Compact Ultra-Wide-Band HI Monopole Antenna Loaded with C-Shaped Parasitic Elements for DVB-T and LTE Applications

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***Abstract*— In this work, a compact ultra-wide-band microstrip antenna loaded with C-shaped parasitic elements, for Digital Video Broadcasting – Terrestrial (DVB-T) and LTE 450 / 700 signal reception, is designed and presented. The proposed antenna is named "HI Monopole", and its geometry has been designed to be simple, lightweight, and compact. Fabrication process is inexpensive and suitable for electronic gadgets. The HI Monopole operates with ultra-wide bandwidth characteristics, encompassing Digital Video Broadcasting – Terrestrial (DVB-T) standard (470–890 MHz), LTE-450 and LTE-700 bands. This feature has been accomplished by inserting an indent in its ground plane, adjusting dimensions of the feeding line, and adding two C-shaped parasite elements onto the region posterior to the antenna's main radiating element. It was verified via electromagnetic measuring that this device is capable of covering the 429-1022 MHz range. Hence, its total bandwidth is 593 MHz. The superior and inferior cutoff frequencies have been defined using the –10 dB return loss reference level. Therefore, the proposed antenna can be employed for receiving DTV and LTE signals broadcasted in any country, independently of its adopted standard.**

***Index Terms*—** HI monopole, DVB-T, LTE, parasitic elements, ultra-wide-band printed antenna.

I. INTRODUCTION

As a robust communication mechanism, television has had an important role in social and cultural development of several civilizations, along many decades, connecting citizens to their country and to the whole world. However, with the replacement of obsolete analogue VHF (Very High Frequency) system by the newest and digital UHF (Ultra High Frequency) TV standard, the substitution of equipment is inevitable in order to provide access to technically superior Digital TV (DTV) channels.

This analogue-to-digital transition (A/D) has occurred in various countries and, facing this scenario, researchers began to investigate different antenna configurations and designs aiming to improve signal reception characteristics for Digital Video Broadcasting – Terrestrial (DVB-T) standards. With that in mind, several models of DTV antennas, based on various shapes and design techniques, have been presented, with extra attention to the bandwidth in which the equipment operates [1]–[11].

For UHF bands, the communication between devices has to operate with low-power solutions for minimizing interference with other wireless systems. In this context, the solutions must involve low-power spectral density whilst making transmissions with high data rates possible, as well as a high performance in multi-path channels with high signal-to-noise ratios and present sufficient penetration levels through different types of dielectric materials.

Nevertheless, wideband requirements must be fulfilled by the compact lightweight receiving antennas in this kind of application. Receiving devices should be able to operate at various DVB-T spectral bands in existence around the world, such as: Integrated Services Digital Broadcasting Terrestrial (ISDB-T), 470–770 MHz; Advanced Television System Committee (ATSC), 470–860 MHz; Digital Terrestrial Multimedia Broadcast (DTMB), 470–860 MHz; and Digital Video Broadcasting – Terrestrial (DVB-T), 470–890 MHz. Seeking to meet those requirements, the authors in [1] proposed an asymmetric fork-like monopole antenna for DVB-T system, specifically for the 451–912 MHz frequency range. Thus, the device proposed in [1] reached the bandwidth of 461 MHz, which corresponds to 100% of DVB-T range.

More recently, the authors of the studies presented in [3]–[5] have proposed a monopole antenna integrated into its ground plane for receiving DTV signals. The device was loaded with parasitic elements to enhance its bandwidth. However, operation band therein defined was obtained using return loss threshold of –6 dB, which may cause signal reception problems, since only approximately 74.9% of the received power could be transferred to the receiving electronic device. In practice, reception could also be affected by interference caused by other systems, thus further lowering that percentage. Despite the faulty cutoff criterion, the greatest bandwidth reached by the prototype is 510 MHz.

In [6] a low-profile wideband planar antenna for DTV reception is proposed. It is capable of operating with 390 MHz bandwidth, approximately. Still, to reach the antenna's most robust configuration, a high complexity multilayered geometrical configuration was necessary to achieve the bandwidth design goals.

A compact internal antenna for handheld devices and its DTV applications have been discussed in [7], but authors also consider cutoff to be –6dB and achieve a bandwidth of 390 MHz with the constructed prototype. Besides, the device is also geometrically complex, as far as many antenna non-coplanar parts must be integrated to attain high performance.

A novel metal-plate monopole antenna for DTV application is proposed in [8], in which the device is able to cover entirely the 468–880 MHz band. However, it is not so compact and only external installation is possible.

Authors in [9]–[11] have suggested compact monopole antennas for DTV operation, which are printed upon fiberglass/glass epoxy substrate (FR-4). The miniaturized dimensions make these prototypes possible to install internally into electronic devices, such as television sets and tablets. But the antenna in [9], despite its reduced dimensions (35 × 117.5 × 1.57 mm), is able to cover only the

447–818 MHz spectrum.

To reach a device with wider bandwidth, [10] and [11] display an addition of sleeve-type parasitic elements to its respective antennas, positioned by the side of their main radiators. For [10], the dimensions achieved are 45 × 154 × 1.57 mm providing a 459–801 MHz operation band. And, in [11], the device presents dimensions of 48 × 240 × 1.57 mm, operating in the 455–733 MHz band.

