

WIDE-BANDWIDTH AND FLAT-GAIN PRINTED DIPOLE WITH EBG REFLECTOR FOR TERRESTRIAL DTV RECEPTION

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Abstract

This paper reports the design of a compact high-gain broadband printed dipole antenna for receiving digital television (DTV) signals from any broadcast station in remote areas of Thailand with the frequency bandwidth of 470 MHz - 862 MHz. The proposed antenna consists of a modified step-shaped printed dipole antenna, to which the band-notch technique is applied by adding 8 small slots on the inner edge of the long side arm for bandwidth enlargement up to 7.65% compared to the conventional one, while the directive gain of the antenna is increased up to around 8 dBi over the frequency bandwidth by using a mushroom-like EBG reflector, which can suppress the surface wave on the surface and wave diffraction on the edges of such a reflector. In order to validate the simulation results from CST licensed software, the prototype antenna was fabricated and measured in the laboratory. We found that the proposed antenna can provide a high gain around 7 - 8 dBi over the desired bandwidth. Moreover, the radiation patterns over the bandwidth of the antenna are a little bit changed in the front direction.

Keywords: Digital television (DTV), step-shaped printed dipole, mushroom-like EBG

Introduction

Nowadays, terrestrial digital television (DTV) broadcasting has already reached the implementation stage in many countries after more than a decade of intense research and development (Wu *et al.*, 2006). The DTV system can offer high data rate transmission, provide interactive services, and operate at low power. With these advantageous features, the DTV system becomes very attractive for applications in mobile communication devices such as laptop computers, mobile phones, and signal reception devices equipped in vehicles (Holopainen *et al.*,

2010; Iizuka *et al.*, 2005; Wong *et al.*, 2006). In Thailand especially, DTV broadcasting with the DVB-T2 system (470 MHz - 862 MHz) is expanding with the installation of broadcasting network stations to cover all areas of the country. However, some areas are out of the coverage area or far away from any broadcasting station and cannot receive the DTV signal. Antenna factories in Thailand have proposed many types of Yagi-Uda antennas to overcome this problem. Nevertheless, a Yagi-Uda antenna cannot resolve the problem completely because

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it cannot provide the flat gain over the desired bandwidth, its front beam of radiation patterns changes direction when the frequency is changed, and the antenna's structure is too long and heavy. Therefore, this paper proposes a compact antenna, which provides the high and flat gain around 7-8 dBi over the specific bandwidth and overcomes the problems that a Yagi-Uda antenna cannot do.

In the past, a patch antenna was developed for utilization in many applications, especially the receiving antenna due to its attractive features, such as low radiation loss, low profile, light weight, and ease of fabrication. However, the disadvantages of patch antennas are that they provide a narrow bandwidth and low gain. Therefore, many researchers are exploring methods and techniques for designing wideband patch antennas (Ke and Wong, 1994). Many techniques have been reported in the literature for improvement in frequency response (Descardecì and Giarola, 1992; Wong *et al.*, 1994). A thick dielectric substrate having a low dielectric constant is more desirable since this provides better efficiency, larger bandwidth, and better radiation (Kumar *et al.*, 2005). However, these patch antennas still have complicated structures and selected dielectric materials which are expensive and thus they are not suitable for mass production. Therefore, the printed dipole was selected to develop the required performance because it has been comprehensively studied for broadband operation, especially with a step-shaped feed gap (Chi and Wong, 2007). After that, other researchers proposed various techniques and several shapes of printed antennas for wideband operation, such as the dual band-notched characteristic antennas, and the dual band-notched small monopole (Mehranpour *et al.*, 2012; Ojaroudi *et al.*, 2013; Weng *et al.*, 2009; Weng *et al.*, 2012). However, the antennas in the family of band-notched printed dipoles still provide low gain due to their bidirectional patterns. In order to improve the directive gain of bidirectional antennas, some authors have presented the patch antenna with a perfect conductor plane, but the image current has the opposite direction and cancels the radiation

from the original current (Kumar *et al.*, 2012; Tang and Ziolkowski, 2013; Taguchi and Kozaki, 2012). Therefore, we propose a technique for directive gain and wideband improvement of DTV reception antennas by using a new printed dipole antenna with a notch structure at the edge of the right arm of the dipole together with a mushroom-like electromagnetic band gap (EBG) reflector. The proposed antenna has a simple structure and lower cost compared to other high gain and wideband antennas. Furthermore, if we want to increase the directive gain of the proposed antenna, while its wide bandwidth is still maintained, the structures of the frequency selective surface (FSS) can also support this requirement (Chatterjee and Parui, 2015; Li *et al.*, 2017; Narayan and Jha, 2015).

In this paper, our proposed antenna comprises a step-shaped printed dipole antenna, which is modified for wide bandwidth operation, while the directive gain has been archived by using a mushroom-like EBG reflector. Furthermore, the FSS will be used to increase the directive gain in the last step as an option when we need a higher gain antenna for utilization in remote areas far away from broadcasting stations. The organization of this paper is as follows: Section I is the introduction, Section II will mention the configurations of the antenna and Section III discusses the optimized simulation results; after that, the conclusion will be presented in section IV.

Antenna Configurations and Mechanism

The structure geometry of our proposed antenna is shown in Figure 1 and consists of 2 parts: (1) a step-shaped printed dipole as the main radiator, and (2) an array of mushroom-like EBG with a surrounding metallic frame as the reflector.

A Wideband Step-shaped Printed Dipole

The proposed wideband printed dipole is made from the planar printed dipole antenna, in which its feed gap is formed in the shape of a step, while the band-notched technique is added into the long side arm of the step-shape printed dipole for enlarging its bandwidth at the

lower-edge frequency.

