Design of a Spiral-Mode Microstrip Antenna and Matching Circuitry for Ultra-Wide-Band Receivers

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Abstract *- The expanding use of wireless devices has prompted the need of larger bandwidths by these devices. This need is a result of larger bit-rates or the use of different standards using different frequency bands. In this work, the design and test of a wide band antenna and its matching circuit is presented. The wide band antenna is of the Archimedes type because it has a compact size and can be easily manufactured using inexpensive PCB technology. The possibility of including the matching circuitry in the same PCB is also studied.*

1. INTRODUCTION

The bandwidths of radio systems are increasing due to the increase in bit-rates and the use of different standards corresponding to different frequencies bands. Therefore it is important to study radio systems that cover large frequency bands.

One of the first problems to be solved in these systems is the antenna; typically antennae are tuned elements and thus have a small bandwidth compared to the central frequency. There are several types of antennas that exhibit large bandwidths, such as: Bow-Tie, Equiangular Spiral, Log-Periodic and Archimedes spiral [1]. These can be easily constructed using inexpensive PCB technology and exhibit constant input impedance throughout the band.

Next it is necessary to connect the antenna to the receiver, whose first block is normally a low noise amplifier (LNA). Typically the input impedance of the LNA is different from the input impedance of the antenna and it is necessary to add circuitry to realize an impedance matching. This matching circuit has to be carefully designed to guaranty that the bandwidth of the antenna is fully utilized. The main difficulty is that this circuit is constituted by a resonant circuit tuned to a central frequency and thus exhibits a small bandwidth.

In this paper these two problems are studied. Firstly a wideband Archimedes spiral antenna covering a frequency band from 800 MHz to 2.4 GHz is studied, designed and tested. Secondly, matching circuits capable of adapting the impedance of the antenna through most of the antenna bandwidth are studied, designed and experimentally evaluated.

2. DESIGN AND EXPERIMENTAL EVALUATION OF THE SPIRAL MICROSTRIP ANTENNA

The Spiral antennas, such as Equiangular and Archimidean [2,3], are particularly known for their ability to produce very wideband, almost perfectly circularly-polarized radiation over their full coverage area. Spirals have nearly constant input impedance, radiate to both sides of the spiral plane, and are particularly well suited for low-gain mobile communication systems.

A. Theoretical Study

Fig.1 shows the configuration and coordinate system of the proposed two-arm Archimidean spiral antenna. The arms of the spiral are described by the following equations:

$$\begin{aligned}\rho_1(\varphi) &= a.\varphi + b\\ \rho_2(\varphi) &= a.(\varphi - \pi) + b\end{aligned} \qquad (1)$$

Where ρ and φ are polar coordinates, a and b are constants. With as many as 1.5 to 2.5 turns, the radiation pattern of the antenna displays two broad lobes whose maxima are normal to the plane of the antenna. This antenna is made of two microstrip lines printed on a dielectric substrate. The spacing between the conductors ($\Delta\rho$) is chosen to be the same of the line width (Δ) so that the antenna works as a self-complementary [2]. Accordingly to the principles of frequency independent antennas [1], the spiral antenna exhibits *automatic cut-off of radiating currents* [2]. It consists in the fact that the currents in the spiral arms are attenuated by a factor of 40 dB or more as they go through one turn of the spiral, normally equal in perimeter to one wavelength. As so, the outer part of the structure remains unexcited, does not have an effect in neither the radiation pattern nor the impedance of the antenna. The geometric characteristics of the antenna are chosen by the following rules; the lower limit of the frequency span is determined by the perimeter of the last turn of the antenna, which is equal to the wavelength of the lower frequency. The upper limit is set by fact that the wavelength must be equal to the perimeter of the region where the antenna is feed.

The spiral antenna could be feed in phase or in anti-phase. In this case, the antenna was excited in anti-phase. With the anti-phase feed, the perimeter of each turn is equal to one wavelength. Since the reasoning set forth above holds at any wavelength, an anti-phase spiral antenna is frequency independent in terms of both radiation pattern and input impedance.

