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Research Article

Spiral Slotted Microstrip Antenna Design for 700 MHz Band Application

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This work describes the design and implementation of spiral slotted microstrip antenna. Recently, just like other countries, in Mexico, terrestrial digital television has been implemented (analogic shutdown); as a consequence, the 700 MHz UFH Band (698–806 MHz) has been opened to new telecommunications services, particularly wireless mobile communication. This technological advance represents a radio mobile antenna design challenge because it is necessary to design an antenna whose dimensions must be small enough, which satisfies gain, resonance frequency, and bandwidth requirements and is of low cost.

1. Introduction

It is widely known that, a long time ago and nowadays, the frequency bands have been assigned by the government through laws implemented by itself or by owners of big businesses; as consequence, the transmitted information quantity using the free space as transmission media (radio communications services) is too much, that is, radio, TV, radio cellular, and so forth, which have saturated the electromagnetic spectrum causing slow communications and ineffective utilization of the radio spectrum, and particularly radio cellular bands are overloaded in most countries; this way, a great part of the radio frequency electromagnetic spectrum is used in an inefficient way; most of the time, some other frequency bands are only partially or largely unoccupied and the remaining frequency bands are heavily used [1–4].

As far as that is concerned, it is a unique opportunity in order to make the end of the old analogic TV and the beginning of the digital TV easy; just like in other countries, the Mexican Government has established some changes to telecommunications laws since June 2013.

Particularly, according to one of the states, "the concessionaires and official agents have an essential requirement to give the frequency bands back to the Mexican State, which initially were granted permission to attend the TV broadcasting service, as soon as the transition to the terrestrial digital television (TDT) has already been done, in order to guarantee the efficient use of the radio electric spectrum, as well as encourage a fair competition and an optimal use of the 700 MHz UHF Band" [2].

This work proposes a spiral slotted microstrip antenna, single turn and half turn, whose resonance frequency can be designed along the 700 MHz UHF Band (698–806 MHz) LTE, variable when some antenna dimensions are adjusted. To determine the performance of the design parameter, as impedance, resonance frequency, radiation pattern, and polarization, HFSS simulation software has been used and experimental tests under an anechoic camera have been applied.

The paper is organized as follows. Section 2 describes brief antenna design foundations; Section 3 describes simulation and measurements results; Section 4 presents a discussion; and Section 5 comprises conclusions and references.

2. Antenna Design

2.1. Design Foundations. Some of the most used design techniques to miniaturize an antenna are the vertical meandering

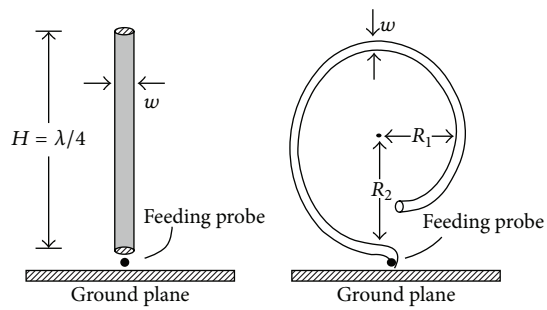


Figure 1: Quarter wavelength monopole, $\lambda/4$, twisted to form a single turn spiral microstrip antenna.

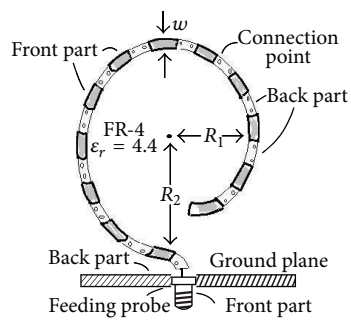


Figure 2: Single turn spiral slotted microstrip antenna geometry.

and the slotted line. Several papers have used these techniques in order to reduce the antenna size; for instance, [5–7] apply the first one to $\lambda/2$ dipole, meandering the wire; on the other hand [7, 8], the second technique applies to a printed spiral patch antenna using slots or small truncated segments.

In our case, these techniques are applied to a single $\lambda/4$ monopole, a quarter-wavelength monopole which is reduced to form a single turn spiral microstrip antenna [9], as shown in Figure 1. Based on [7], it is divided into a set of symmetric rectangular small segments jointly connected in both faces and firmly fastened to small rectangular ground plane, in order to perturb the TM modes and produce circular polarization, as shown in Figure 2.

