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Omnidirectional antenna with modified ground plane for wideband DVB in handheld devices[☆]

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ABSTRACT

Miniaturized monopole planar antennas operating in the VHF/UHF band applied for Digital Video Broadcasting and mobile communication have gained research interest due to their low-profile, compact, and wideband nature. This antenna is capable of penetrating surfaces more easily, faster and can broadcast larger data because it operates in the wideband. The challenge of designing an antenna small enough to be adopted for Digital Video Broadcasting in handheld devices with capabilities of covering the DVB wideband and at the same time omnidirectional, with enough gain, good impedance coefficient which translates into efficiency is the drive of this paper. The proposed antenna in this paper is a rectangular patch with two large slots created in its radiating surface and extension on its edges for wider bandwidth and better matching. It employs a modified ground plane that uses coupling to achieve low return loss. CST microwave studio software was used for the simulation and optimization. The characteristics and simulated results are analyzed before the prototype structure is fabricated on an FR-4 substrate. A monopole planar antenna with total dimensions of 185 × 45 × 1.6 mm^3 with an omnidirectional radiation pattern in the H-plane is fabricated and the results are presented. The antenna has high impedance bandwidth characteristics with operating frequency at -10 dB return loss from 470 MHz to 900 MHz and about 63% bandwidth efficiency. It has a VSWR ratio of less than 2. The significance of the various sections of the antenna together with the simulated and fabricated results is presented. It shows a suitable antenna with a wide operating frequency domain. The proposed antenna would be useful in Africa's development agenda in wide-area wireless communication as countries are migrating to DVB-T2 and DVB-NGH space.

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Introduction

The need to provide efficient High Definition Television (HDTV) on the go is driving Digital Video Broadcasting (DVB) in handheld devices. Digital Video Broadcasting (DVB) is adopted in most parts of the world [1] and the research to miniaturize the DVB antenna for Digital TV services on tablets and mobile phones is ongoing. DVB-T2 antennas must be service-specific, robust, allow easy allocation of frequency within the Ultra-High Frequency (UHF) and possible extensions to support higher frequency bands. It should have a higher impedance bandwidth, less peak-to-average-power ratio of the transmitted signal to reduce interference and transmission costs [1,2]. The advantage of DVB-T2 systems in areas such as reliable data transmission with high point-to-multipoint speed data transfer modules makes the DVB-T2 an important research area [3]. DVB-T2 antenna in handheld devices implies that the antenna should be compact and suitable for handheld devices in terms of size, material and, performance. The analysis of DVB-T2 signals can be used to detect airborne objects in Passive Coherent Location (PCL) systems [4] such as in drone detection and tracking. DVB-T2 high-speed transmission system can be used to detect and measure drone distance and velocity in the signal domain [5].

Different types of miniaturized antennas have been designed using several mechanisms to attain the wide bandwidth that is needed for Digital Video broadcasting in Handheld devices. There is however some degree of compromise when it comes to the size and performance of DVB antenna; a good design is the one with small size and covering the entire frequency range for DVB in handheld devices application. A small monopole antenna for DVB was presented in [6,7]. In [6], an antenna that has an operating bandwidth of 470 to 702 MHz at -6 return loss was proposed with dimensions of $25 \times 15 \times 4$ mm^3 (with the ground plane of $65 \times 45 \times 1$ mm^3). This covers only part of the DVB operating frequency band and has a high return loss. It however has a good gain between 7 and 10 dB in its operating region despite its small dimensions. The high gain of this antenna is necessary for portable handheld devices, operating in the low-frequency band with such poor matching. In [7], a small size planar broadband antenna configured for a DVB in handheld devices and used for digital TV band was proposed. It uses a magnetodielectric material which is expensive to fabricate on a commercial basis. The antenna has dimensions of 135×75 mm^2 with coupling based on fixed lumped elements. The lumped element was employed to improve the matching, making the design bulky. It has a high return loss of 1.5 dB for its operating frequency ranging from 470 to 702 MHz. In [8], a planar meander monopole antenna was presented, it used parasitic strips and a sleeve feed to obtain a wide bandwidth for the small size of 100×44 mm^2 antenna. A wide impedance bandwidth characteristic of VSWR$\leq$3 of about 101.7% from 440 to 1350 MHz was achieved. The material used is easy to fabricate compared to the FR-4 substrate.