When exploring new materials and geometric patterns with the purpose of achieving greater antenna operating bandwidth, the authors in [12] proposed in their study the design of an ultra-wide-band textile antenna. According to the authors, their antenna would be capable to cover the entire 200-800 MHz frequency range. However, there are serious discrepancies between the measurements and the results obtained with the simulated model for the return loss, since there are several crossings of the -10dB cut-off threshold in the experimental curve. Thus, it may be said that it is not possible to consider -10dB as cut-off threshold to define the bandwidth of that device.

In this context, in the study proposed in this paper it is designed a HI Monopole-type antenna to cover 100% of the DVB-T standard band, and the bands of LTE-450 and LTE-700 [13]. This project was developed so that the device, in a single structure, displays characteristics such as: ultra-wide-band operation, low complexity design and simple geometry, compactness, lightweight and inexpensive fabrication that can be easily integrated into the housing of electronic equipment.

For return loss measurements, two epoxy glass substrate prototypes of the device have been built, both with dimensions of 48 × 152.5 × 1.57 mm. With these physical parameters, it is verified that the HI Monopole with C-shaped parasite load configuration is capable of operating within the band 429–1022 MHz (593 MHz of bandwidth), i.e., the device is an ultra-wide-band antenna. The antenna design details are discussed in Section 2. Simulated and measured results are presented in Section 3, and Section 4 holds the conclusions of this work.

II. Antenna design

The HI Monopole geometry was originally proposed in [14]. The antenna's geometry was developed according to studies on the classic planar monopole antenna, and by taking into account the fact that electrical current flows only through the metallic border of the patch due to the influence of the skin effect on electromagnetic (EM) waves interacting with metal. Thus, the radiator is formed using a closed metallic loop along with a central coplanar metallic conductor connecting two opposite sides of the loop, as Fig. 1 precisely defines. The central conductor has the purpose of balancing magnetic fields produced by the loop sides oriented parallelly to that conductor, improving impedance matching as a consequence [14]. The name "HI" is due to the geometrical similarity between the antenna's metallic patch and the Japanese *kanji* ideogram HI, 日 (pronounced as *he*), which means sun or day. Figure 1 presents a schematic of the HI Monopole and of the produced magnetic fields.

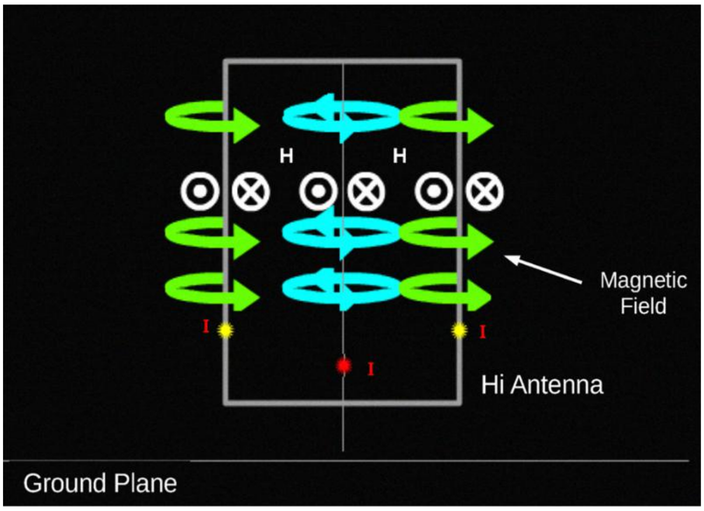


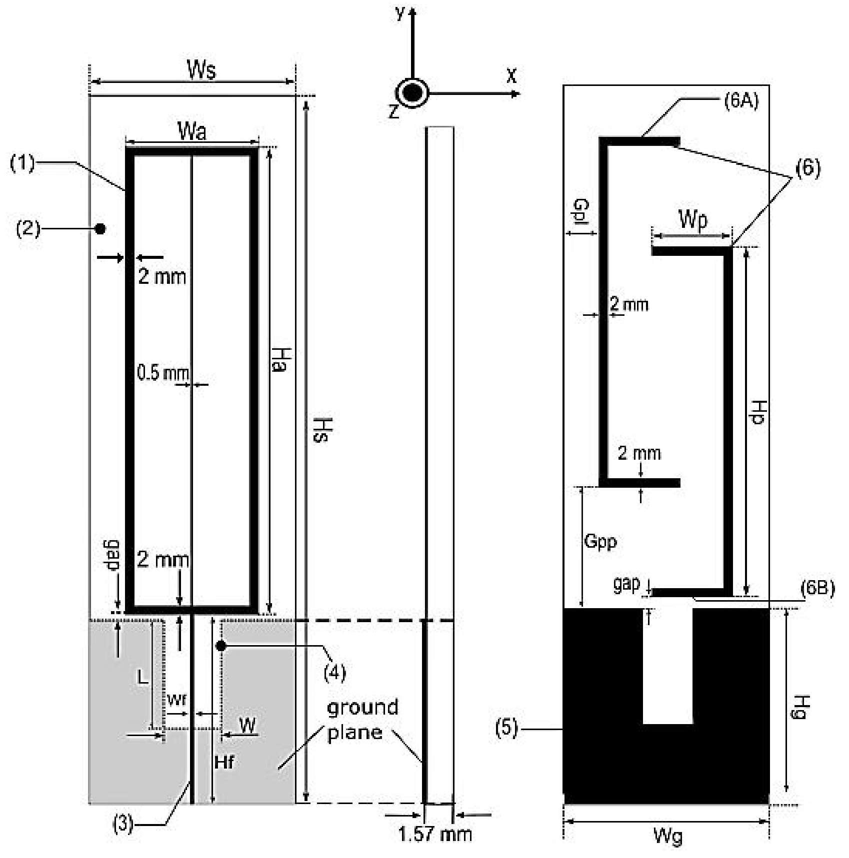
Fig. 1. Geometry of HI monopole and representation of the magnetic field due to current flows of HI antenna [14].

