Indonesian Journal of Electrical Engineering and Computer Science
Vol. 19, No. 2, August 2020, pp. 855~863
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v19.i2.pp855-863

A review of microstrip antenna designs for TV white space applications

Chamath Kalanaka Vithanawasam, Yi Lung Then, Hieng Tiong Su
Department of Electrical and Electronic Engineering, Faculty of Engineering, Computing and Science,
Swinburne University of Technology Sarawak Campus, Malaysia

Article Info

Article history:

Received Feb 7, 2020
Revised Mar 6, 2020
Accepted Mar 24, 2020

Keywords:

Characteristic mode analysis
Microstrip antenna
Monopole
Omnidirectional
Television white space
Ultra-wideband
Wideband

ABSTRACT

A review on prominent microstrip antennas fabricated for TV White Space applications is presented. This paper will delve into some of the most notable microstrip antenna designs in this frequency band that have come up in recent years. They will be analyzed to identify their strengths and weaknesses, and feedback is provided on their perceived usefulness. These antennas are designed with specific intentions, such as being placed in areas prone to harsh weather, or for long distance communications. One of the most recent antenna types to enter mainstream discussion is the microstrip patch antenna, which can easily be altered to fit various applications. Methods of connectivity such as TV White Space are enthusiastically used in various applications pertaining to connectivity and various microstrip antennas have been designed for this purpose. A conclusion was reached on the compact shorted printed monopole antenna being the most plausible choice from the antennas that have been considered and discussed.

Corresponding Author:

Chamath Kalanaka Vithanawasam,
Department of Department of Electrical and Electronic Engineering,
Faculty of Engineering, Computing and Science,
Swinburne University of Technology Sarawak Campus, Malaysia.
Email: chamathkv@yahoo.com

1. INTRODUCTION

Microstrip antennas came into mainstream usage during the 1970s due to a multitude of reasons, such as the need to fit wireless communications antennas in smaller spaces, and the pursuit of discovering more affordable methods of designing antennas. The advantages are clearly visible ever since its introduction and therefore microstrip antennas can be found in mobile phones, laptops, and other devices in need of communication. Conventional antennas, such as the Yagi-Uda antenna tend to be costly and the cables used for connections will also contribute to costs that may be borne by the end user. Simpler antennas, such as monopole antennas or microstrip antennas have gained popularity due to this. Microstrip antennas in particular are very popular due to their ease of fabrication. These antennas are frequently used for WiFi and Bluetooth applications, where a small yet practical microstrip antenna is utilized. Recently, this approach is used for applications that require far smaller frequencies, such as in the case of TV White Space (TVWS), which will utilize the unused portions of the TV band spectrum (470 – 790 MHz) to transmit data. This has been very tempting for numerous areas of the world and therefore has been implemented in urban and rural scenarios and has been tested in communities in locations such as Maharashtra, India [1]. Other methods, such as the use of WiFi based long distance (WiLD), which propagates 2.4 and 5.8 GHz for long distances, has also been used in rural scenarios, sometimes in combination with TVWS [2]. Testing has also been carried out with LoRa, a chirp spread spectrum (CSS) based technology, for potential use in remote areas where healthcare can be improved [3]. This was done by creating a long-range transmission platform for communication at a lower data rate.

Microstrip antennas enjoy the benefit of being considerably small if they are designed for higher frequencies. This is not the case when designing for lower frequency ranges. Researchers have come up with various methods to fabricate patch antennas for TVWS applications which are reasonably sized and have a satisfactory gain. These designs have been simulated and fabricated to test their capabilities, and some are used in conjunction with TVWS compatible equipment to identify their strengths [4].

This review paper will focus on recent microstrip antennas which have been designed with the intention of use with TVWS technology. These designs are studied in detail, in regard to the material used for fabrication, the return loss, gain, etc. After a thorough analysis, they will be compared and discussed. Section 1 of this paper will provide a brief overview of microstrip antennas along with an explanation on TVWS, followed by sections analyzing three distinct designs

1.1. Microstrip patch antennas

The use of metal patches on substrates for antenna designs has proven to be increasingly popular. These antennas do have their fair share of disadvantages, as they tend to have low efficiency, low power, spurious feed radiation, and a very narrow frequency bandwidth (2% or slightly higher) [5]. Small bandwidths can be considered desirable in some instances, however, modern applications (TVWS, etc.) will demand wider bandwidths.