Compact design with enhanced bandwidth for DVB application was presented in [9–11]. In [9], a monopole antenna with a C-shaped ground plane embedded in a modified patch fed by a 50 ohms coaxial feedline capable of providing wide operating bandwidth and stable radiation properties was proposed. It had a total dimension of $400 \times 84 \times 0.8$ mm^3 and -6 dB return loss ranging from 220 to 860 MHz for VSWR$\leq$3. It had an omnidirectional pattern in the H-plane and kept the direction of the radiation pattern in an E-plane near the horizon plane. In [10], an omnidirectional antenna for application in TV white space cognitive radio was presented. It has a bandwidth of 460 to 870 MHz for VSWR $<$ 2, and a total physical dimension of $261 \times 30 \times 0.8$ mm^3. This antenna mainly consists of a compact strip profile monopole, a pair of parasitic elements and, a brief impedance matching network, all etched on an FR-4 substrate. Another compact wideband monopole antenna was presented in [11]. It is a fork-shape omnidirectional antenna with a surface dimension of 247×35 mm^2 that employs concavity in the ground pattern. The length of the asymmetric fork-like strips resulted in wider bandwidth and the slot served the purpose of improving the matching. It has a wide operating frequency range in the UHF band from 451 to 912 MHz for DVB-T. Another possible design for DVB antenna for handheld devices was proposed in [12]. This omnidirectional antenna consists of a grating patch and a concave rectangular ground plane with a defected ground plane. The ground plane was extended to reduce the antenna height. It had an operating band of 470to862 MHz corresponding to 60 % of impedance bandwidth of 7.5 dB return loss. This antenna has 13 slots in its radiating element, each has a size of 2 mm and they were created to widen the operating bandwidth [13–15]. The concave ground plane with the extended monopole helped reduce the antenna total height. Arza et al. [16] achieved high gain with a wide bandwidth of 400.2 MHz by using a parasitic patch and air gap method. It employed CPW-fed with an operating frequency of 433.8to834 MHz at 10 dB return loss. This antenna is relatively large with a unidirectional radiation pattern with elliptical polarization. Adhiyoga et al. [17] employed a structure called Split Ring Slot (SRS) in the ground plane for dual-beam radiation pattern. SRS works as a radiator and as an inductive component that contributes to the antenna miniaturization. Its operating frequency is 551.50 to562.25 and MHz 539.21to 559.52 MHz for S11 less than 10 dB return loss. The portable nature of the targeted devices implies a premium is placed on miniaturization and lightweight antennas in future designs. These features were considered in this proposed omnidirectional antenna.

This work proposed a wideband monopole antenna for DVB-T2 reception in portal devices. The antenna patch has two large slots in it and extensions at the edges with a modified ground plane. The gap on top of the patch was introduced between the monopole and the concave ground plane which were coupled together through optimization to introduce excitation that extends the upper bound of the operating region. The results showed a good design for a compact antenna for DVB in handheld devices. The antenna has a VSWR $<$ 2 of about 63 % bandwidth, ranging from 470 to 900 MHz. The antenna had good matching measured at -10 dB return loss for its wide operating bandwidth. It is miniaturized to be applicable in handheld devices. It has an omnidirectional radiation pattern in the H-field. Analysis of the simulation and measurement of the elements making up the antenna circuit was presented. The proposed antenna has a total size of $185 \times 45 \times 1.6$ mm^3.

Table 1
Dimensions of the proposed antenna.

Part	Size (mm)	Part	Size (mm)	Part	Size (mm)
S1	10	W9	1	L5	183
W1	2	W10	0.4	L6	45
W2	1	W11	1	L7	42
W3	6	W12	5.2	L8	107.7
W4	1	W13	0.4	L9	12.9
W5	1	L1	92	L10	73.9
W6	2	L2	5.5	L11	185
W7	2	L3	89	L12	13.9
W8	4.4	L4	45		

The antenna is versatile in terms of the direction in which the signal can be received since users move their devices all the time. The antenna improves DVB-H performance by increasing spectral efficiency and modulation flexibility. The proposed antenna has an easy implementation, small size, and wide operating frequency that covers the DVB band beyond which allows for higher data rates that could be used in the future for a wider range of channels.