Two orthogonal modes are produced by the effect of perturbation created by the slots or small truncated segments. The paper [7] has proved that if the number of segments increases, the resonance frequency value decreases. Also, in order to achieve the resonance frequency value along the 700 MHz UHF Band and satisfy the small size antenna, we propose a second antenna, half-turn spiral slotted microstrip antenna, as shown in Figure 3.

On the other hand, because the circuit has been broken down into unit sections, the antenna can be seen as a transmission line divided into circuit elements and considered to be lumped, so the currents on the symmetric and adjacent segments have opposite phase, in accordance with the line transmission theory. Meanwhile, N increases, the antenna shows a smaller resonant width because the wire is folded, the gain is achieved with the highest radiation resistance when the total wire length is the smallest, and the main lobe of the radiation pattern tends to be thin.

Hence, the antenna can be considered as N segments and circuit elements, circularly aligned; all elements adjacent to each other are separated by a distance d (expressed in wavelengths) and if it is considerably small, they can be seen as linearly uniform; thus, the linear array theory [10, 11] can be applied, which establishes the notion that the electric field in the far field is given by [12, 13]

$$\begin{aligned} &\left|E_T\right| \\ &\quad = \left|E_0 + E_1 e^{j\Psi} + E_2 e^{j2\Psi} + E_3 e^{j3\Psi} + \cdots E_{N-1} e^{j(N-1)\Psi}\right|. \end{aligned} \tag{1}$$

But a modification in the phase factor Ψ should be considered, an increment of ϕ angle, caused by the circular orientation of each element, given by

$$\Psi = \beta d \cos\left[\phi + n\left(\Delta\phi\right)\right] + \alpha, \tag{2}$$

where $\Delta\phi = 2\pi/N$, which is azimuth angle, and E_n is the electric field amplitude generated by each element. $d(\lambda)$ is the spacing distance between adjacent elements. α is the progressive phase shift between elements. N is the number of elements. And $n = 1, 2, 3, \ldots, N-1$, $\beta = 2\pi/\lambda$, and α is the angle by which the current in any element leads the current in the preceding element.

This way, the relative electric field can be expressed as

$$\left|\frac{E_T}{E_0}\right| = \left[\frac{\sin\left(N\Psi/2\right)}{\sin\left(\Psi/2\right)}\right]. \tag{3}$$

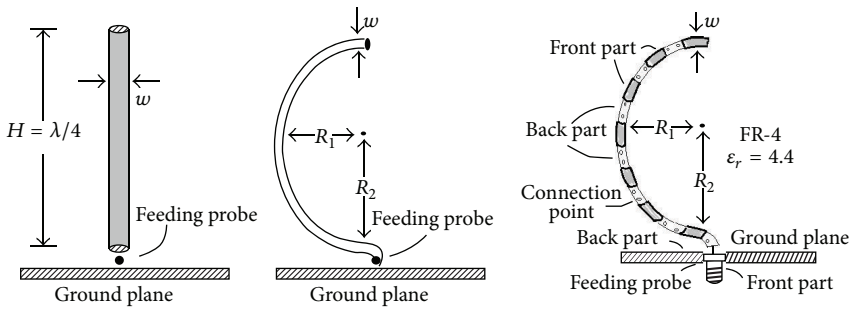


Figure 3: Half-turn spiral slotted microstrip antenna geometry.

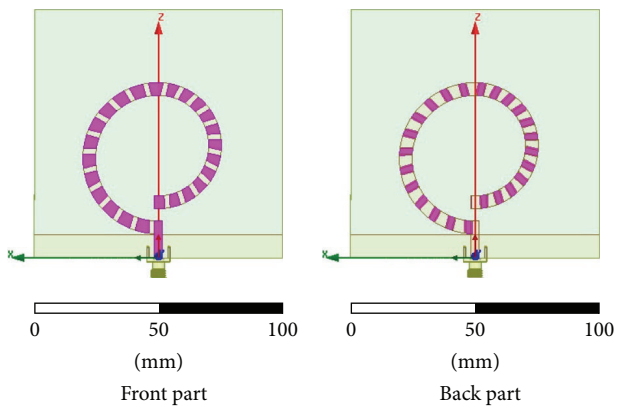


Figure 4: Spiral slotted antenna simulation.