Differently from the antenna presented in [14], the device proposed in this work has been designed to be printed on fiberglass substrate (FR-4), in a compact manner so it can be integrated into the inner part of electronic devices such as television sets and tablet computers. Figure 2 presents the compact and ultra-wide-band HI Monopole geometry designed in this paper. In Figure 2a, we have the following parts and dimensions indicated: (1) the main radiator element (patch) of the device: patch height is Ha and its width is Wa, metallic strip borders measuring 2 mm in width, and main central conductor filament of which width measures 0.5mm; (2) glass epoxy substrate (FR-4), with dimensions 48 × 152.5 × 1.57 mm; (3) feeding line, of which line height is Hf and line width is Wf, in accordance with the structure presented in [10]; (4) ground plane notch in order to match the device impedance with 50 Ω, as seen in [9], measuring length L and width W; and, finally, (5) the ground plane with height Hg and width Wg.

Figure 2b shows the antenna side opposite to the side on which the main radiator element is printed, and it highlights: (6) both C-shaped symmetric parasitic elements, each one turned against each other, with height Hp and width Wp. The C-shaped parasitic elements are made using conductive strips measuring 2 mm in width. The distances from the parasitic elements (6A) and (6B) to ground plane is given by Gpp and gap, respectively. The Gpl parameter is the distance measured from the parasitic elements (6A) or (6B) to the substrate borders.

The ultra-wide-band performance of the proposed antenna is reached due to excitation of two resonating modes. The first mode is controlled directly by the radiator geometry (length, width and central conductor), as well as by the ground plane dimensions. The second mode is produced mainly by the C-shaped parasites positioned on the opposite side of the board (see Fig. 2). Ultra-wide-band impedance matching was obtained mainly by optimizing dimensions of feeding line, ground plane and parasites. All the optimized geometric parameters of the proposed devices are given in Table I. Figure 3 presents the fabricated HI Monopole prototype.

ISSN 2179-1074

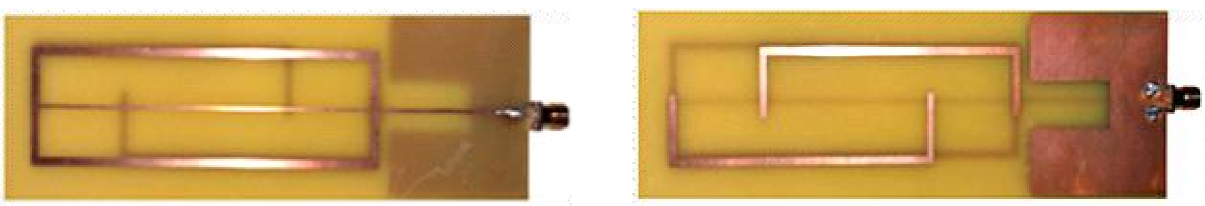


(a) (b)

Fig. 2. The geometry of the proposed antenna: (a) frontal view and (b) back view.

TABLE I. HI-ANTENNA'S GEOMETRIC PARAMETERS IN MILLIMETERS

Figure 2a		Figure 2b	
Parameter	**Value**	**Parameter**	**Value**
Ws	48	Wp	17.25
Wa	25	Hp	75
Ha	110	Wg	48
Hs	152.5	Hg	42.5
Hf	35.5	gap	3
Wf	3	Gpp	38
L	29	Gpl	11.75
W	9.5	--	--



(a) (b)

Fig. 3. HI Monopole Prototype: (a) frontal view and (b) back view.

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III. Results and discussions

The main antenna parameters have been studied and optimized to obtain satisfactory results. The EM properties of two categories of antennas were calculated using the Finite Element Method (FEM), with the aid of the commercial software HFSS. The first class of antenna was conceived without the ground plane notch and with no loaded parasitic elements, i.e., it has just the main HI radiator element and a rectangular ground strip printed on the surface opposite to the antenna's patch side. The second class of antenna analyzed is the proposed antenna, depicted by Fig. 2, with all its constituent parts, designed for achieving ultra-wide-band operation characteristics. In both cases, the antennas are printed on FR-4 substrate, which is characterized by relative permittivity ε_r = 4.4, loss tangent δ = 0.02 and thickness h = 1.57 mm. Validation of numerically obtained return losses are carried out via measurements conducted using Anritsu Site Master S331C. Figure 4 shows the measurement setup, consisting of the antenna connected to the measuring equipment.

Fig. 4. The return loss measurement setup.