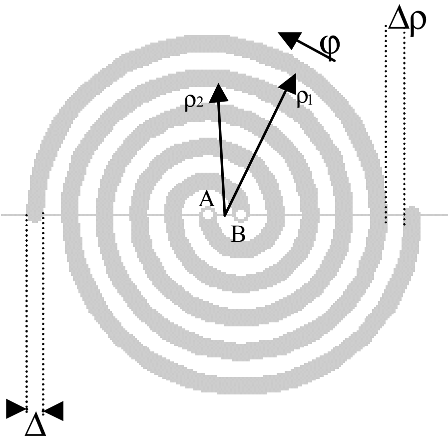

Fig. 1- Two-arm Archimedean microstrip spiral antenna

B. Design and Simulated Results

In this section we investigate the antenna characteristics operating in the frequency range of 0.8 GHz to 2.4 GHz. In manner to operate the spiral as a complementary-antenna, we choose the parameters as follows: space between the conductors = 0.5 mm; line width =0.5 mm; number of turns =2.5. With these parameters, the antenna has an outside diameter of ~6.28λ (λ = 0.375 m) operating at the lower frequency, and a inside diameter of ~ 6.28λ (λ = 0.125 m) at the frequency of 2.4 GHz. This design was analyzed using the simulator MININEC Professional [5]. Fig. 2 illustrate the E_θ far-field ($\phi = 0$) radiation pattern of the spiral antenna for the operation frequencies of 0.8 GHz and 2.4 GHz. Examination of the radiation patterns reveals insignificant changes with the variation of the frequency in terms of gain and radiation fields.

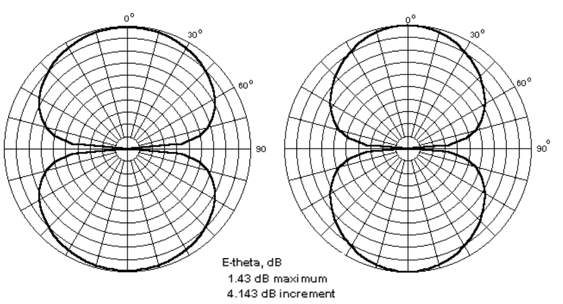

Fig. 2: Simulated radiation pattern for 800 MHz (left side) and 2.4 GHZ (right side).

Figs. 3 shows the distribution of the current along the arms of the spiral. Note that for 2.4 GHz only the first turn of the antenna is excited due the *automatic cut-off principle*. The input impedance is nearly constant over all the bandwidth as shown in the graph of fig. 4.

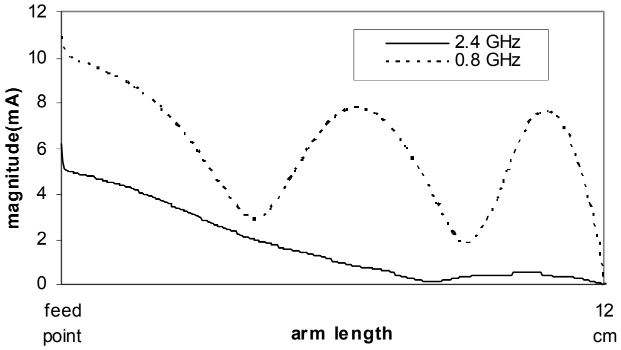

Fig. 3: Current magnitude in one arm of the spiral as a function of arm length and frequency.

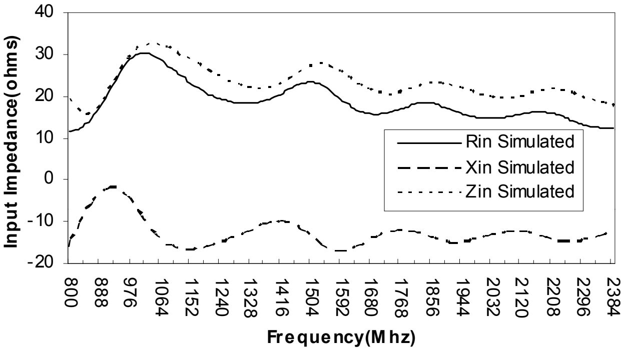

Fig. 4: Simulated input impedance as a function of frequency

C. Measured Results

To verify the validity of the simulated results, a planar spiral microstrip antenna was designed and fabricated accordingly to the dimensions specified above, using FR4 pre-sensitized PCB Laminated - dielectric constant=5.4; thickness=1,6mm. The antenna was feed by a coaxial cable of 50 Ω, and connected to a network analyzer – HP8510B. Using this experimental setup the *S11* parameter was measured and the result is depicted in Fig. 5. The input impedance was calculated from the *S11* parameter and is shown in Fig. 6. The analysis of this experimental data confirms the validity of the simulation results. There are some discrepancies that can be justified by the construction of the antenna, specifically the connection between the ground of the coaxial cable and the PCB board of the antenna. This connection caused the input impedance to increase for frequencies above 2 GHz due to a parasitic inductance effect.