In Figure 2(a), the structure of the antenna element was started with a design based on a planar center-fed dipole generating a fundamental resonant mode centered at around 650 MHz of the operating band, for which the dimensions are 230.5 mm ($0.5\lambda_c$) in length (L_d) and 20 mm ($0.043\lambda_c$) in width (W_d), where λ_c is the free space wavelength. The antenna is built on the FR4 substrate with a thickness (h_2) of 1.6 mm, the dielectric constant (ϵ_2) 4.4, and loss tangent 0.02. However, all dimensions were optimized again by using the CST simulation software for better matching. In consequence, the optimal dimensions of the printed dipole, which provided around -15 dB of S11, are 223 mm ($0.48\lambda_c$) and 35 mm ($0.075\lambda_c$) in length (L_d) and width (W_d), respectively, while it provided the frequency bandwidth from 550 MHz to 620 MHz, as shown in Figure 3. In order to cover the desired bandwidth (470 MHz – 860 MHz), an additional resonant mode adjacent to the antenna's fundamental resonant mode (0.5 -wavelength) can be excited by replacing from

the center-fed printed dipole to the step-shaped feed gap (Chi *et al.*, 2007). With this technique, the antenna is divided into asymmetric radiating arms (R_2 and L_2) and, consequently, 2 resonant modes that are excited at the feed gap can provide a 50% larger wide operating band band (voltage standing wave ratio (VSWR) ≤ 2.0) as required. Here, the configuration of the step-shaped feed gap on the planar printed dipole is optimized by using the CST simulation software. It was found that the proper dimensions of the step-shaped feed gap structure are $L_1=110.5$ mm, $L_2=66.5$ mm, $R_1=111.5$ mm, $R_2=152.5$ mm, $g_d=1$ mm, $g_{d1}=4.5$ mm, $g_{d2}=4$ mm, and $Y_1=4$ mm, as depicted in Figure 2(b). Meanwhile, the first and the second resonant modes are around 550 MHz and 806 MHz, respectively, and the frequency bandwidth is around 355.55 MHz or 51.69% (510 MHz – 865.55 MHz), as shown in Figure 3. However, the obtained bandwidth is still not enough for the requirements, especially at the lower-edge frequency of 470 MHz.

In order to meet the requirements of the DTV band in Thailand (470 MHz - 862 MHz),

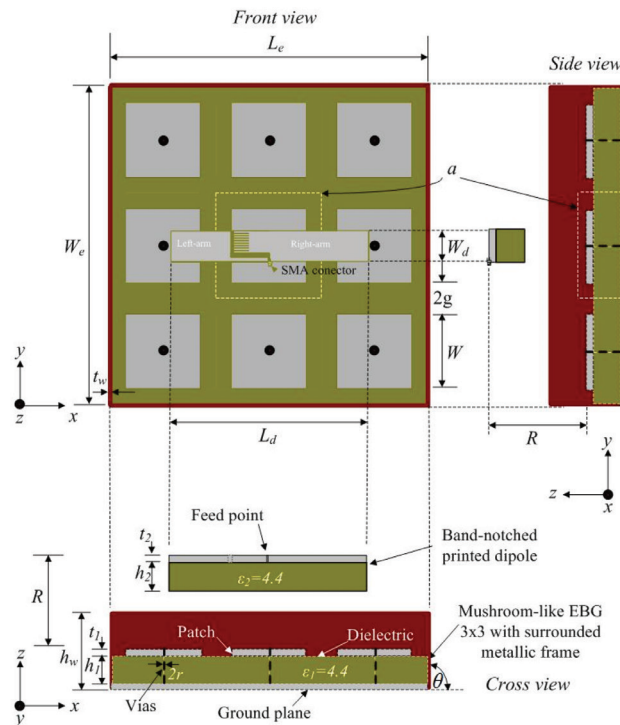


Figure 1. Structure geometry of the proposed antenna

the band-notched technique has been applied into the step-shaped printed dipole to cover 470 MHz of the operation band. The 8 small slots with the dimensions of $A=1$ mm, $B=2$ mm, and $X=17.5$ mm are notched into the long side arm that is close to the feed point, which supported the lower resonant frequency of the step-shaped printed dipole, as depicted in Figure 2(c). Moreover, we found that the antenna's bandwidth could be controlled with a number of small slots on the step-shaped printed dipole. Here, 8 slots are the proper number of slots for the desired bandwidth of 470 MHz – 866.55 MHz at $S_{11} = -10$ dB or 59.34% of the center frequency

at 668.27 MHz, as shown in Figure 4. Furthermore, Figure 5 shows the simulated current density at 541 MHz of the first resonant mode and 800 MHz of the second resonant mode. It is found that the current density on both arms of the step-shaped dipole are in the same direction and similar to that on the conventional dipole excited at the fundamental mode of half-wavelength, while the current density on both arms at 800 MHz are in the opposite direction, which is similar to that of the conventional dipole excited at the second resonant mode of full-wavelength. In addition, the current density on the longer side arm has a