The contribution and motivation behind the antenna design in this paper are to ensure efficient DVB communication and provide an allowance in frequency for the future expansion of DVB communication. The radiating element's size is determined by a fraction of the wavelength. VHF/UHF antennas receive shorter wavelengths and wider bandwidth; with these antennas, data is transferred at a faster rate. The operating frequency of 470MHz to 900MHz allows the signal to easily penetrate surfaces. Agenda 2063 of the African Union is a 50-year program to elevate the continent to the status of a global force to be reckoned with. One of the union's main goals is to effectively exploit wireless communications between people and devices throughout the continent to improve both social and economic trade among countries and their members. The introduction of quick and efficient antennas and communication equipment is one technique to improve this effective communication. Innovative educational technologies, such as African virtual and E-university programs, are part of the union's objective. This paper's omnidirectional wideband DVB antenna could aid in the resolution of pan-African E-networking challenges on the continent. This antenna could provide a reliable connection to aid the development of relevant and high-quality Open, Distance, and e-Learning (ODeL) resources to provide students with guaranteed access to the educational broadcast learning resources on the DVB-H platform. The wideband characteristic makes it a capable choice for high-quality multi-media applications in education and business. As a medium for multimedia content distribution, conferences, lectures, churches, and community education may be filmed live or prerecorded and distributed to respective audiences through the DVB-H platform escaping the cost of internet connectivity and aiding communication in pandemic times such as the COVID-19.

DVB antennas have been around since 1998 [18] and have seen revolutionary improvements through repeated testing and redesigning. The hurdle with the DVB antenna was to design one that could operate in an omnidirectional pattern, provide high gain and suitable impedance coefficient, all while being portable and compact enough to be placed in handheld devices. The proposed design presents all such features while overcoming the challenge by successfully miniaturizing the DVB antenna through optimization. The optimization was carefully implemented by the incorporation of slots in the patch and an extended monopole in the ground plane without negatively altering the good characteristics of the antenna. The novelty of the proposed work is not only realized in the miniature nature of the antenna but also in its ability to radiate in all directions. These advantages make this design a good competitor to other DVB antennas.

Antenna design and configuration

The proposed antenna configuration is shown in Fig. 1 The structure is designed and etched on a lightweight FR-4 substrate with er = 4.3, tand = 0.02, and a thickness of 1.6 mm.

The resonator consists of a printed monopole in a rectangular form with 2 mm x 6 mm extensions at the edges and two large slots on the resonator. The edge extension is to increase the impedance bandwidth of the operating region. The resonator surface has a 2 mm gap at the top which is occupied in the direct opposite on the ground plane by a horizontal pole.

The modified ground plane has a concave slot, L12 by W12 of dimensions 13.9 mm by 5.2 mm in the lower section partially covered by a 45 mm x 1 mm pole which is 0.4 mm away from the top of the slot in the ground plane. The monopole on the bottom surface is coupled with the ground plane by a 1 mm gap, W11. L6 is extended by L7 on both sides to provide a longer length for lower frequency resonance. L6 is 45 mm and extended by 42 mm for the proposed antenna. The antenna has a total dimension of 185 mm x 45 mm x 1.6 mm and employs a microstrip feed that is excited through a 50 Ω waveguide port. The antenna is fabricated and the resulting structure is shown in Fig. 1 (c) and (d). The antenna label is shown in Fig 1 (a) and (b). The detailed dimension of the proposed antenna is presented in Table 1.

