Miniaturized Loaded Crossed Dipole Antenna with Omni-directional Radiation Pattern in the Horizontal Plane

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***Abstract*—In this paper, a new design of a loaded cross dipole antennas (LCDA) with an omni-directional radiation pattern in the horizontal plane and broad-band characteristics is investigated. An efficient optimization procedure based on a genetic algorithm is employed to design the LCDA and to determine the parameters working over a 25:1 bandwidth. The simulation results are compared with measurements.**

I. Introduction

In Spectrum monitoring systems for ITU measurements, the capabilities of state-of-the-art receivers can only be fully utilized if an equally high-grade antenna optimizes the interface where the electromagnetic wave is brought in [1]. Otherwise signal quality is lost. Many antennas exhibit natural resonances. They work best if their dimensions are in a certain relation to the wavelength, depending on the type of antenna used. This is also valid for conventional broadband solutions such as log-periodic antennas. Thus, coverage of wide frequency ranges has always been a specific challenge for the antenna designer and this is precisely where a big demand is emerging as the electromagnetic spectrum in use is continuously and systematically extended.

A complete monitoring system for accurate ITU measurement requires the ability to receive any polarization [1]. This can be done by combining both vertical and horizontal polarization. For broadband vertically polarized antennas, there are well-known solutions, but a horizontally polarized antenna with broadband frequency coverage is still a challenge. Therefore, for the targeted system, working between 20 MHz and 500 MHz, we are aiming at a miniaturized antenna with horizontal polarization. In addition the structure should be assembled and moved easily.

The proposed basic topology is discussed in section II. The design of the dedicated antenna is performed in section III and the measurement results are presented in section IV. Finally the paper is concluded in section V.

II. Horizontal Pattern

There is no problem to achieve ultra wideband omni-directional vertical polarization with well-known broadband antenna structures [2]. The best examples of these kinds of antennas are biconical or discone antennas. Through symmetry they produce a horizontally omnidirectional pattern.

A straightforward topology to generate a horizontally omnidirectional pattern is to use a horizontal loop antenna. However, this type of antenna has a relatively low bandwidth. Another idea is to rotate the vertical dipole and mount it horizontally. Of course, the radiation pattern is then no longer omnidirectional.

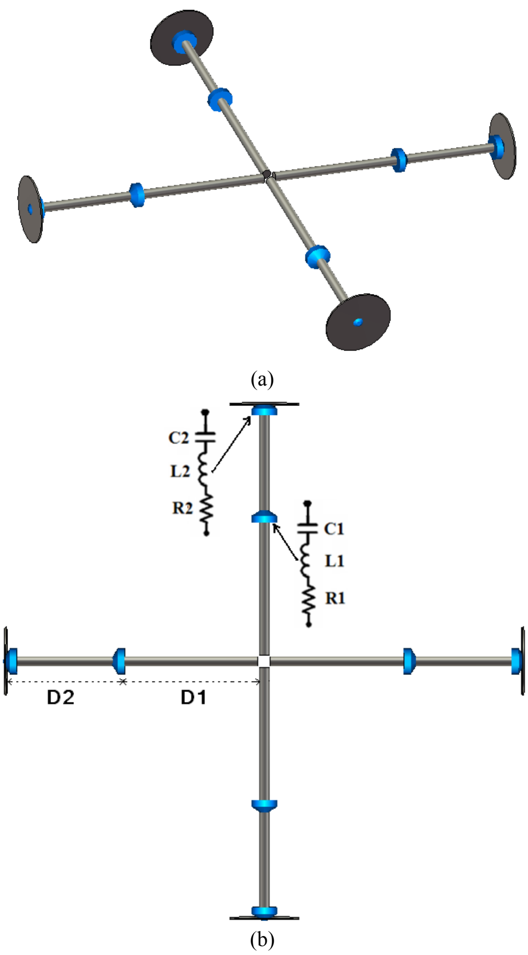

Fig. 1 The Crossed Dipole structure

This problem can be tackled by using two crossed dipoles. In this case, each antenna compensates the null of the other one. Unfortunately, doing so the radiation pattern is no longer really omnidirection over a wide frequency range, due to the change of the radiation pattern (directivity) with frequency. This problem can however be solved by miniaturizing and optimizing the topology using two sets of lumped elements.