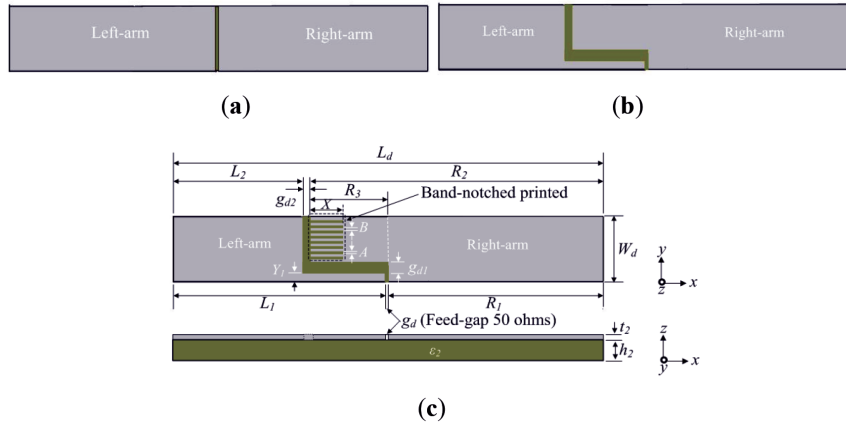


Figure 2. Structure geometry of step-shaped printed dipole antenna

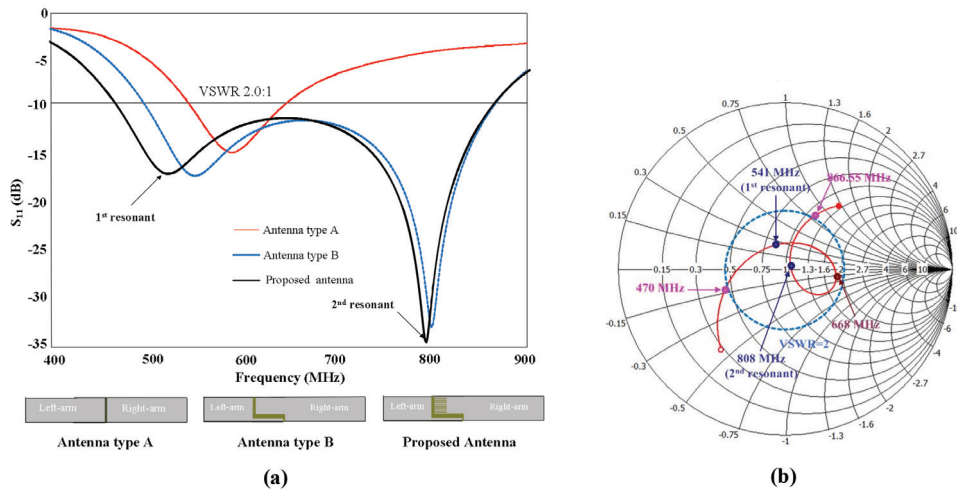


Figure 3. Comparison of the printed dipole antenna: (a) S_{11} impedance bandwidth (VSWR 2.0:1) of all antenna types, and (b) Input impedance of proposed antenna on the Smith chart

much longer length than the shorter arm causing the current density on this arm to be stronger than that on the shorter one; consequently, the radiation of this dipole at the second resonant mode is dominated mainly by the longer arm and is similar to the radiation of the dipole excited at the first resonant mode. Therefore, the obtained radiation patterns in both planes of the antenna are rather stable over the wide operating band, as shown in Figure 6.

A Wideband Step-shaped Printed Dipole with Mushroom-like EBG Reflector

In order to utilize a step-shaped printed dipole to be the directional wideband antenna, we used the mushroom-like EBG as a reflector (Yang *et al.*, 2009) to increase the directive gain in the boresight and suppress the surface waves which propagate towards the edges of the

reflector; consequently, the back lobe will be reduced. The scattering characteristics of the structure shown in Figure 7(a) and (b) are derived using a lumped element model. A resonance is generated inside the structure by the capacitance due to the fringing gap fields between adjacent patches and the inductance due to the current path created by the patches, vias, and ground plane. However, this can be represented as a parallel combination of an inductor and capacitor, as shown in Figure 7(c), while the structure can be assigned a surface impedance given by Equation (1) and a resonant frequency given by Equation (2).

The parameters of the EBG design consists of a patch width (W), gap width (g), substrate thickness (h_i), dielectric constant (ϵ_i), and vias radius (r), as illustrated in Figure 7, together with its typical equivalent circuit. The capacitance

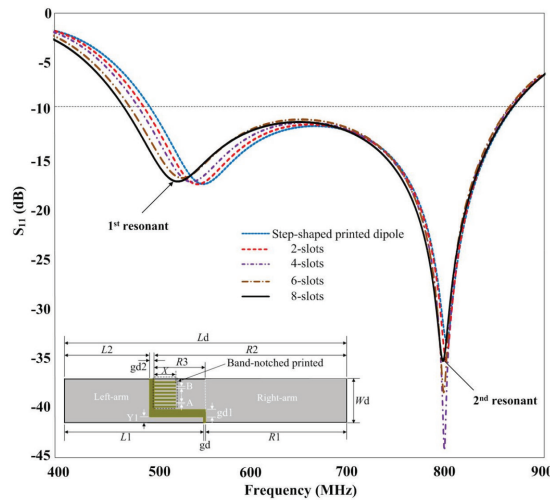


Figure 4. Simulated reflection coefficient (S_{11}) for bandwidth consideration of a step-shaped printed dipole with and without 8 slots on the right arm

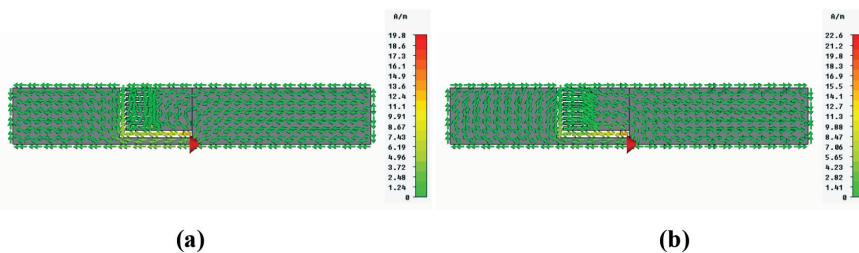


Figure 5. Simulated current density on the proposed dipole at: (a) 541 MHz, and (b) 800 MHz

and inductance of the EBG's equivalent circuit are C and L , which are represented by the gap between the adjacent metallic patches and the thickness of the substrate, respectively.