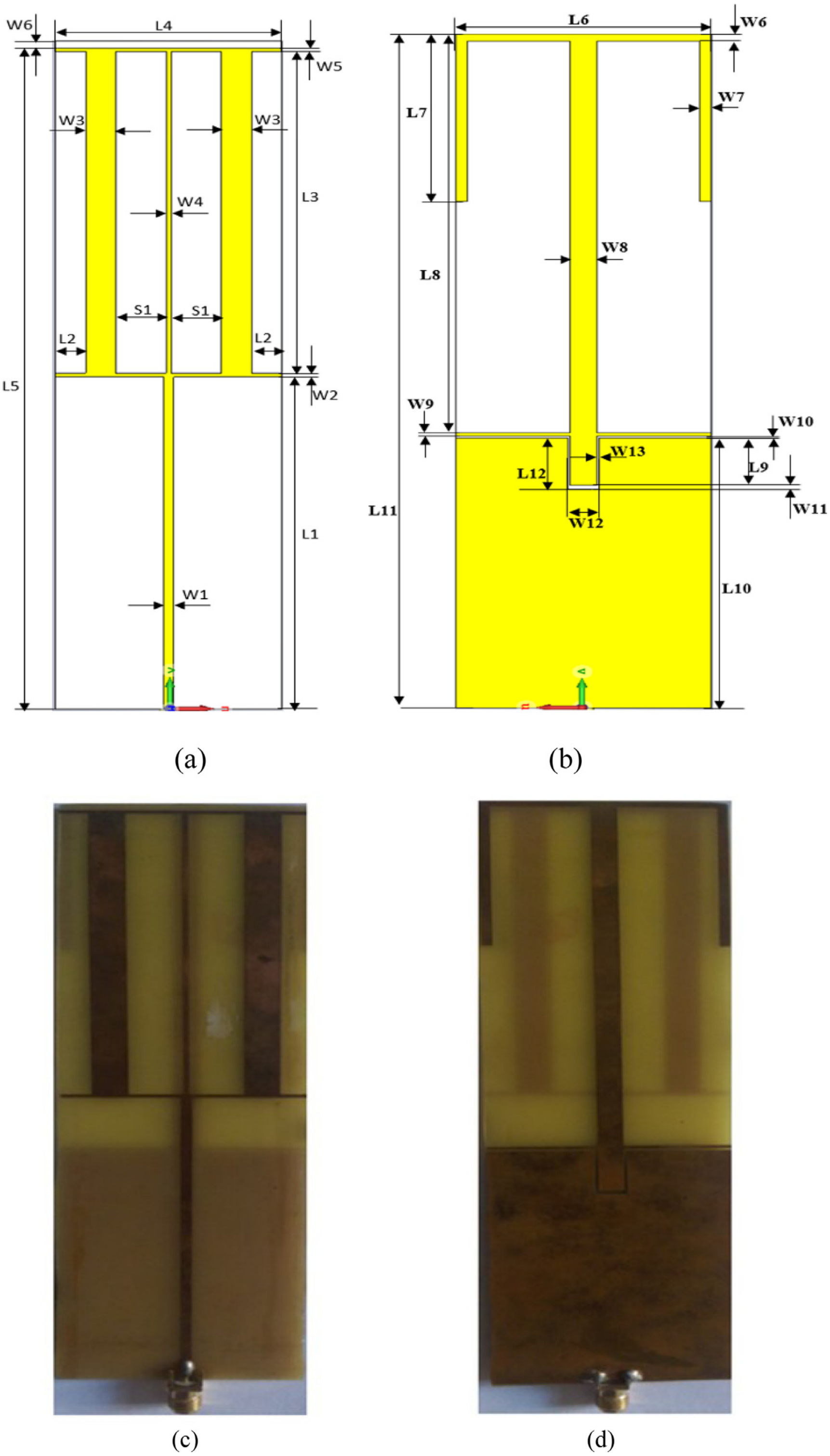

Fig. 1. (a) The proposed antenna top surface geometry with labels. (b) The proposed antenna ground plane with labels. (c) The fabricated antenna top surface. (d) The fabricated antenna ground plane.