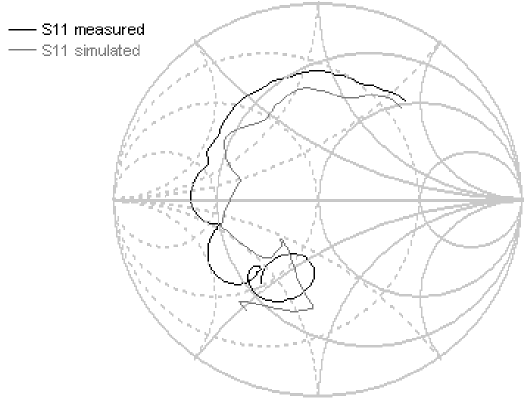

Fig. 5 – Measured and simulated S11 parameter of the antenna

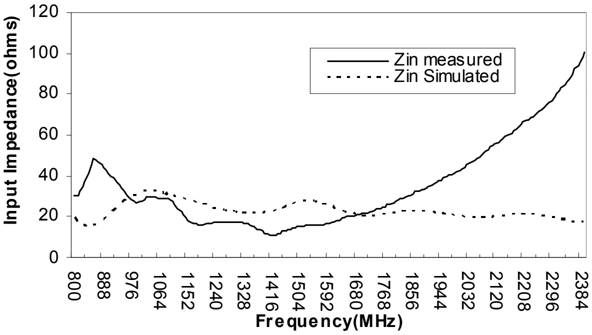

Fig. 6 – Input impedance of the antenna, calculated from the experimental S11 parameter.

3. STUDY OF BROADBAND MATCHING NETWORKS

The wide band characteristics of the antenna *per se* are useless unless the signals can be transferred from the antenna to the RF receiver over the same bandwidth. It is necessary to adapt the impedance of the antenna to the impedance of the low-noise wide-band amplifier of the receiver (typically 50 Ω). This impedance matching is extremely difficult to realize over a large frequency range. In the case of smaller bandwidths, the matching network is usually realized using transmission lines, for larger bandwidths passive components must be used. There are several possible topologies for the matching network [6]. All the circuits depicted in Fig. 7 can be used to realize impedance matching. These circuits also work as filters: low-pass, high-pass and band-pass. This is the problem; all filters exhibit a pass-band with more or less ripple and loss depending on the order of the filter. To obtain larger bandwidths with smaller ripple and loss it is necessary to increase the order of the filter. This is the reason why the circuits on Fig. 7 can only realize impedance matching over small bandwidths. In order to obtain a wideband impedance matching it is necessary to use more complex circuits with more elements (*i.e.* higher filter order). This introduces a new problem, how to size all these components. This is a non-trivial issue because the impedance can change according to the frequency and the matching circuit has to be adjusted to each frequency. Normally a theoretical approach is not recommended due to the complexity of obtaining an exact solution. The solution is to size the component values by trial and error (tuning) or by using an optimization algorithm. The detailed description of such method is out of the scope of this paper and can be found elsewhere [8].

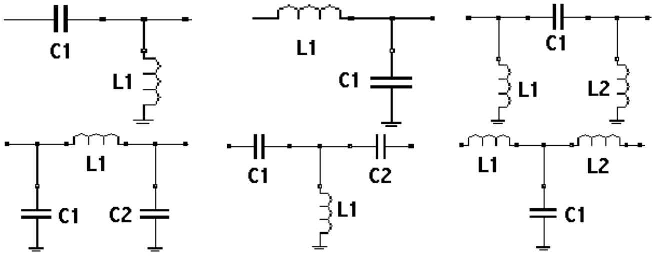

Fig. 7: Possible topologies of matching circuits.

Two topologies were chosen, one to realize the matching from 800 MHz to 1100 MHz and the second to realize the matching from 0.8 GHz to 2.4 GHz. The first approach was to verify the matching for a small bandwidth and the second to verify the matching throughout the entire bandwidth of the antenna. These circuits are depicted on Fig. 8 and Fig. 9 respectively. The hand tuning of these circuits was done through RFSim99 [7] using the experimental *S11* values of the antenna.