From the equivalent circuit in Figure 7, the impedance of a parallel resonant LC circuit is given by

$$Z = \frac{j\omega L}{1 - \omega^2 LC} \quad (1)$$

and

$$\omega_0 = \frac{1}{\sqrt{LC}}. \quad (2)$$

The inductance and capacitance in Equations (1) and (2) are derived analytically (Yang and Rahmat-Samii, 2009) and are given by

$$C = \frac{W\epsilon_0(1 + \epsilon_1)}{\pi} \cosh^{-1} \left(\frac{W + g}{g} \right) \quad (3)$$

And

$$L = \mu_0 h_1, \quad (4)$$

where ϵ_1 is the dielectric constant, $\epsilon_0 = 8.854 \times 10^{-12}$ F/m, and $\mu_0 = 4\pi \times 10^{-7}$ H/m (permeability

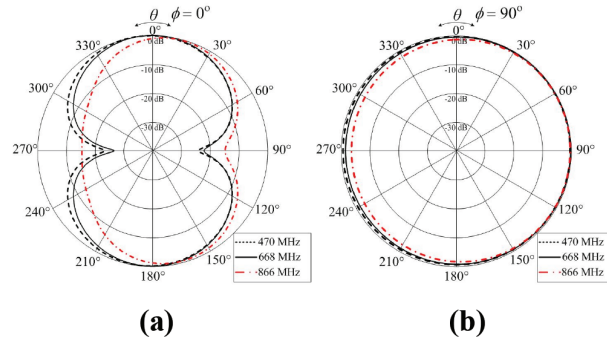


Figure 6. Simulated radiation patterns of single step-shaped printed dipole at different frequencies: (a) in the E-plane, and (b) in the H-plane

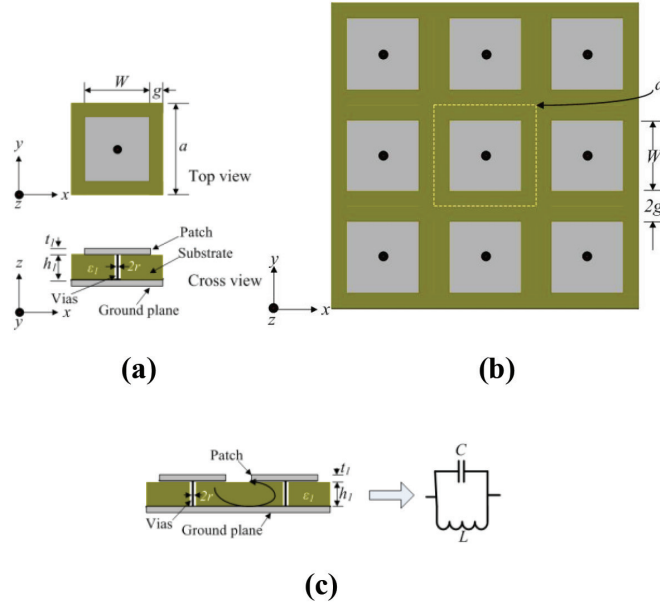


Figure 7. Mushroom-like EBG structure: (a) unit cell of EBG structure, (b) a mushroom-like EBG 3×3 elements, and (c) equivalent circuit

and permeability of air, respectively). Then, the reflection coefficient is derived by considering the transmission line analogy with a system impedance of $Z_o = \eta$, where η is the wave impedance in free space, terminated with a load impedance of Z_L . Since the load is modeled as a purely reactive load, the magnitude of the reflection coefficient is unity and the phase can be determined by

$$\Gamma = \frac{Z_L - \eta}{Z_L + \eta} \quad (5)$$

and

$$\phi = \text{Im} \left\{ \ln \left(\frac{Z_L - \eta}{Z_L + \eta} \right) \right\}. \quad (6)$$

The inductance and capacitance are calculated for an arbitrary geometry of $a = 132$ mm, $W = 78$ mm, $\epsilon_r = 4.4$, $h_f = 1.6$ mm, $g = 27$ mm, and $r = 0.5$ mm using Equations (3) and (4). The resulting reflection phase profile is plotted

by using the CST software, as shown in Figure 8. The reflection phase varies from $+180^\circ$ to -180° around the resonant frequency of the structure and an in-phase reflection bandwidth is defined from $+90^\circ$ to -90° . This reveals that the mushroom-like structure behaves as an artificial magnetic conductor supporting in-phase reflection for an incident plane wave over a desired bandwidth.

In our study, we found that 3×3 elements of unit cells are the proper size for the EBG reflector, as it then provides better radiation characteristics such as high directive gain, and low side lobe and back lobe over the desired bandwidth. After that, we investigated the proper distance between a step-shaped dipole and reflector based on the acceptable impedance matching ($S_{11} = -10$ dB) and its gain is high enough over the bandwidth, as shown in Figure 9. In this step, the proper distance is chosen at 130 mm ($0.28\lambda_c$), which provides very good front-