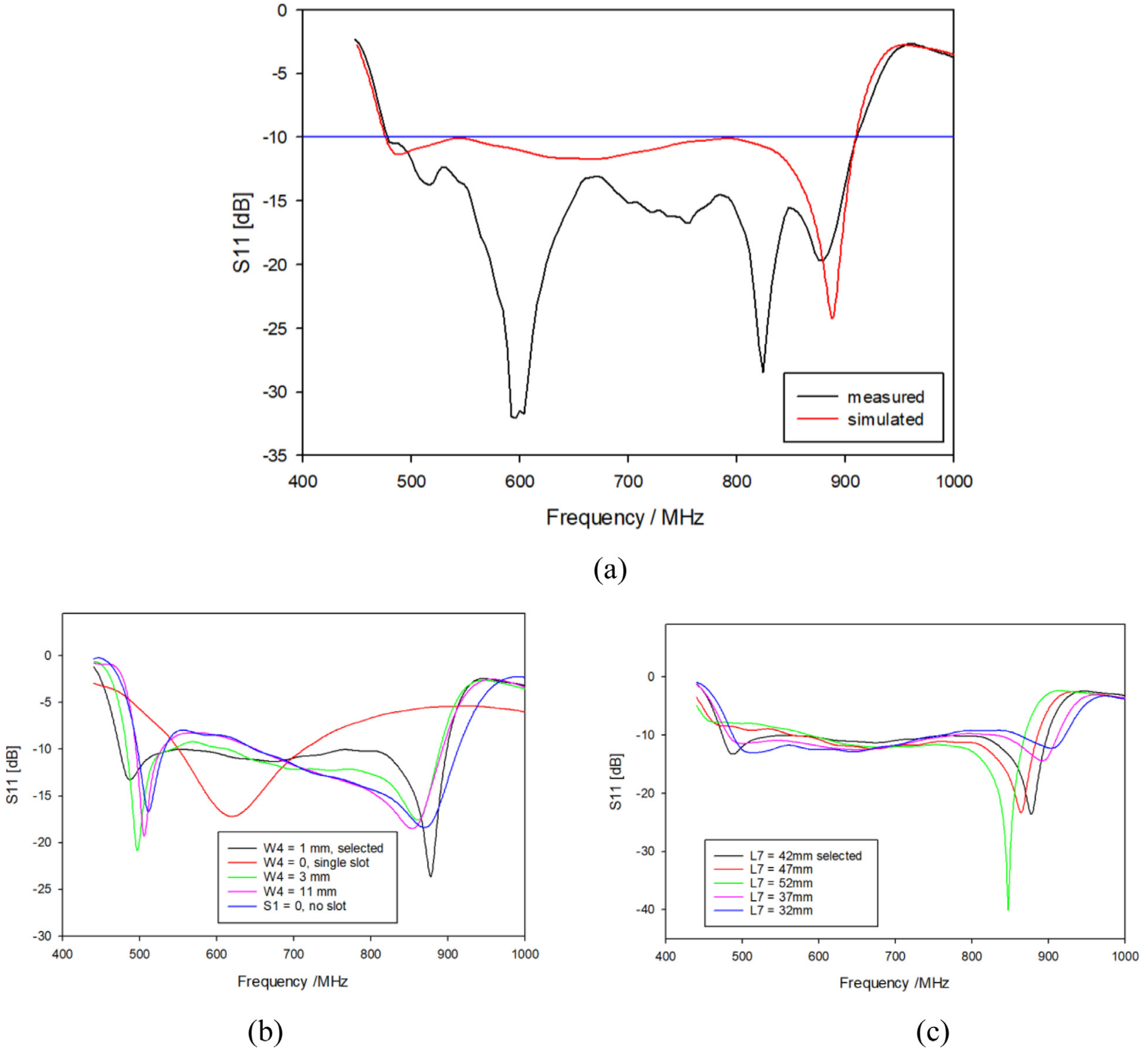

Fig. 2. (a)The simulated and measured frequency responses of the reflection coefficient of the proposed antenna. (b) The return loss of variation of radiating element width, W4 to control slot S1. (c) The return loss of variation of L7.

Analysis of Simulation results and measurement

The antenna was fabricated with a minimum slot W10 and W13 of 0.4 mm due to fabrication constraints with an operating frequency of 470 to900 MHz at -10 dB return loss with bandwidth efficiency of 63% computed from Eq. (1), where f_H and f_L are the upper and lower bound frequencies of the antenna operation region. This is shown in Fig. 2 (a). The proposed antenna explores slots, parasitic elements, and the partial ground plane.

$$\frac{f_H - f_L}{f_C} \times 100\%, \ where \ f_C = (f_H + f_L)/2 \quad (1)$$

The width of the S1 slot is employed to shift the operating region towards the lower frequency. The two symmetrical slots are separated by the radiating element of width W4. This is significant to widening the bandwidth by extending the length of the radiating surface of this miniaturized monopole antenna. The S11 plot of the variation of W4 and number of slots is shown in Fig. 2 (b). The two symmetrical slots improve the matching and widen the bandwidth. The two slots have a better effect than the single one (W4 = 0). The single-slot shifts the operating frequency higher with poorer matching. Increasing the slot width by reducing W4 gives a wider bandwidth but the matching gets poorer. At 8.0 dB return loss, increasing the W4 from 1 mm (selected) to 3 mm gives a better matching but the bandwidth is reduced from 466 to 905