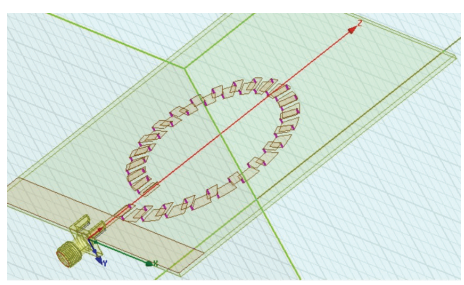


Figure 5: Perspective view.

On the other hand, in order to calculate the resonance frequency, [14] proposes the following expression:

$$f_r = \frac{nc}{4\pi r\sqrt{\varepsilon_r}}, \tag{4}$$

where f_r is resonance frequency, r is spiral radius, ε_r is electric permittivity, and $n = 1$.

Applying this expression and considering $r = 0.015$ m, $\varepsilon_r = 4.4$ (FR-4), and $n = 1$, the calculated resonance frequency value is approximately 750 MHz.

3. Simulation and Measurement

Both antennas have been simulated and measured. HFSS software [15] has been used to simulate the designed antennas, satisfying the following requirements:

(i) Operation frequency $f_{\text{res}} = 750$ MHz ($\lambda \approx 40$ cm).

(ii) Internal radius $R_1 = 1.5$ cm.

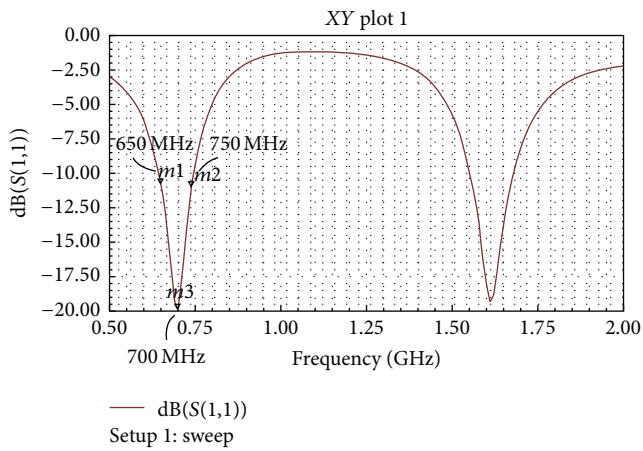
(iii) External radius $R_2 = 2.5$ cm.

(iv) Material: FR4.

(v) Spacing distance between adjacent segments: $\phi = 15^\circ$ ($\pi/12$).

(vi) Spiral perimeter ($2\pi R_1 = \lambda/4 \approx 10$ cm).

3.1. Single Turn Spiral Slotted Microstrip Antenna. Figure 4 shows the front part and back part of the simulated antenna, where $N = 24$, and Figure 5 shows a perspective view. Figure 6 shows magnitude versus frequency simulation graphic, parameter S_{11}, which represents how much power is reflected from the antenna and hence is known as the reflection coefficient or return loss. It is possible to observe that the resonance frequency value is equal to 700 MHz, and the wideband is equal to 100 MHz. The simulation process allowed identifying the necessary dimension adjustments in



Name	Delta(X)	Delta(Y)	Slope(Y)	Invslope(Y)
$d(m1, m2)$	0.0900	−0.1770	−1.9663	−0.5086

Figure 6: Magnitude versus frequency (simulation).

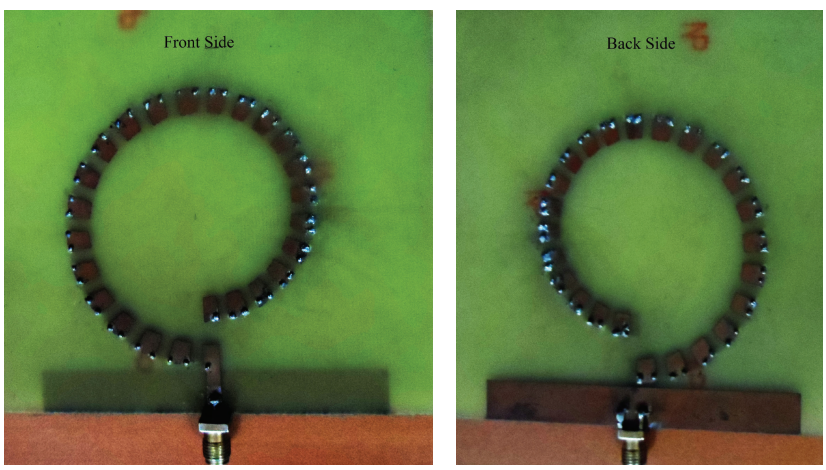


Figure 7: Prototype antenna.

order to achieve the resonance frequency along the 700 MHz UHF Band.

