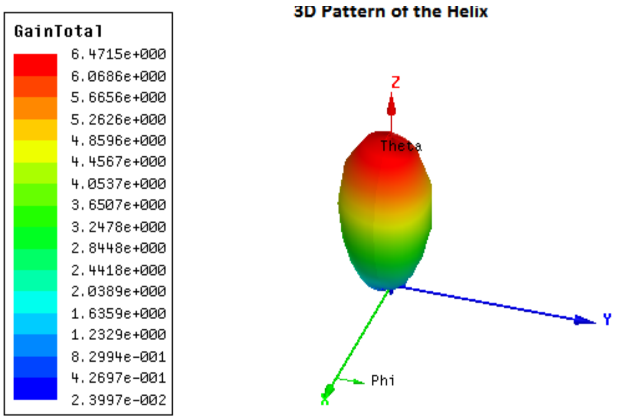


Fig. 3. The 3D pattern of helix antenna.

Next, the input resistance and the S parameters are depicted in Fig. 4 and Fig. 5, respectively. As it is observed, the input resistance is 75 ohms and the S parameter is -10 dB approximately.

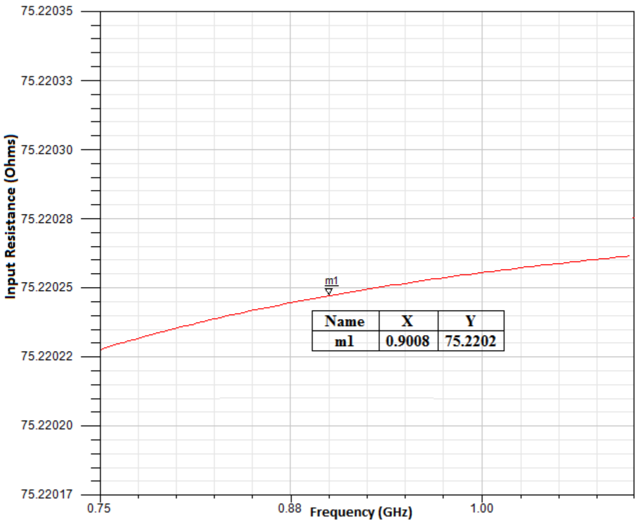


Fig.4. Helical antenna input resistance in HFSS.

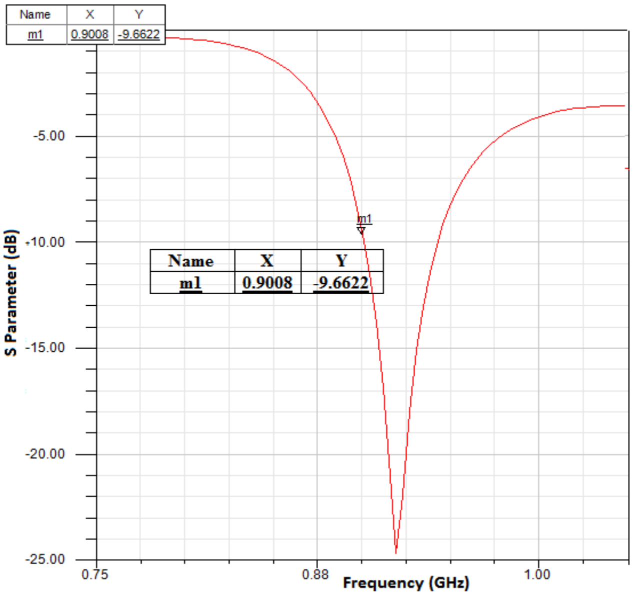


Fig.5. Parameter S_{11} in HFSS.

Furthermore, as depicted in Fig. 6, the voltage standing wave ratio (VSWR) is obtained as 5.9 dB which is almost equal to 1.9. On the other hand, we know that VSWR and the reflection coefficient are related to one another by the following equation:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}. \tag{9}$$

So, the reflection coefficient becomes 0.3.

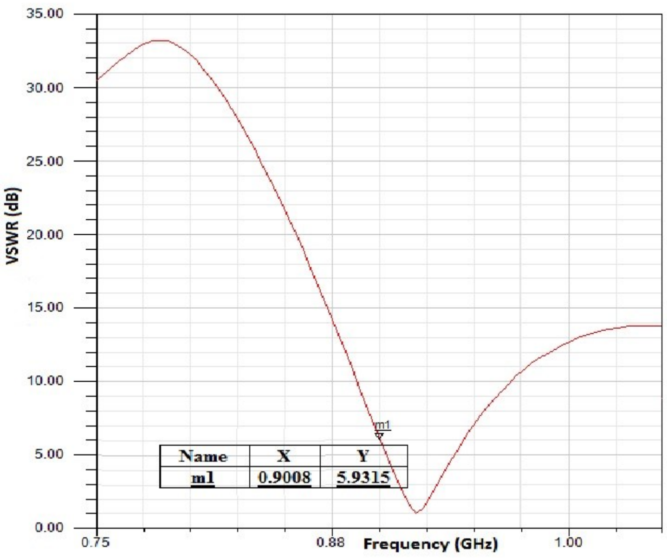


Fig.6. Parameter VSWR in HFSS.