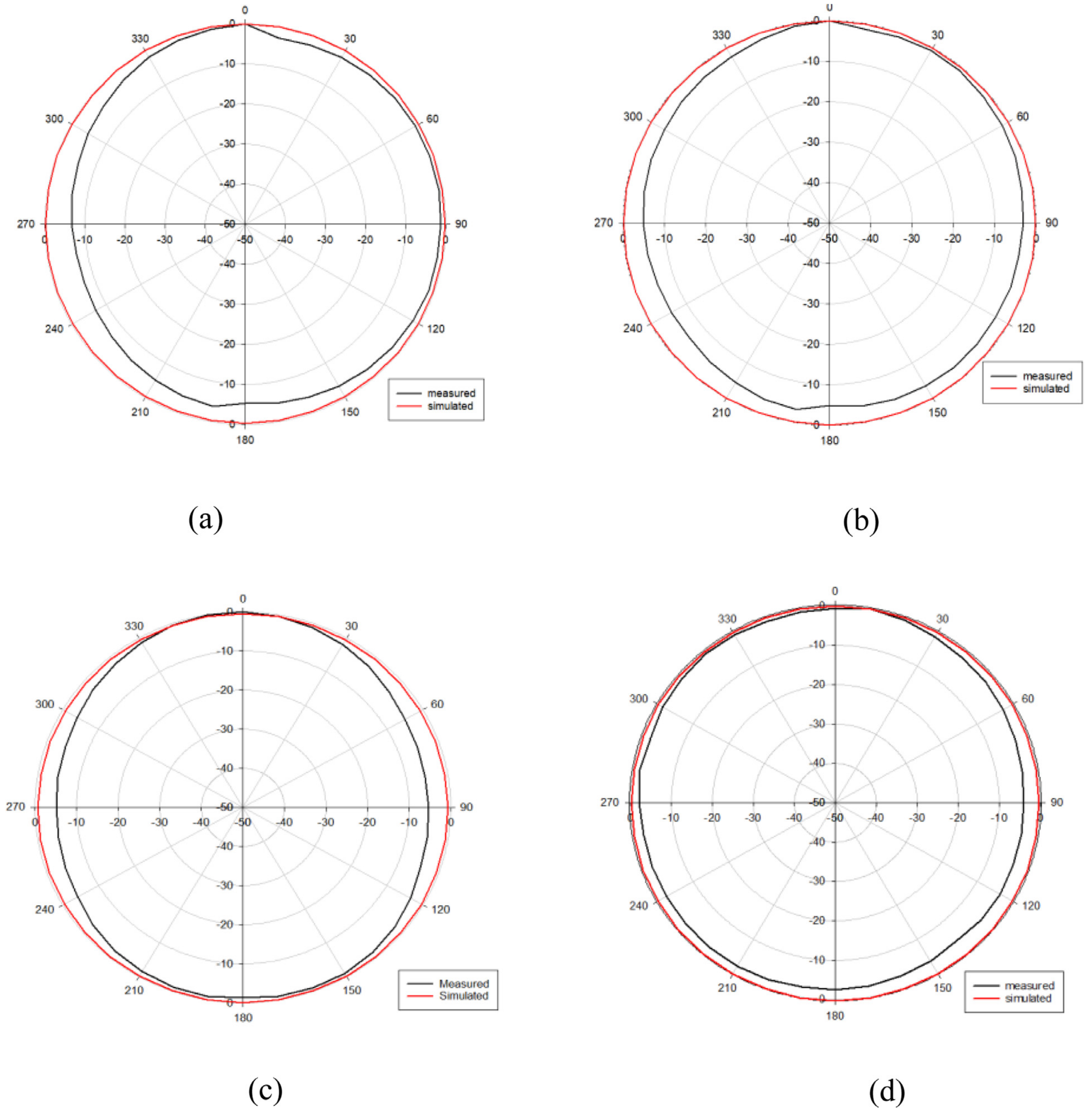

Fig. 3. Polar plot of measured and simulated H-field radiation pattern at the frequencies; (a) 480 MHz (b) 660 MHz (c)700 MHz (d) 860 MHz.

MHz for W4 = 1 mm to 479 to 896 MHz for W4 = 3 mm. W4 = 11 mm gives 492 to 900 MHz and 492 to 922 MHz for W4 = 21 mm (S1 = 0).

Although the longer length of the antenna is needed for resonance at the lower operating frequency, care is taken in extending the reflector surface for this chosen dimension to achieve miniaturization that covers the lower frequency of the DVB band so that the antenna can be adapted in handheld devices. The parasitic element in the ground plane is used as a way of widening the bandwidth. Adding extension L7 to L6 shifts the operating frequency lower from 520 MHz - 1 GHz at -8.5 dB to without the extension at 468 MHz to 974 MHz with the extension as shown in Fig. 2 (c). Increasing L7 gives poorer matching at the lower region in an effect to shift the operating frequency lower. The operating frequency for L7 = 52 mm is 530 to 868 MHz and that of L2=32 mm is 478 to 923 MHz at -8 dB S11 parameter, which show a lower and upper shift respectively from the selected L7 = 42 mm which has an operating region of 463 to 899 MHz at -8 dB S11 parameter.

The addition of the concave slot in the ground plane (L12 x W12) however was mainly because of the coupling it creates with the ground plane. That was necessary for finding ways to obtain wide bandwidth for this relatively small DVB antenna.