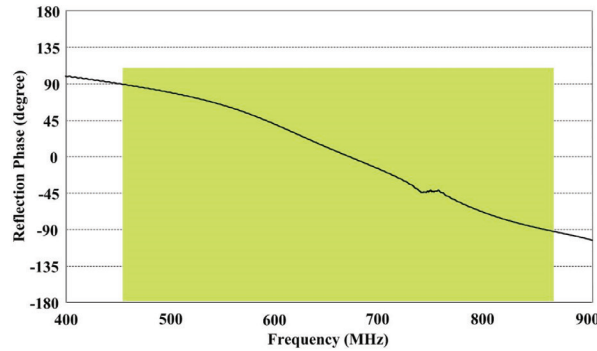


Figure 8. Lumped element model reflection phase profile

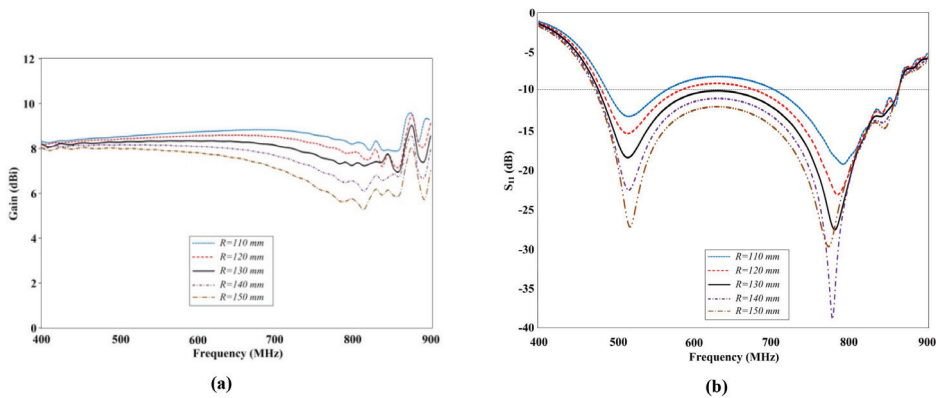


Figure 9. Simulated results of a step-shaped printed dipole with an EBG reflector with the different distance between dipole and reflector: (a) gain, and (b) reflected power (S_{11})

to-back ratios of more than 15 dB in both the E- and H-planes (Balanis, 2005).

In order to increase the radiation characteristics of the proposed antenna and realize this antenna for utilization, we contained the EBG reflector into a square aluminum tray, with its frame surrounding the 4 edges of the reflector, as shown in Figure 16. We investigated the effect of the aluminum frame's height with the CST simulation software calculating S_{11} against different frames' heights, as illustrated in Figure 12. It is seen that the proper height of the frame should be around 60-65 mm, since it provides a better and lower S_{11} over the desired bandwidth when compared to the EBG reflector without a frame.

From the aforementioned process, the simulated results such as S_{11} , directive gain, and radiation pattern of each case will be compared in 1 graph, which consists of the results of a

step-shaped printed dipole without/with an EBG reflector and such printed dipole together with the EBG reflector with a square aluminum tray, as shown in Figures 13-15.

The comparison results of S_{11} at -10 dB of the 3 antenna types are shown in Figure 13. We found that the frequency bandwidth of each antenna type is capable of covering 470 MHz – 862 MHz for DTV band reception. In addition, we also compared their simulated directive gain, as shown in Figure 14. It was found that the directive gains of a step-shaped printed dipole antenna with the EBG reflector and square aluminum tray are around 7.94 dBi, 8.753 dBi, and 9.375 dBi at the frequencies of 470 MHz, 668 MHz, and 866 MHz, respectively, while the maximum gain is around 9.674 dBi at 842 MHz.

The comparison of the simulated results of radiation patterns are illustrated in Figure 15. The main beam of the radiated power is retained

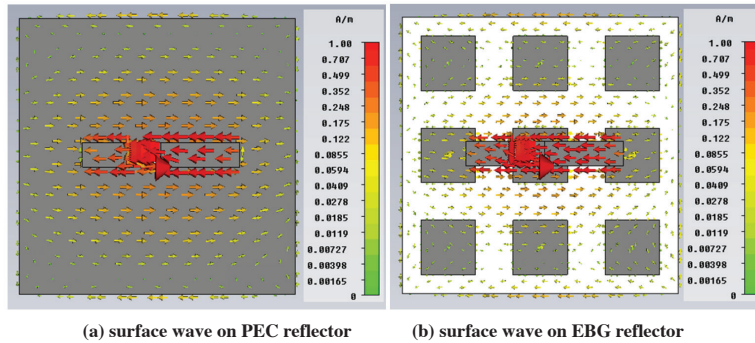


Figure 10. Surface waves in the proposed step-shape dipole with PEC and EBG reflectors

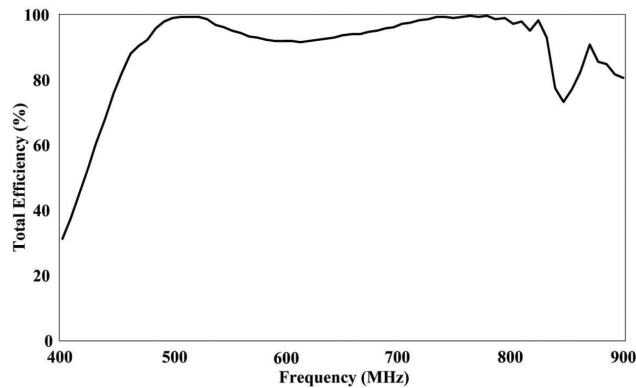


Figure 11. The total efficiency over the operating band of the proposed antenna

in the desired direction in both the E- and H-planes, even when operated at different frequencies, while the front-to-back ratio of our proposed antenna is more than 15 dB over the desired operating bandwidth. Furthermore, the other advantage of the proposed antenna is to provide a rather wide beam in the H-plane (the HPBW's in the H-plane are 85.0°, 77.9°, and 81.2° at frequencies of 470 MHz, 668 MHz, and 866 MHz, respectively), and it provides increased ease of installation because there is compensation for the antenna pointing error.

Finally, in order to confirm that our step-shaped printed dipole with the surface wave suppression properties of the mushroom-like EBG reflector can improve the radiation characteristics when compared to that with a perfect electric conductor (PEC) reflector, the CST software is used to simulate the current density on the surfaces of the PEC and EBG reflectors at 650 MHz of the designed frequency of the EBG unit cell. Figure 10 shows a comparison of the surface wave propagation with and without the mushroom-like EBG reflector. It was verified that the distribution of current density on the surface of the PEC reflector spreads from the center to the 4 edges of the reflector's area and that the surface currents are stronger than those on the EBG reflector, whereas those on the surface of the EBG reflector rather spread all over the area of the reflector but the surface currents are weaker and attenuated as they propagate towards the edges of the reflector, causing the lower back lobe and higher directive gain.