Other antenna structures, without lumped elements, have also been reported. Multi-radiator antennas with orthogonal structures that branch off symmetrically from a central stem are found to be potential candidates. The turnstile antenna in Fig.2 (a) is one of the best promising structures. This structure is more suitable for circularly polarized radiation patterns but can be designed to show a good horizontal polarization [3]. Properly designed the structure can show up to 3:1 radiation pattern bandwidth. However, we need a much wider frequency range, 25:1. Structures (c) and (d) in Fig.2 are employing a conical pole to increase the bandwidth and to make the antenna physically smaller. The smaller size will also help to keep the omnidirectional radiation pattern up to higher frequencies. However, these two structures have a very low efficiency at lower frequencies, because of the very small dimensions required in order to obtain the omni-directional pattern. To increase the efficiency at lower frequencies, it is possible to use dielectric or magnetic materials. For frequencies in the HF or low VHF bands, using lumped elements is a well-known procedure [4, 5]. The loads can enhance the antenna characteristics to yield high gain and low VSWR by modifying the current distribution. They can force the structure to radiate with an almost omni-directional pattern in the azimuth plane in the whole frequency band. It is worth to mention that the proposed crossed dipole is actually also a simple turnstile structure, with lumped elements added.

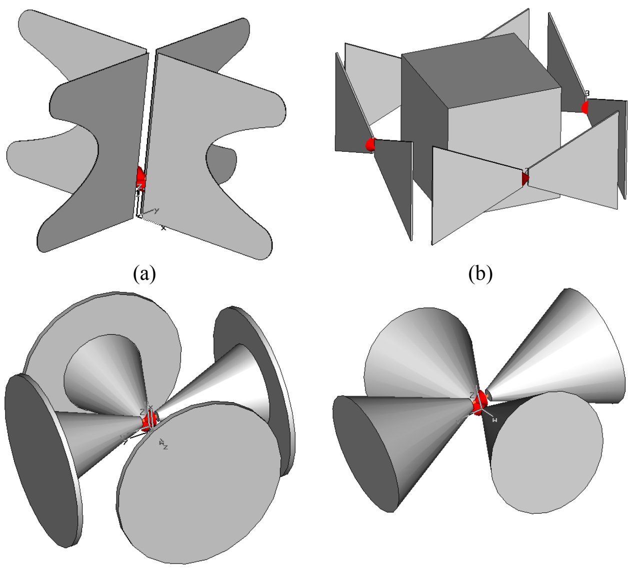

Fig. 2 Some candidate structures to obtain a UWB omni-directional pattern in the horizontal plane.

III. LCDA Antenna Design and Simulation

A. Design Procedure

With a proper feeding, LCDAs produce a broadband circular polarization in the direction perpendicular to the antenna plate (z-direction in Fig. 1) [6], while showing a quasi omnidirectional horizontally polarized pattern in the plane of the antenna (x-y plane), with a small reduction in gain compared to the z direction.

The goal is also to reduce the electrical size of the antenna at the lower frequencies to about 0.1 wavelengths while keeping an acceptable performance. A window of acceptable VSWR at different frequencies is shown in Fig. 4. It is obvious that the antenna will show the worst VSWR in the lower band.

If a circular disc is placed at the end of a dipole/monopole, it increases the capacitance and the electrical length as well [7]. This is applied in our structure. To miniaturize the physical length of the antenna, two sets of compact lumped elements are used as shown in Fig. 1(b). To feed the antenna, both dipoles are exited with equal amplitude but 90 degree constant phase difference over the whole frequency band.

B. Feeding structure

The impedance for each dipole is a balanced 200 Ohm. This has to be transformed to the unbalanced coaxial 50 ohm of the used standard SMA connector. To this purpose, a wideband 4:1 balance-to-unbalance transformer from M/A-COM, model MABACT0064-V1P, has been selected [9]. Fig. 3 shows the required feeding components for the antenna. Two transformers that work as a balun are connected directly to the feeding points of the dipoles. The outputs of both transformers are combined with equal amplitude and 90-degree constant phase difference over the whole frequency band. This phase shift is achieved using a commercial wideband 2-way 90 degree power combiner, QH6031 from Werlatone [10].

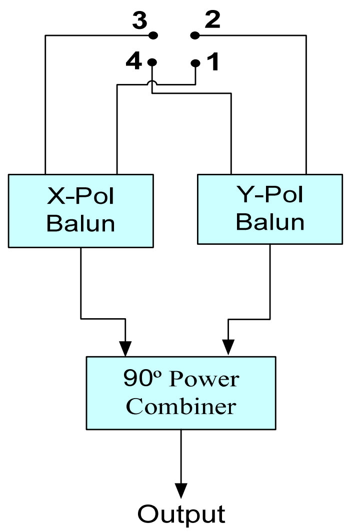

Fig. 3 Feeding requirement

C. Simulation and Optimization Results

To optimize the antenna performance, a genetic algorithm optimizer code in Virtual Basic is combined with CST microwave studio [9] to determine the load components, their locations, and the parameters of the matching network, in order to reach to the maximum pattern flatness while keeping the VSWR within the required window. Thus, a complex fitness function considering both wideband beam shaping and VSWR reduction is defined. After the optimization, the maximum length of the antenna is less than 7 % of the wavelength at the lowest working frequency, 20 MHz. Fig. 4 shows the final optimized results for the VSWR of each dipole.