Figure 5 presents the simulated and measured return losses for the first antenna configuration (without the C-shaped parasite elements and with absence of notches in its rectangular ground strip). Return losses measured and simulated for the second class of antenna (as fully depicted by Fig. 2) can be seen in Fig. 6.

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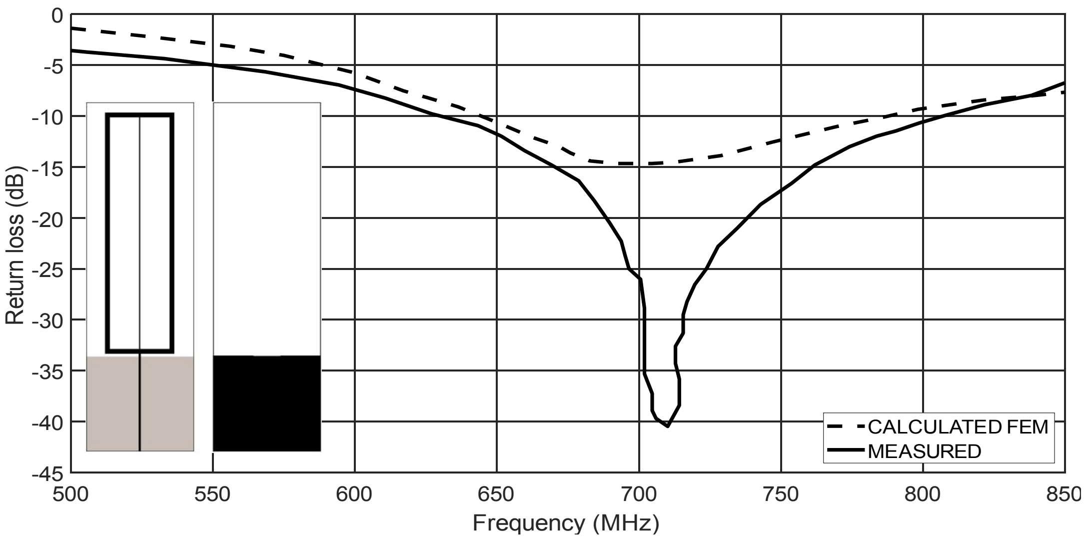


Fig. 5. Simulated and measured return losses for the first type of antenna (without C-shaped parasitic elements and rectangular ground strip).

In Figs. 5 and 6, proper agreement is observed between the measured and simulated data. By inspecting Fig. 5, one may say that measured curve shows that the HI monopole without parasitic elements and not aided with ground plane notch is able to cover the frequency range 643.3–805 MHz, yielding a bandwidth of 161.7 GHz, covering ~38% of the DVB-T standard frequency band. According to Fig. 6, the antenna loaded with the parasitic elements is able to operate in the range 429–1022 GHz, i.e., it has a bandwidth of 593 MHz, covering 100% of the frequency range of the DVB-T standard and, additionally, it encompasses the bands of LTE-450 and LTE-700 standards. Numerical results show a lower resonant mode at approximately 700 MHz for the case of Fig. 5 and a higher resonant mode between 900 MHz and 1 GHz for the case of Fig. 6.

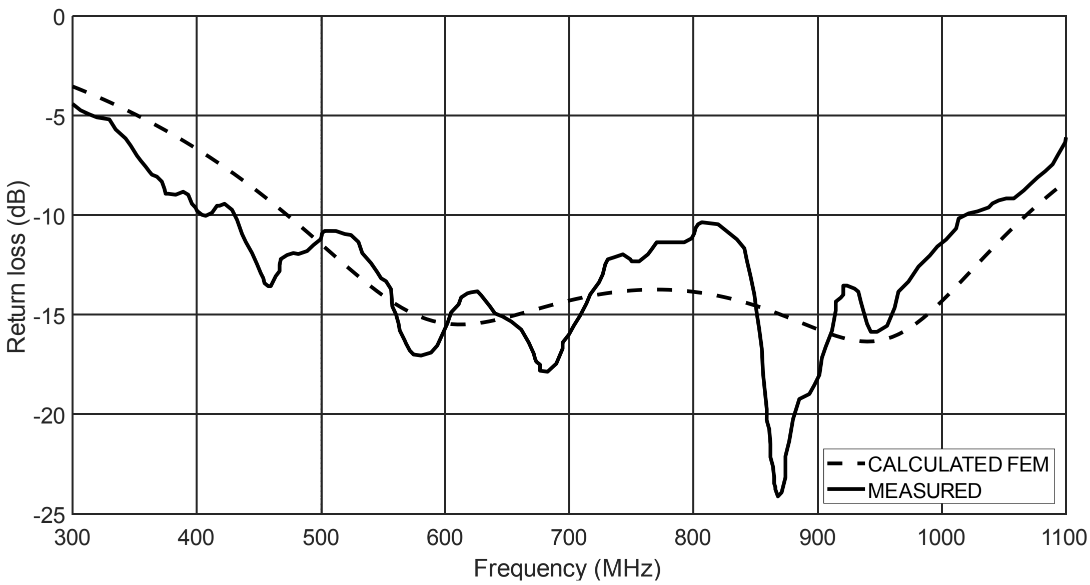
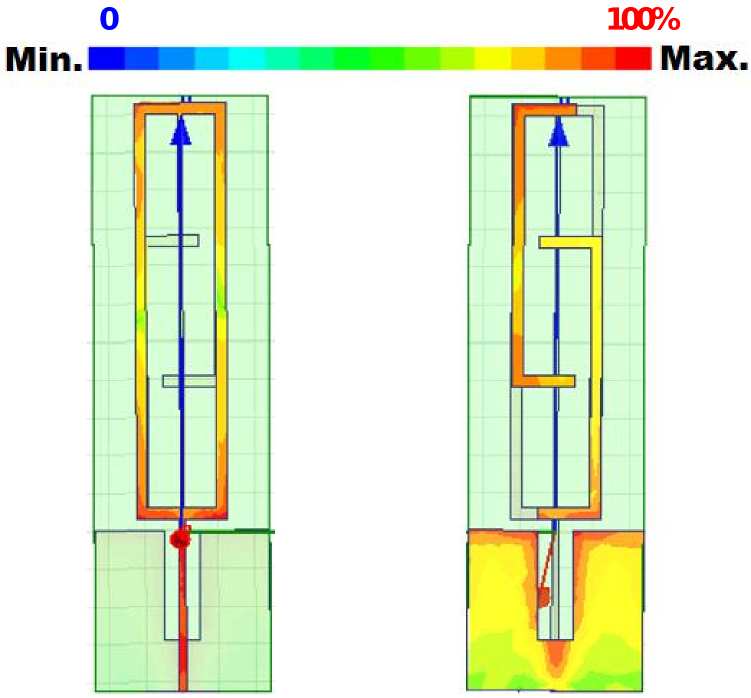