Finally replacing the gain and the reflection coefficient in (4), the correction factor is calculated as K=117.

IV. EXPERIMENTAL DEMONSTRATION

In this section, we have done some tests on the constructed antenna which is shown in Fig. 7.

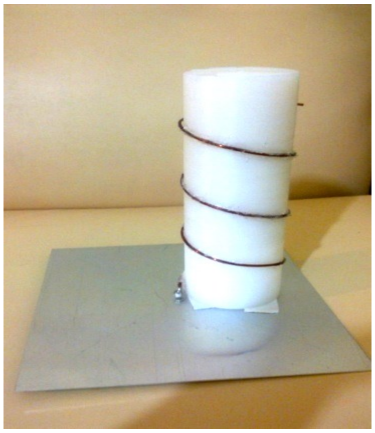


Fig. 7. Constructed Helical antenna

In the first test, we measured S parameter using spectrum analyzer and found the input impedance, reflection coefficient and VSWR accordingly. The S parameter has been measured to be around -20 dB. So, we have:

$$\Gamma = S_{11} = -20dB = 0.1$$

Neglecting the Im{S} and using the fact that our coaxial cable input impedance is 50 ohms, Z_{in} is calculated by (10) which gives as 61 ohm:

$$Z_{in} = Z_0 (\frac{1+S_{11}}{1-S_{11}}) . \quad (10)$$

Substituting this in (9), gives us VSWR as 1.22.

In the second test, we estimated the gain of the helical antenna without the need of the antenna room. To this aim, we used a dipole antenna with known gain of 1.5dBm. The ratio of the powers from two antennas with the same distances to the receiver antenna is equal to the ratio of their gains. So, we connected the dipole antenna to the signal generator as a transmitter. An isotropic antenna was connected to the spectrum analyzer with the fixed distance of 1.5 meter from the transmitter. The received power from the dipole antenna was measured -60.48dBm.

Next, we replaced the dipole antenna with the helix. This time, the received power from the Helical antenna was measured -55.03dbm.

As the last step we could calculate the helix antenna gain:

$$\Delta PdBm = \Delta GdBm$$

$$\Rightarrow P_{isotropic} - P_{helix} = G_{isotropic} - G_{helix}$$

$$\Rightarrow (-60.48) - (-55.03) = (1.5) - \mathrm{G}_{helix}$$

$$\Rightarrow G_{helix} = 6.95dB$$

Hence, the total correction factor of the antenna was calculated by (4), which found to be K=104.

Finally, in our last experiment, we found the total correction factor of the antenna. For this test, we connect the dipole antenna to the signal generator and the helical antenna to the spectrum analyzer, as the transmitter and the receiver, respectively. The distance of the two antennas was set to 70cm. The received power was measured to be -9.71dBm.

Next, we replaced the receiver part with the isotropic antenna connected to Selective Radiation Meter (SRM) to measure the exact received power. In this case, the received power was 490 nw/cm2.

It is noticeable that the SRM measures the power density in nw/cm2. We can obtain the power in watt multiplying the power density by the spherical surface with the radius of 70cm. Then, we can calculate the correction factor as follows:

$$\text{correction factor} = \mathrm{K} = \frac{P_{isotropic}}{P_{Helix}} = \frac{30}{0.327} \cong 92 .$$

The last part of this test was to check the linear relation between the transmitted and the received power. To this end, we doubled the transmitted power. Then we repeated the previous parts measuring the received power on the helix and SRM. These two values became -5.5dBm and 980nw/cm2**,** respectively. It is obvious that both received powers were doubled in this case. This result shows that the antenna has a linear behavior.

We compared the theoretical, simulation and experimental results in the table below.

TABLE I. COMPARISON OF $S_{11}(\Gamma)$, Z_{in} , *VSWR*, *D* AND *K*

Parameter Case	$S_{11}(\Gamma)$	VSWR	R_{in} (Ω)	D (dB)	K
Theory	-10.7	1.82	91	7	112.5
Simulation	-10	1.9	75	6.47	117
Measurement	-20	1.22	61	6.95	104
Final Test	_	_	_	_	92

Comparing the measured correction factor in the last test to the one calculated in the second test, we see around 10% error in our design which is due to experimental errors that can be caused by environmental factors such as noises, instrument resolution, calibration failure and parallax (This error can appear when there is some distance between the instrument that the measurement is done on and the indicator) .

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