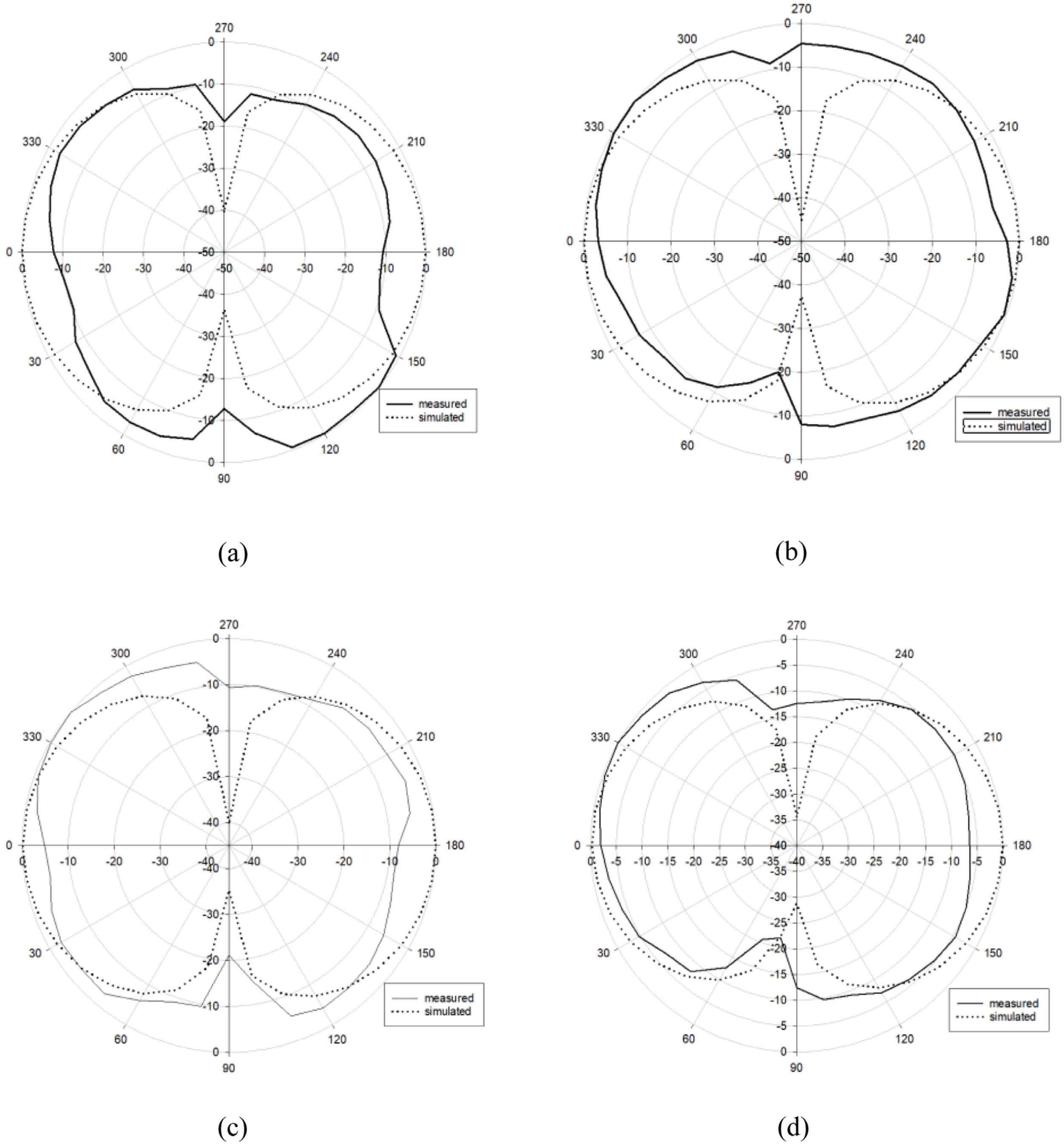

Fig. 4. Polar plot of measured and simulated E-field radiation pattern at the frequencies; (a) 480 MHz (b) 660 MHz (c) 700 MHz (d) 860 MHz.

The S11 parameter plot of the study of the omission of the coupling elements in the ground plane shows the coupling effect is removed. This results in poorer matching. The gap, W13 between the parasitic element and the rest of the modified ground plane is inserted to significantly improve the operating frequency by using coupling to spike resonance at the upper bound. As the distance W10 reduces, the coupling gets stronger and the matching gets better at the higher frequencies. This is important for a miniature antenna design because, in the quest to reduce the length of the ground plane to shift the resonance to the lower frequency, there is the need to improve the matching at the higher frequencies to widen the operating bandwidth. Optimizing various radiating elements' lengths and gaps of this symmetric antenna results in wider bandwidth. The matching is generally improved by increasing the width of the vertical elements and decreasing the width of the horizontal elements in the ground plane for this proposed design.