Fig. 6. Simulated and measured return losses for the HI Monopole antenna designed with C-shaped parasites and ground plane notch, acting as an ultra-wide band device.

Lower resonance at approximately 700 MHz (return loss in Figure 5) is directly influenced by the antenna's main radiator, with an approximate length of 0.25λ. With respect to the second resonant mode (at ~990 MHz, return loss in Figure 6), one may say that it is directly influenced by the C-shaped parasite elements, also measuring approximately 0.25λ for that frequency. These features result in the combination of both resonance modes in the proposed antenna, forming a wider bandwidth operation resulting from those superposed effects. This fact can be confirmed observing Figure 7, which shows the current density magnitude diagram for both resonating modes of the HI Monopole, for the proposed configuration, with the loaded C-shaped parasite elements and the ground plane notch. It is possible to see that lower frequencies tend to resonate with the HI patch and higher frequencies radiate with strong dependence on the C-shaped parasites and the ground plane notch.



(a) (b)

Fig. 7. Normalized current density distributions at: (a) 700 MHz and (b) 990 MHz.

By analyzing the numerical result shown in Figure 5 and comparing it to Figure 6, we see that the lower resonant mode is shifted from 700 MHz to 600 MHz. This can be justified by the electromagnetic mutual coupling among the main radiator and the parasitic elements, producing an increased effective electrical length of the radiator. The confined field within the substrate due to the introduction of the C-shaped parasites also contributes to mold the resonance profile in Fig. 6.

During the parametric optimization process, it was possible to understand the influence of geometric parameters on the response of the device. Results plotted in Fig. 8 and Fig. 9 show the influence of ground plane dimensions Hg and L, respectively. Other parameters of the device were

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preserved as given in Table I. In Fig. 8, it is clear that increasing Hg from 32.5 mm to 52.5 mm tends to produce improved impedance matching. However, further increases of Hg are not beneficial to the device, as return losses increase. Notice that although Hg = 52.5 mm produces smaller return losses, it does not provide the largest bandwidth, which is obtained when Hg = 42.5 mm. Fig. 9 clearly shows the benefits of the notch. As the notch depth L is increased, bandwidth is increased accordingly. The favorable effects observed from the ground plane optimization come from adjustments of current amplitude at the input terminal of the microstrip line over the frequency band as Hg and L are tuned, leading to beneficial variations of impedance at the antenna's input terminal [9]–[11], [15], [16].