Figures 7 and 8 show the prototype antenna and the antenna under test in the anechoic camera, respectively, which is built using Epoxy glass fibre FR-4; hence, $\varepsilon_r = 4.4$, which is electric permittivity, and SMA connector is used. Vector Network Analyzer ZVB 40, calibrated in the band 500 MHz–2 GHz, has been used to measure the resonance frequency of the designed antenna, and Figure 9 shows the obtained measurement, magnitude versus frequency graphic, parameter S_{11}. It is possible to observe that the resonance frequency of the designed antenna is equal to 717 MHz, with magnitude −16 dB and wideband approximately 50 MHz.

Figure 10 shows the simulated and measured (Plane E) radiation pattern. It can be seen as a semicircle shape, due to scan-blindness phenomena and the scattering behavior in the printed phased arrays.

Figure 8: Prototype antenna under test (anechoic camera).

3.2. Half-Turn Spiral Slotted Microstrip Antenna. In the same way, HFSS software [15] has been used to simulate the designed antenna; Figure 11 shows the prototype antenna, but unlike the single turn spiral antenna this one uses $N = 12$,

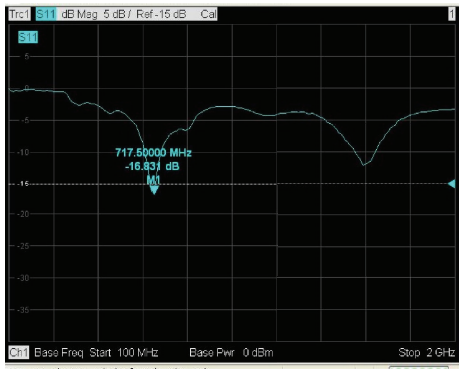


Figure 9: Magnitude versus frequency (measurement).

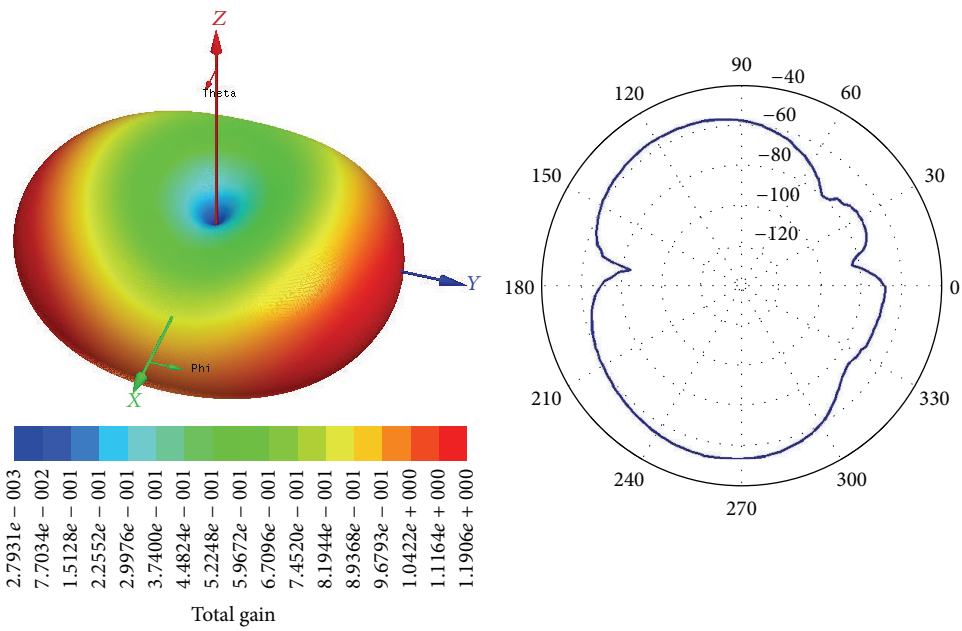


Figure 10: Radiation pattern graphic (measurement), single turn spiral.