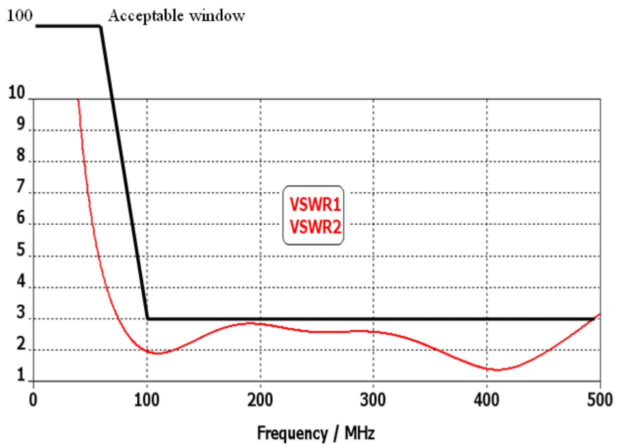

Fig. 4 Final simulated VSWR using CST in comparison to defined mask

The optimized values for the load components, their locations and the size of the loaded disk have been summarized in Table I. Simulation results of radiation patterns, directivity, gain and realized gain of the antenna are shown in Fig. 5 and Fig. 6.

TABLE I
OPTIMIZED PARAMETERS OF THE ANTENNA

Parameter	Value	Description
C1	2.2e-10 F	Capacitor 1
C2	2.2e-10 F	Capacitor 2
H1	276.5 mm	1st Elements distance
H2	480 mm	2nd Elements distance
L1	7e-8 H	Inductor 1
L2	1e-7 H	Inductor 2
R1	120 Ohm	Resistor 1
R2	120 ohm	Resistor 2
Disc_R	75 mm	Disc Radius
g	25 mm	The Gap for lumped elements
Rad	10 mm	Rods' radius

Fig. 5 shows the radiation pattern of the optimized LCDA for different frequencies. As stated before, the maximum of the radiation pattern wihin the working range is directed prependicular to the horizontal plane but the magnitude of the radiation pattern in the horizontal plane is still acceptable. The polarization of the antenna in the whole frequency band in the maximum direction is CP. In the horizontal plane the pattern is reaching a sufficient level of omnidirectionallity. In Fig. 6 the directivity, gain and realized gain versus frequency are shown. The maximum deviation from omnidirectionallity in the azimuth plane versus frequency is shown in Fig. 7. It can be seen that the maximum deviation occurs at 350 MHz at an angle varying within ± 3 degrees, which is acceptable for monitoring measurements.

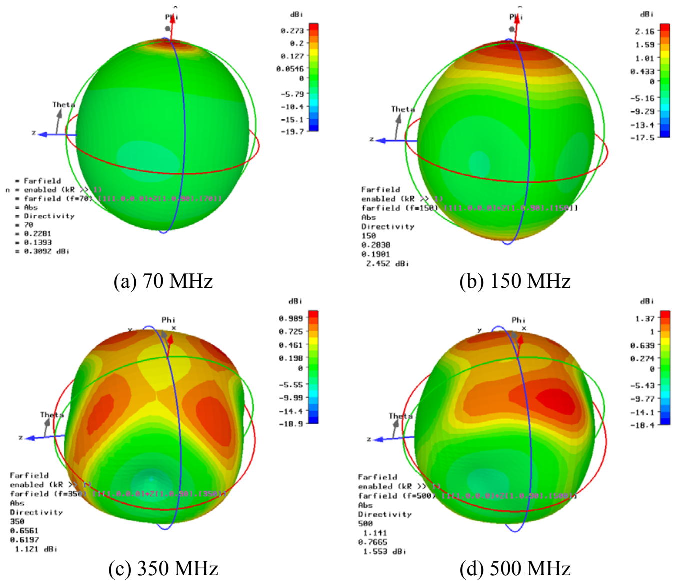

Fig. 5 3D Horizontal radiation pattern of proposed antenna at different frequencies