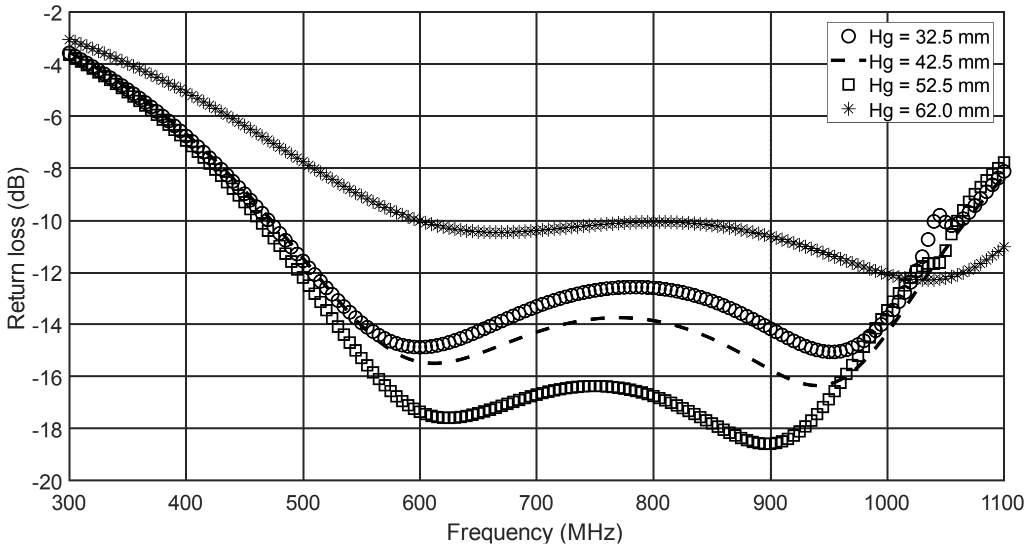


Fig. 8. Calculated return losses for various values of ground plane length Hg of the proposed HI Monopole antenna. All other parameters have been preserved.

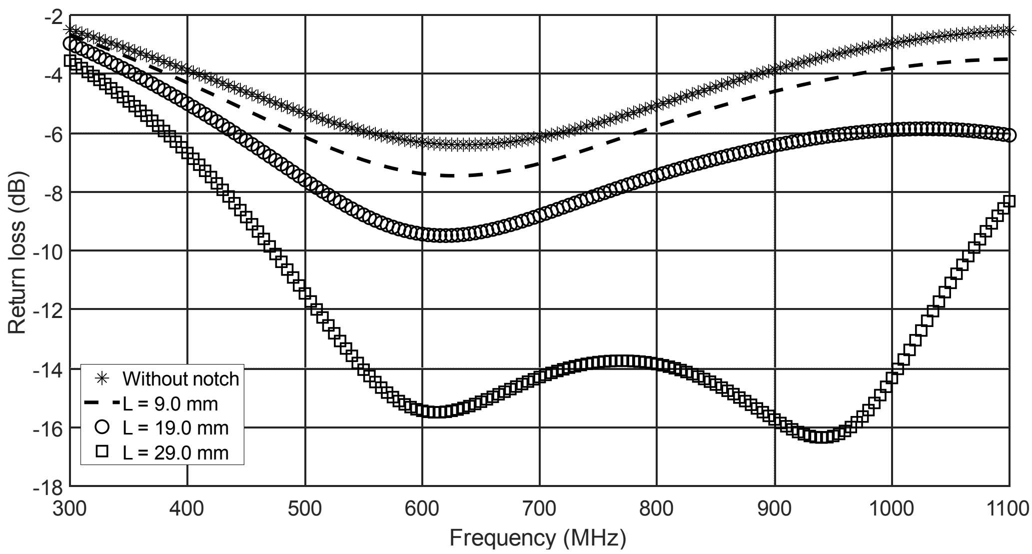
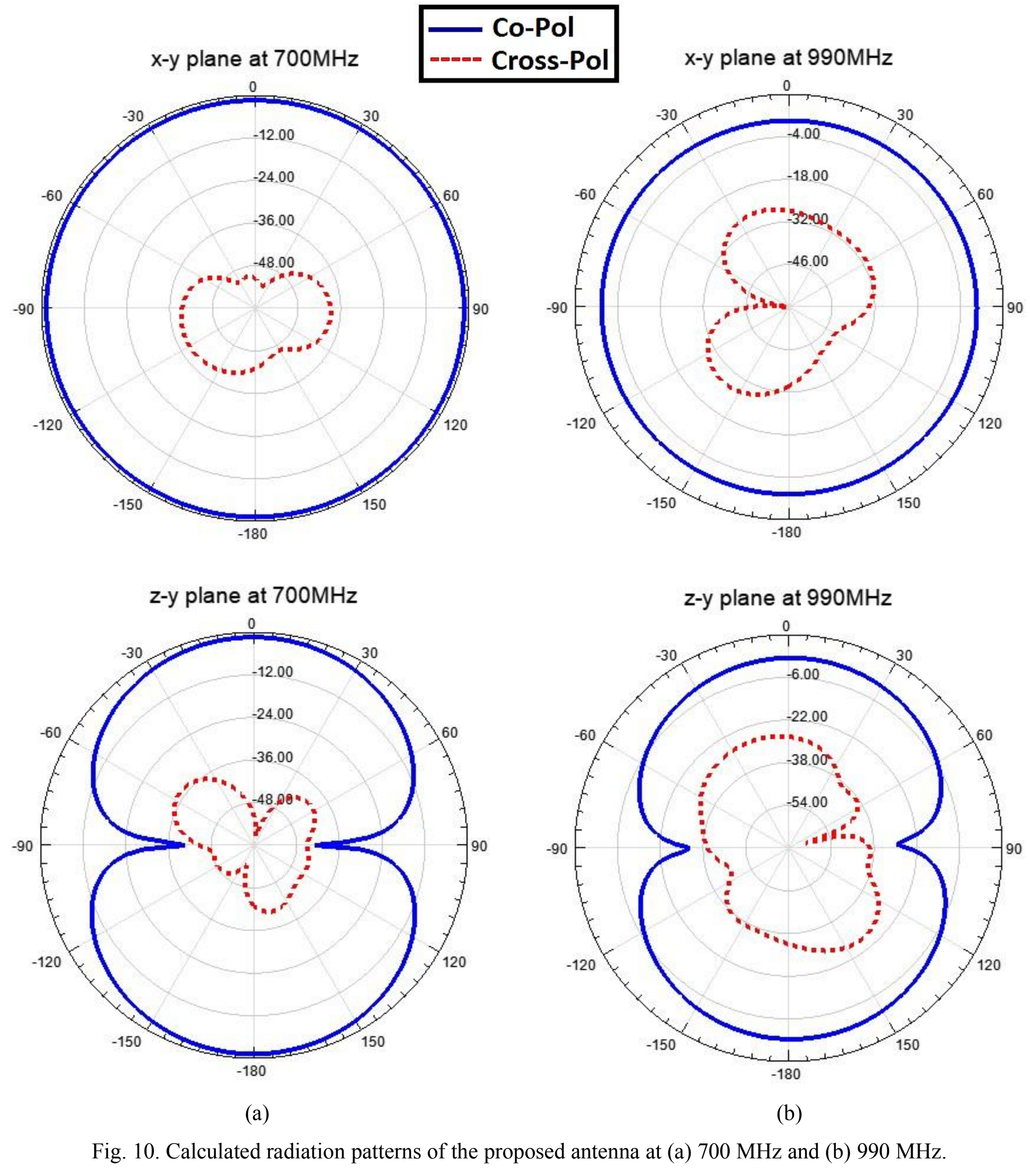