Figure 11: Prototype antenna.

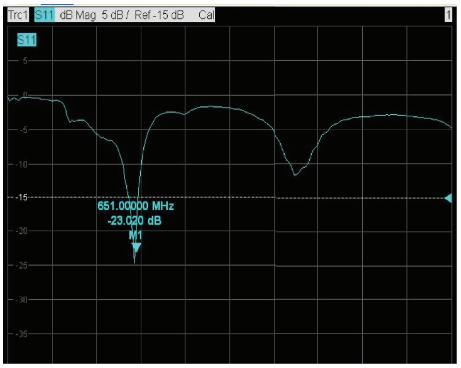


Figure 12: Magnitude versus frequency (measurement).

Figure 14: Antenna gain measurement method.

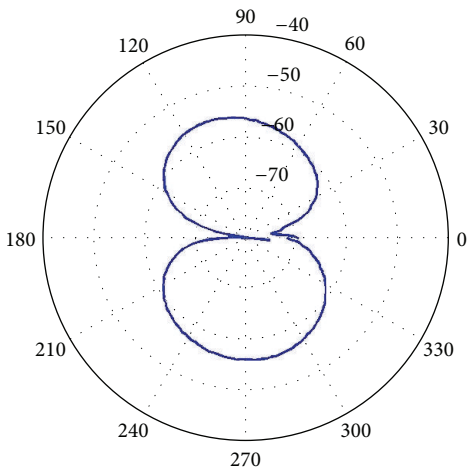


Figure 13: Radiation pattern graphic (measurement).

and the radius dimensions have changed; that is, $R_1 = 2.5$ cm and $R_2 = 3$ cm.

Figure 12 shows magnitude versus frequency measured graphic, parameter S_{11}. It is possible to observe the resonance frequency value equal to 651 MHz, −23 dB, below 700 MHz Band; this value can be increased if the number of segments decreases, in this case by 10 or 11 segments.

Figure 13 shows the radiation pattern. It is possible to observe nulls in the radiation pattern, along the 0°–180° position; the radiation is low, reducing the efficiency of the antenna.

4. Discussion

It is possible to observe that there are small differences, in particular the resonance frequency value of the half-turn spiral antenna, 651 MHz, between the simulation and experimental results, due to construction anomalies, that is, inappropriate soldering, unequal segments, the low quality of the SMA connector, and so forth; this can be corrected by decreasing the number of segments. On the other hand, mismatch, large radiation loss, polarization distortion, several nulls, relatively narrow bandwidth, and low directivity can be improved by combining more segments into the array, but this action carries serious problems, that is, scan-blindness phenomena and the scattering behavior in printed phased arrays. In that respect, [16] refers scan blindness to a condition where, for a certain scan angle, no real power can be transmitted (or received) by a phased array. This situation is observed in the radiation pattern achieved, which shows along the 170°, 45°, and 15° position. Even though it is a counterproductive action, the current method to improve the bandwidth consists of increasing the ground patch separation using a thicker substrate, because the interaction between the segments degrades array efficiency, producing surface wave modes; mutual coupling results in impedance mismatch, considerable radiation loss, and scan blindness in phase array antennas [17]; therefore, in order to avoid these collateral harmful effects which reduce the antenna efficiency, the insertion of a defected ground structure (DGS) is recommended; in that sense, the spiral acts as a DGS, because it can be seen as a defect etched in the ground plane of the microstrip, disturbing the shield current distribution circulating along it, modifying the characteristics of a transmission line, and increasing effective capacitance and inductance; this situation can be seen comparing the radiation patterns of the designed antennas.

Finally, in order to measure and calculate the antenna gain, a second known antenna was used as a reference, placing both antennas into the anechoic camera, spaced 2.1 m apart, as shown in Figure 14; this way, considering the overall transmission loss (free space and cable loss), antenna gain is approximately equal to 1.5 dB.

5. Conclusion

Spiral microstrip antennas have been designed, single turn and half turn, using uniform slotted line technique, meeting the resonance frequency, with an appropriate geometry of the radiation pattern. The achieved results show the feasibility of this kind of small antenna to be used on radio mobile devices operating at 700 MHz UHF Band.

Competing Interests

The authors declare that they have no competing interests.

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