In order to observe the total efficiency of the proposed antenna over the desired bandwidth, we used the CST software simulating the efficiencies (in dB) of the antenna over the band of 470 MHz – 862 MHz; then, we converted them to percentage (%) unit, as illustrated with the graph in Figure 11. The total efficiencies of this antenna are 77.86% - 99.80%, approximately, over the bandwidth, and at the first and second resonant modes provide approximately 97.20% and 99.18% of the efficiency at 541 MHz and 800 MHz, respectively. It is seen that the antenna with the proposed technique can provide high total efficiencies over the desired bandwidth.

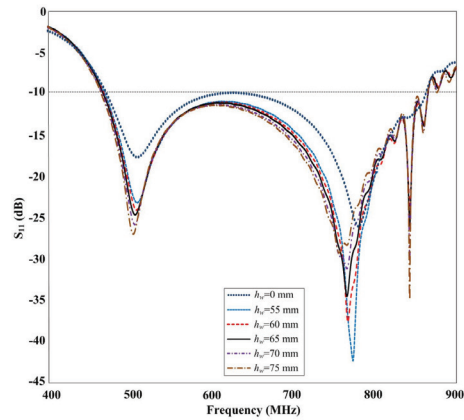


Figure 12. Simulated S_{11} versus the different frames' heights of the aluminum tray (h_w) for the printed dipole above the EBG reflector

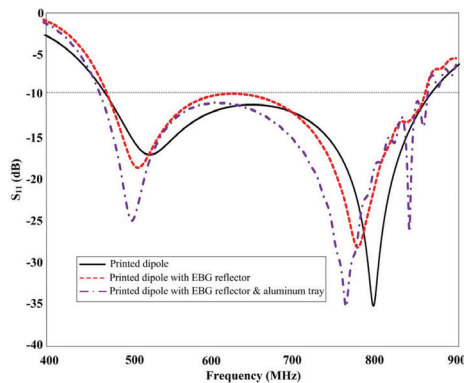


Figure 13. Simulated comparison results of S_{11} of 3 antenna types

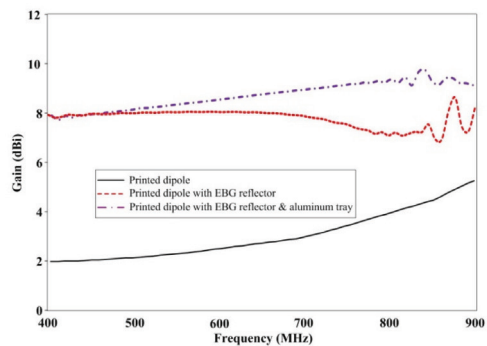


Figure 14. Simulated results of gain against the frequency for all antenna types

Results and Discussion

Figure 16(a) shows the photographs of the prototype antenna comprising a step-shaped printed dipole and EBG reflector that are contained in the square aluminum tray and shielded with a cover that made is from acrylic plastic with a dielectric constant of 3.5 and 3 mm of thickness at the front of this antenna, as displayed in Figure 16(b). In order to verify the simulated results, the prototype antenna without/with the acrylic cover have been measured in

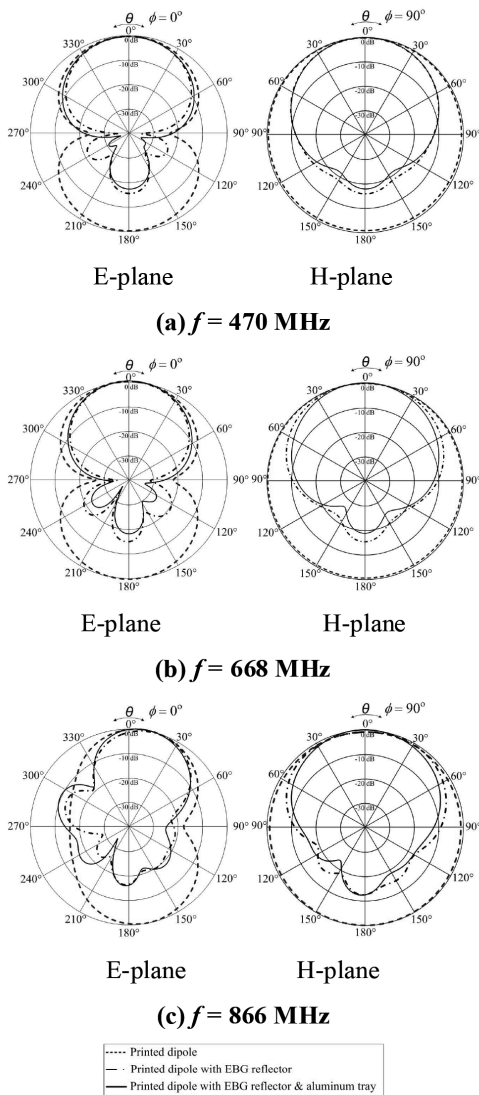


Figure 15. Simulated results of the radiation pattern in the E- and H-planes of all antenna types

an echoic chamber, and then compared to the simulated results in the comparison graphs in Figures 17-19. In Figure 17, we note that the measured results of S_{11} of the antenna shielded with an acrylic plastic cover are around -11.71 dB, -13.225 dB, and -10.884 dB at frequencies of 470 MHz, 668 MHz, and 866 MHz, respectively. However, as we know that if S_{11} is at -10 dB or less, then the value of the standing wave ratio (SWR) will be not more than 2.0. Therefore, this proposed antenna will be well utilized for reception of the DTV signal in the frequency bandwidth of 470 MHz – 862 MHz. For this reason, it is implied that there is reasonably good agreement, even though the antenna with the acrylic plastic cover did not provide the lower S_{11} at the lower frequency bandwidth.