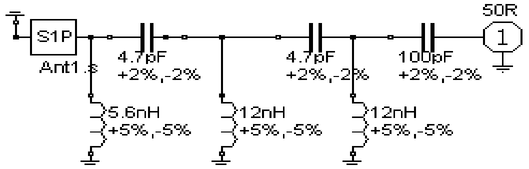

Fig. 8- Impedance matching circuit (800 MHz – 1100 MHz)

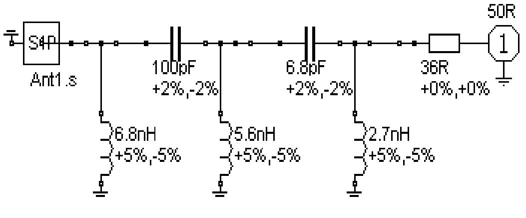

Fig. 9: Impedance matching circuit (0.8 GHz – 2.4 GHz)

4. EXPERIMENTAL RESULTS

The two matching circuits were built on a small PCB, using SMD components; this PCB was soldered to the back of the antenna's board. Using the same experimental set up of section 2, the *S11* parameter was measured for both matching circuits. These experimental results are shown, together with the simulated results, on Fig. 10 and Fig. 11. The simulated results show that it was not possible to obtain a complete match in all the bandwidth (as expected), but reasonable results are feasible. In the case of the matching from 0.8 GHz to 1.1 GHz the *S11* parameter is close to 0 only in the chosen bandwidth and for larger frequencies, the *S11* parameter increases implying a worst match. In the case of the matching from 0.8 GHz to 2.4 GHz the *S11* parameter is inferior to 0.3 in the entire frequency range, which is considered a reasonable match. The experimental results are close to the simulated results in the case of the circuit tuned to the band of 0.8 GHz to 1.1 GHZ. The observed phase difference can be explained by parasitic inductance. The divergence between the simulated and measured results of the *S11* parameter for the circuit tuned to all the bandwidth is still under investigation.

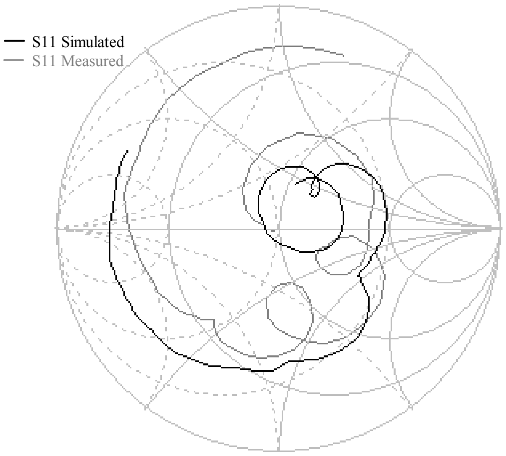

Fig.10: Experimental results for antenna and matching circuit tuned to 0.8 GHz –1.1 GHz, measured from 0.8 GHz to 2.4 GHz

5. CONCLUSIONS

In this work, it was presented the design and test of a wide-band Archimedean antenna and possible matching circuits. The wide-band antenna was manufactured using inexpensive PCB technology. We also studied the possibility of including the matching circuitry and part of the radio circuit on the back of this PCB. The matching networks were designed to produce a good impedance match for most of the antenna bandwidth. The experimental evaluation shows good results and the validity of this approach.

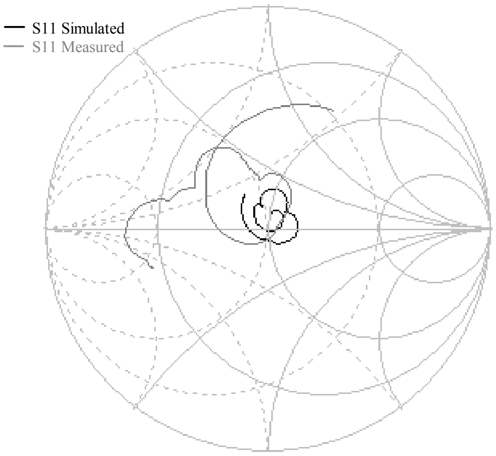

Fig.11: Experimental results for antenna and matching circuit tuned to 0.8 GHz –2.4 GHz, measured from 0.8 GHz to 2.4 GHz

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