Fig. 9. Calculated return losses for various values of ground plane notch depth L of the proposed HI Monopole antenna. All other parameters have been preserved.

Brazilian Microwave and Optoelectronics Society-SBMO received 27 April 2020; for review 7 May 2020; accepted 2 July 2020
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

Figure 10 shows the calculated 2-D radiation patterns at 700 MHz and 990 MHz for the proposed antenna. The antenna presents nearly omnidirectional radiation patterns at different frequencies on the *x-y* plane and dipole-like radiation patterns on the *y-z* plane. These characteristics are similar to those observed for the conventional dipole for DVB-T. In addition, the cross-polarization patterns of the antenna present very lower levels on the three conventional coordinate planes.



(a) (b)

Fig. 10. Calculated radiation patterns of the proposed antenna at (a) 700 MHz and (b) 990 MHz.

Figure 11 shows the calculated antenna peak gain over the 470–1075 MHz band. This result shows that maximum gain increases with frequency in a range from 0.47 to 1.64 dBi.

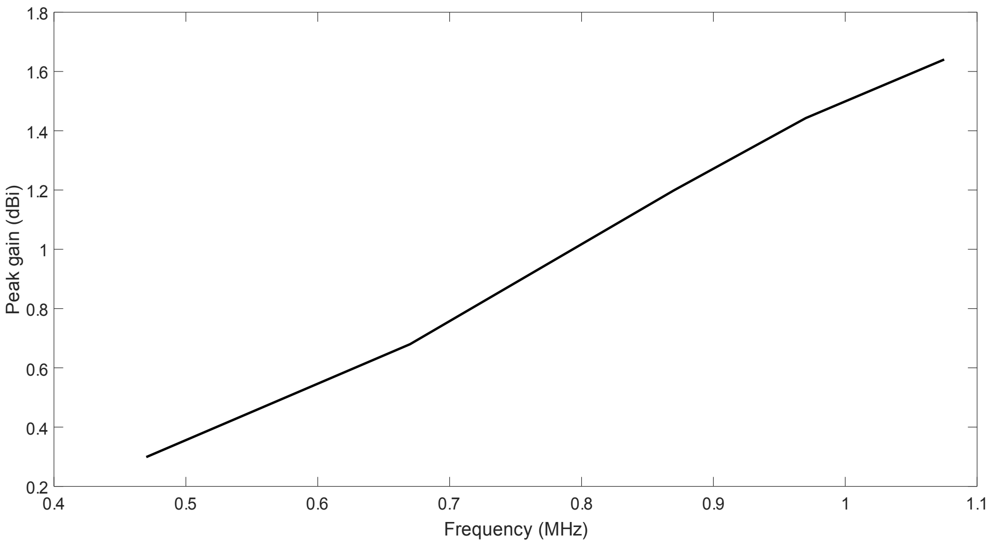


Fig. 11. Calculated antenna peak gains for the proposed device.

The calculated input impedance of the proposed antenna is shown by Fig. 12 between 100 MHz and 1100 MHz. Notice that the real part of the impedance is relatively close to 50 Ω over the shown frequency spectrum. Additionally, imaginary part is very close to zero over a significant part of the shown spectrum, especially between 450 Ω and 950 Ω. These features indicate the impedance matching to the 50 Ω load. As previously seen in Fig. 6, the operation band of the antenna is between 429 and 1022 MHz, which meets the –10 dB criterion for the return loss.