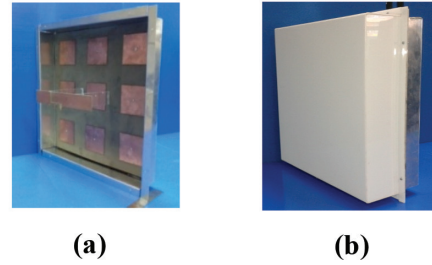


Figure 16. Prototype antenna is contained into aluminum tray: (a) without and (b) with acrylic plastic cover

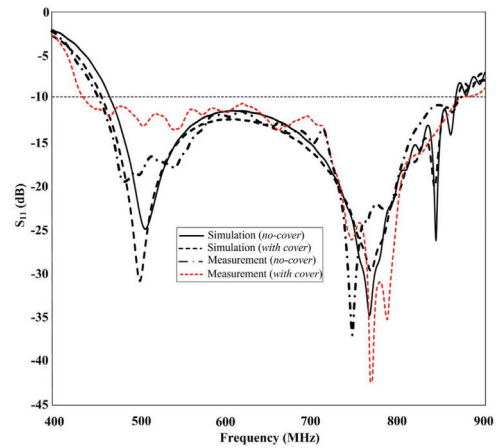


Figure 17. Comparison results of S_{11} for simulated and measured results of the proposed antenna without/with an acrylic plastic cover

The simulated and measured E-plane and H-plane co-polar and cross-polar radiation patterns at 470 MHz, 668 MHz, and 866 MHz are shown in Figure 18(a-c), respectively. Once again, good agreement between the simulation and experiment is evident from these plots, particularly in the main lobes that will be accurately pointed to the broadcast station over the frequency bandwidth of digital TV channels. Besides that, it is found that the half power beamwidth (HPBW) of the proposed antenna is not rather different, even though it operated over the wide bandwidth (the E-plane patterns are around 69.8° , 58.8° , and 51.2° , while the H-plane patterns are around 85.2° , 78.0° , and 50.2° at 470 MHz, 668 MHz, and 866 MHz, respectively).

In addition, in Figure 18, it is found that the E- and H-planes' co-polarized fields are maximum at $\theta = 0^\circ$, while the E- and H-planes' cross-polarized fields are much weaker than the co-polarized fields (around -25.2 to -31.4 dB for the E-plane and -28.2 to -31.5 dB for the H-plane). This shows that this antenna can operate with only horizontal linear polarization according to the horizontal polarized fields of DTV broadcast stations, whereas it also provides very good front-to-back ratio (F/B > 15 dB) over the desired bandwidth (E-plane: 18.88 dB, 19.29 dB, and 18.34 dB, and H-plane: 18.80 dB, 19.73 dB, and 14.80 dB at the frequencies 470 MHz, 668 MHz, and 866 MHz, respectively).

Figure 19 shows the comparison of the directive gains obtained from the simulation and measurement for each case of the prototype antenna. It is noted that the simulated gain of the proposed antenna without an acrylic cover varied from 7.623 dBi to 9.674 dBi, while the antenna with the acrylic cover provides the simulated gain variation from 7.516 dBi to 9.257 dBi along 470 MHz - 862 MHz of the frequency range. The measured gains of the prototype antenna without an acrylic cover are around 8.03 dBi, 8.604 dBi, and 8.498 dBi, while the measured gains of the prototype antenna with the acrylic cover are around 7.62 dBi, 8.05 dBi, and 8.72 dBi at the frequencies of 470 MHz, 668 MHz, and 866 MHz, respectively. These results illustrate that this antenna provided the rather flat-high gain through the desired

frequency bandwidth, while its maximum gain is around 9.257 dBi at 810 MHz of the frequency.

In order to verify a ready-to-use prototype antenna for DTV, the input impedance of the prototype antenna is measured with Network Analyzer Agilent N5224A, as shown in Figure 20. We found that the input impedances of this antenna are around $66.24 + j26.25 \Omega$,

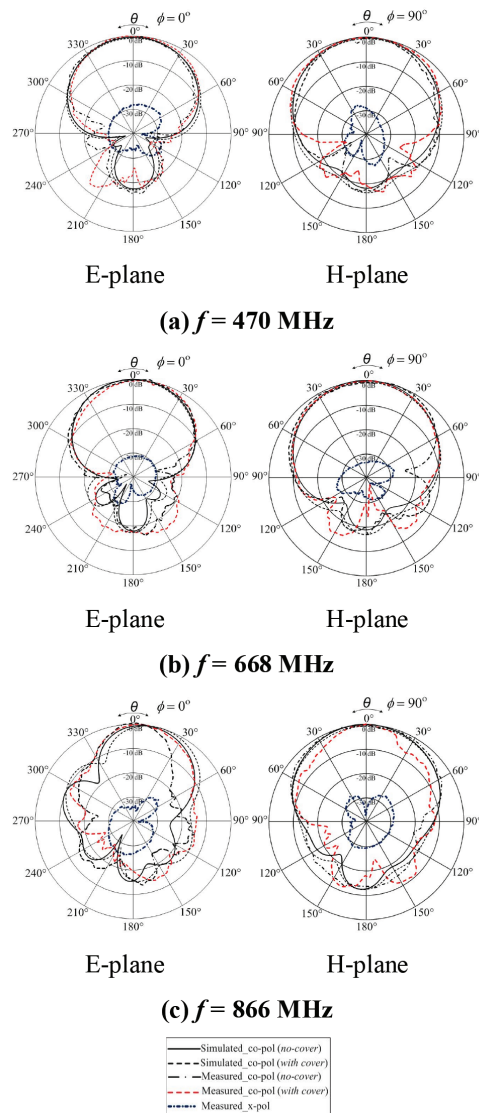


Figure 18. Comparison results of the normalized patterns in the E- and H-planes co-polarized and cross-polarized fields of the prototype antenna with/without an acrylic plastic cover

$62.80 - j21.50 \Omega$, and $65.50 + j30.35 \Omega$ at 470 MHz, 668 MHz, and 866 MHz of the operating frequencies, respectively. Meanwhile, at the frequency of 620 MHz, the prototype antenna provides the best input impedance around $69.92 - j30.69 \Omega$ that is close to the input impedance of standard television. Furthermore, in Figure 21, the measured SWR was also measured to confirm the success of the antenna design. The impedance transformer (75Ω to 50Ω) was used to measure the SWR when connected to the antenna through 75Ω transmission line to 50Ω connector of Network Analyzer. We found that this prototype antenna provides better matching and its SWR is still not more than 2.0 and covered the frequency bandwidth of 470 MHz to 862 MHz.