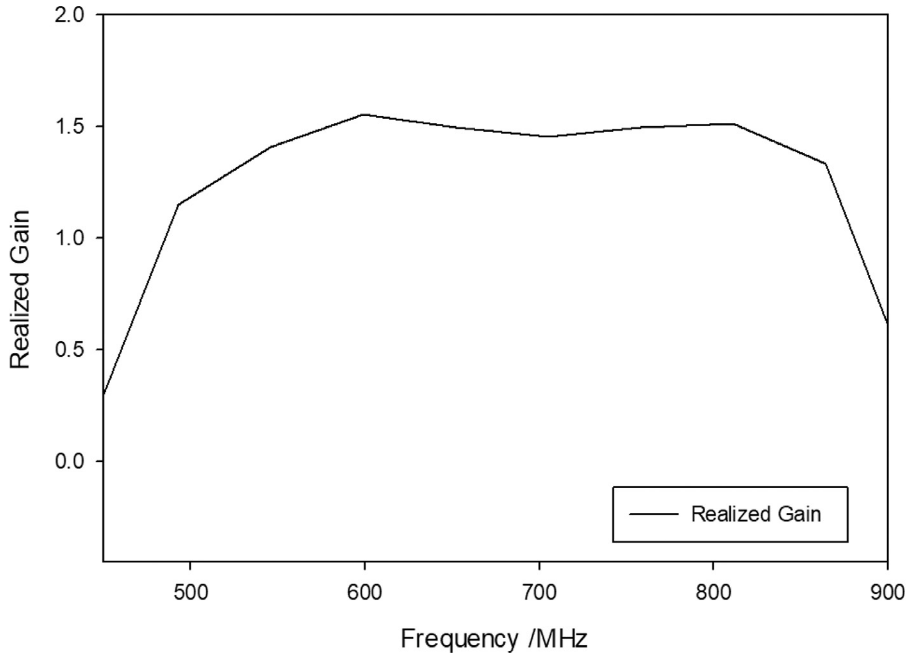

Fig. 5. The plot of gain against frequency within the TV band.

The antenna is applied for TV band reception in all directions and therefore must have an omnidirectional radiation pattern. The proposed antenna is omnidirectional in the H-plane as shown with the selected frequency for the simulated and measured polar radiation pattern in Fig. 3. The comparison of the E-plane measured and simulated is shown in Fig. 4, and the pattern follows that of an eight-like shape of a dipole antenna.

The maximum simulated realized gain is 1.6 dB and is shown in Fig. 5. The planar antenna, although having the advantage of being compact, light-weighted, and wide bandwidth, has the disadvantage of low gain, especially in lower frequency wideband applications like the TV band. DVB-T2 employs a robust high-resolution coding mechanism that takes care of the noisy domain of the TV band. The widened bandwidth beyond the current DVB-T2 band is a good innovation for future use. This monopole antenna employed the planar configuration using lossy copper.

During this study, it was found that the antennas that were capable of operating in the relatively lower frequency band like the TV band often suffered low gain. Research into this challenge can serve to mitigate the issue of low gain. Designing antennas that operate in high and low-frequency bands alike with high gains in both regions will be of interest to the research community. It will also be a substantial addition for future designs if research could go into widening the bandwidth beyond the DVB-T2 band.

Conclusion

This work proposes the design of an omnidirectional compact monopole antenna that operates in the digital TV band. This monopole antenna employed a rectangular shape patch with two large slots in it and extensions at the edges. The patch is embedded on top of the substrate with the modified ground plane behind it for widening the operating frequency and ensuring a stable radiation property. The results show a good design for compact antenna for DVB in handheld devices. Miniaturization was fulfilled in this design by the use of the extended monopole in the ground plane and using slots in the patch. The microstrip-line feed technology was employed for easy integration with the antenna. The features of this proposed antenna make it a competent design for digital video receptions in portable devices. The proposed antenna has a wide impedance bandwidth characteristic of VSWR < 2 of about 63 %, ranging from 470 - 900 MHz. It has low losses measured at -10 dB return loss for its wide operating bandwidth. The future of portable devices places importance on small, fast technology with high-definition video displays. The Next Generation of Digital Broadcast Services to Handheld Devices, DVB-NGH (Next Generation Handheld) has in its characteristics a video coding mechanism for high-speed transmission, Internet Protocol (IP) synchronization mechanism, and frequency division multiple access technologies. The future of antennas must improve the performance factor in these features to enable high video transmission and digital TV synchronization with the Internet of Things (IoT) using the 5G technology through header file compression and translation mechanism for both IP and video encoding packets. It is important to improve physical layer signaling in terms of robustness, capacity, and overhead. Future applications in the course of their advancement will have to look into DVB-NGH which was created to optimize existing mobile broadcasting technologies in terms of capacity, coverage, flexibility, spectral efficiency, and robustness to noise. DVB-NGH has a Multiple-Input Multiple-Output (MIMO) antenna scheme, which is an important technology needed to overcome constraints of single antenna communication due to Shannon theory [19].

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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