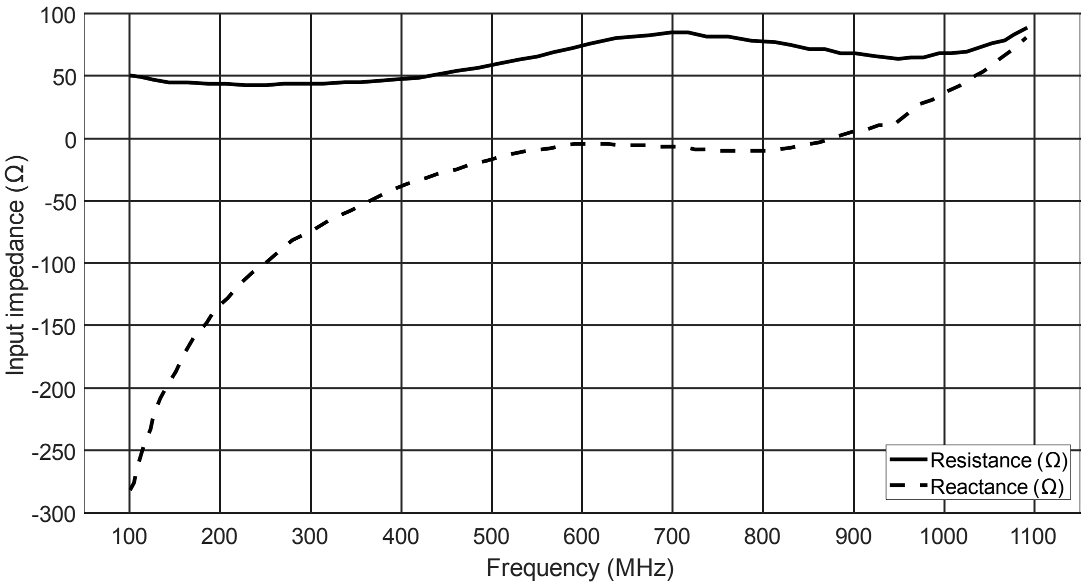


Fig. 12. Input resistance and reactance spectra of the proposed antenna.

Brazilian Microwave and Optoelectronics Society-SBMO received 27 April 2020; for review 7 May 2020; accepted 2 July 2020
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

Table 2 presents, with further details, a comparison among the operation and geometric characteristics of the antenna proposed in this work and those devices designed in [1]–[7], [9]–[11].

TABLE 2. COMPARISON AMONG VARIOUS ANTENNAS

Work	Measured coverage range (MHz)	Bandwidth (MHz)	Antenna Dimensions (mm)	Cutoff threshold for defining operation band (dB)	Coverage capacity of DTV-T standard (%)
Ref. [1]	451 – 912	461	35 × 247 × 0.8	-10	100
Ref. [2]	470 – 798	328	not specified	-10	78
Ref. [3]	430 – 940	510	255 × 9 × 2	> -6	Empty
Ref. [4]	440 – 820	380	976 × 583 × 5	> -6	Empty
Ref. [5]	460 – 870	410	976 × 583 × 15.5	> -6	Empty
Ref. [6]	470 – 790	320	440 × 440 × 20	-10	76
Ref. [7]	470 – 860	390	80 × 15 × 10	> -6	Empty
Ref. [9]	447 – 818	371	35 × 117 × 1.57	-10	88
Ref. [10]	459 – 801	342	45 × 174 × 1.57	-10	81
Ref. [11]	455 – 733	278	48 × 174 × 1.57	-10	66
This work	429 – 1022	593	48 × 152.5 × 1.57	-10	100

As demonstrated in Table 2, the HI Monopole proposed herein presents the largest operation bandwidth, i.e., it covers greater frequency range than other antennas in literature, even by adopting the –10 dB cutoff criterion. The ground plane length Hg = 42.5mm was selected not just because of ultra-wide-band operation, but also because it allows for keeping the antenna design compact. When considering the antenna presented in [1], although it covers the entire range of the DVB-T standard, the HI antenna proposed in this work has a bandwidth about 132 MHz larger than that device. Finally, with respect to Table 2, references [3–5] and [7] do not present their respective percentages of band coverage because the authors consider the cutoff threshold for defining the operation band of their devices above -6 dB.

IV. CONCLUSIONS

A compact ultra-wide-band HI monopole antenna loaded with C-shaped parasitic elements for DVB-T and LTE applications has been developed and presented in this work. As verified from measured results, the designed HI Monopole antenna is capable of covering the 429–1022 MHz band, producing a corresponding fractional bandwidth of 81.74%. Therefore, the device is an ultra-wide-band antenna, since its fractional bandwidth is larger than 20%. In addition, the HI monopole covers 100% of the frequency range of the DVB-T standard, i.e., it is capable of operating in any location in which digital TV signals are broadcasted today.

An interesting characteristic of this antenna is the miniaturization of its geometric dimensions, as well as the reduced size of its ground plane, which makes it feasible its installation inside electronic device's housing, mainly room television sets, portable TVs and tablet computers. The proposed device is highly recommended for DVB-T applications, given that its operation band is adequate to several different broadcasting standards of different countries, therefore making it considerably superior to the antennas previously developed in literature.

ACKNOWLEDGMENTS

The authors thank the support of National Council for Scientific and Technological Development (CNPq), National Institute of Science and Technology in Wireless Communication (INCT-CSF), Coordination of Superior Level Staff Improvement (CAPES), Group of Telecommunications and Applied Electromagnetism (GTEMA) of the Federal Institute of Education, Science and Technology of Paraíba (IFPB), Federal University of Pará (UFPA) and Federal University of Rio Grande do Norte (UFRN).

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