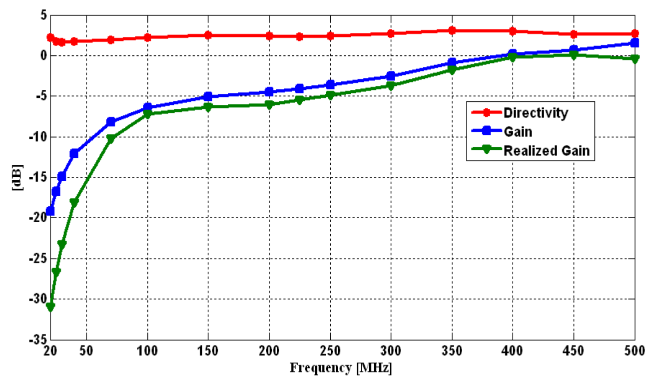

Fig. 6 Directivity, gain and realized gain of the proposed antenna

IV. CONSTRUCTION AND MEASUREMENT

The manufactured antenna is shown in Fig. 8. For the placement of the lumped loads inside the dipole, the body of the dipole is cut and a non-metal holding box is connected to each of the separated parts of the dipole to keep and protect the loads. In the center of the constructed antenna on top of the cross, there is the housing for the combiner of the input signals of both dipoles with 90 degrees phase shift. The final result of the measured VSWR of the constructed structure is given in Fig. 9. It can be seen that the total VSWR in the whole band is below 1.5. This very good VSWR is thanks to the power combiner because in the employed combiner, the two outputs are isolated from the input. Any reflections in this way are kept away from the input.

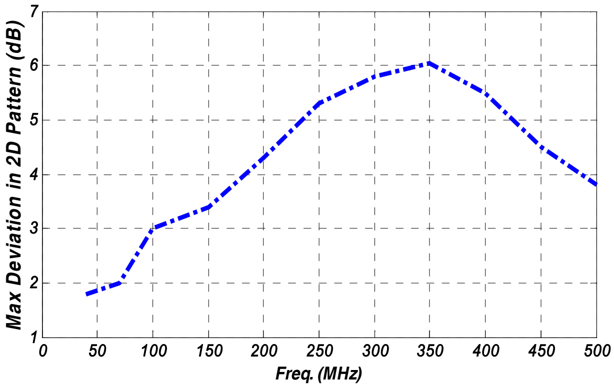

Fig. 7 Maximum variation of the horizontal pattern at different frequencies

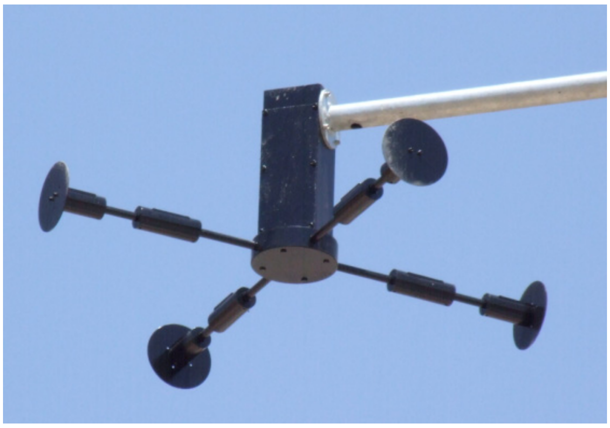

Fig. 8 Constructed Antenna on top of a tower

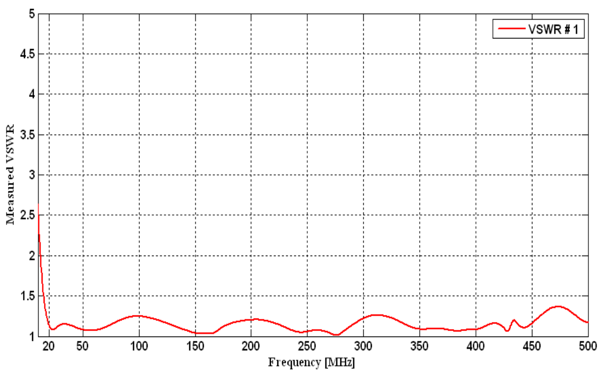

Fig. 9 Measured VSWR of the constructed antenna after power combiner.

V. Conclusions

In this paper a new design of a loaded crossed dipole antenna, (LCDA) with broad-band omni-directional horizontally polarized radiation pattern in the horizontal plane has been proposed. A two-step design procedure was used for this design. First, different unloaded antenna configurations were examined to assess better omni-directional radiation pattern in the horizontal plane. Next, the antenna with the best performance was loaded with resonant tank circuits and a matching network was designed. An efficient optimization procedure based on a genetic algorithm was employed to determine the load components, their locations, and the parameters of the matching network. The simulation results show a maximum deviation 6 dB within a ±3 degree interval over the whole frequency band. The designed antenna was constructed and the VSWR measured.

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