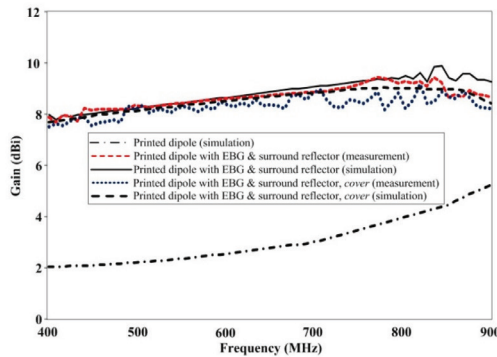


Figure 19. Comparison of directive gain of prototype antenna from simulation and measurement over the operating frequency bandwidth

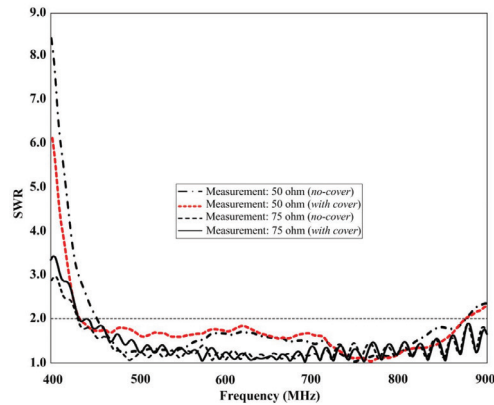


Figure 21. Measured SWR of a ready-to-use prototype antenna

Furthermore, in order to compare the performance of the proposed antenna to some antennas in the literature and on the market, we selected a step-shaped printed dipole antenna which was not modified with the band-notch technique, and 3 types of antennas that are distributed on the market in Thailand, comparing their gains over the DTV bandwidth, as shown in Figure 22. The examples of the 3 antennas on the market are given the labels of Market antennas 1, 2, and 3 such as the 5, 7, and 8 elements of the Yagi antennas, respectively. It was found that the gain over the bandwidth of the proposed antenna is rather flatter than those of the others, whereas some Yagi antennas on the market could not perform. The Market antennas 1 and

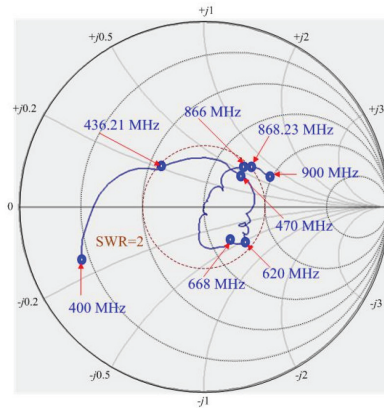


Figure 20. Measured input impedance of a ready-to-use prototype antenna (the dashed circle is the SWR=2)

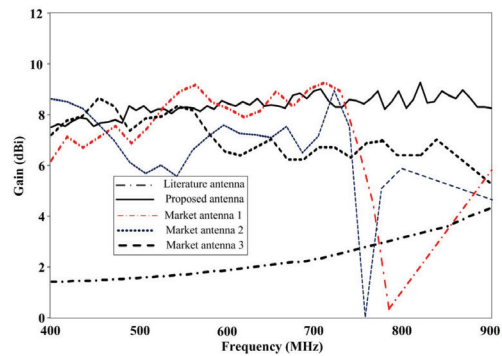


Figure 22. Comparison gain of all types of antenna

2 provide high gains but did not cover the desired DTV bandwidth, while Market antenna 3 can operate over the bandwidth but its gains are rather different. However, it is seen that the gains of the original step-shaped dipole over the bandwidth are lower than the gains of the 3 Market antennas because its pattern is different from the other antennas.

Conclusions

A design technique for a new high gain broadband antenna using a modified step-shaped printed dipole combined with the EBG reflector in the 470-862 MHz frequency bandwidth has been proposed. The step-shaped printed dipole forms the wide operating bandwidth by exciting 2 resonant modes into its feed gap, while the band-notch technique has been used for enlarging the lower-edge frequency to cover 470 MHz by notching 8 small slots on the inner edge of the long side arm. The modified step-shaped antenna has been operated with the reflector comprised of 3×3 unit cells of a mushroom-like EBG. This integration technique allows improved bandwidth and directive gain, whereas the main direction of the radiation patterns over the desired bandwidth, has been retained in the boresight even when operated in different frequencies. The main objective of the antenna design is to utilize it for DTV signal reception in the frequency bandwidth of 470 MHz - 862 MHz. To meet the requirements, the important characteristics of the proposed antenna, such as the reflection coefficient (S_{11}), directive gain, and radiation pattern have been calculated by using the CST simulation software and validated with the measured results of the prototype antenna. We found that the proposed antenna provides the wide bandwidth (-10 dB of S_{11}) covering the frequency bandwidth of 470 MHz - 866.55 MHz (59.34%) by simulation and the frequency bandwidth of 436.21 MHz - 868.23 MHz (66.24%) by measurement. Particularly, it is ready to use for UHF DTV signal reception (470 MHz - 862 MHz) in Thailand at present. Moreover, it provides the directive gain high enough for receiving the DTV signal in remote areas with a directive gain

from 7.623 dBi to 9.257 dBi (at least 90 km from broadcast stations with transmitting power of 5 kW). However, in order for the design to be ready to use the prototype antenna, the structure of the antenna has been contained into an aluminum tray and then covered with acrylic plastic for outdoor utilization. After testing once again, we found that the characteristics of the prototype antenna were slightly changed.

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