Although the microstrip antenna became popular from the 1970s onward, it was initially proposed by Deschamps, back in 1953, with more practical designs coming later on [6-8]. The most basic of microstrip antennas consists of a thin metallic strip (patch), along with another metallic strip, which acts as the ground plane. These two strips are separated by a dielectric sheet to which they are attached. Thick substrates with low dielectric constants will be larger in size but will be efficient and provide a wider bandwidth. Numerous feeding methods are used with microstrip antennas. The easiest technique is the microstrip line fed method, which involves the use of a thin conducting strip, which is connected to the patch for signal feeding. Coaxial-line feeding is another famous method of feeding the antenna. Some designs that are used less frequently include the aperture-coupled and proximity coupled methods [9]. In efforts to improve bandwidth, fabricated designs have shown bandwidths ranging from 3 to 15 GHz, 3.1 to 10.6 GHz, which can cater to a wide range of applications [10, 11].

1.2. TVWS technology

TVWSs are the portions of digital terrestrial TV broadcasting which are not in use at a particular time. This is most prominent with the ultra-high frequency (UHF) band. Research carried out in 11 European countries has shown a TVWS availability of upto 49%. If, however, the use of adjacent TV channels is restricted, this availability drops to 25 and 18% [12]. A separate feasibility study in proximity to certain European cities (Bilbao in Spain, Cagliary in Italy and Brasov in Romania) has shown a mean occupancy of around 32% (68% availability) [13]. As the frequency spectrum is a limited resource, using all portions of it efficiently has garnered a lot of attention. Compared to other methods of communication such as WiFi, which use higher frequencies (2.4 GHz, etc.), TVWS focuses on Very High Frequency (VHF) and Ultra High Frequency (UHF) which allows for longer communications distances and stronger penetration through obstacles [14]. Regulatory frameworks have been finalized in the US, UK and are being finalized in numerous other nations such as Finland, Korea, etc [15]. This gives TVWS a tempting outlook, especially for applications that involve long distances and harsh terrain, such as in rural applications. There is no fixed TVWS frequency range for the entire world, but most nations accept the range from 470 – 790 MHz. One of the prime drawbacks in TVWS usage is the way it may affect users who are already using the TVWS frequency spectrum. Interference to the licensed primary user (PU) from any other user is not desirable, and the mitigation of this should be given a high priority [16].

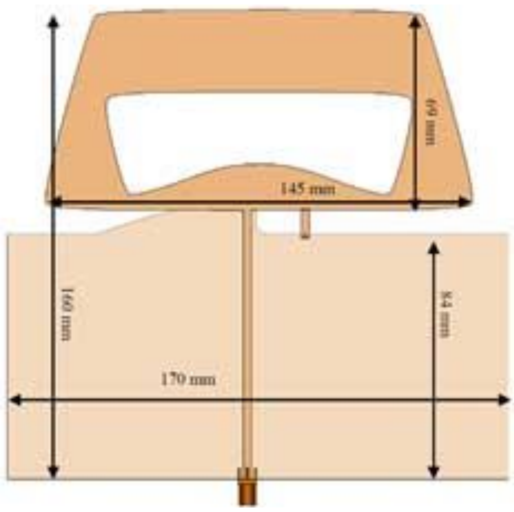
Cognitive radio has been considered as the enabling technology for TVWS and many efforts are being made to regulate TVWS usage and to protect White Space Devices (WSDs) from other users, such as spectrum sensing, which is the frequent monitoring of certain frequency bands in order to identify if they are being used or not [17]. Spectrum sensing usage has been researched on with varying methods, such as a method where sensing the spectrum with appropriate intervals and carrying out background sensing of channels has been proposed, which offered lower latency and higher QoS, and a sub-Nyquist wideband sensing algorithm [18, 19, 20]. Spectrum sensing algorithms have been formulated and tested in North America to test its effectiveness [21]. An overview of spectrum sensing for TVWS indicated that there were still some inadequacies relating to the accuracy and reliability of TVWS detection [22]. A prototype where a spectrum broker is utilized for TVWS allocation among secondary users (SUs) has also been proposed [23]. An antenna has also been designed for spectrum sensing applications in the TVWS band [24]. Research has been carried out on using joint parameters such as false alarm probability and detection probability in order to identify TVWS in a region, with a greater degree of accuracy. This proposed method takes the energy detection criteria along with simultaneous sensing of the noise and signal from primary users ino consideration [25]. Stochastic geometry was utilized to identify the worst-case interference for a finite-area TVWS network, where closed-form expressions on the probability distribution function and an average value of the aggregate interference for various values of path loss exponent under Rayleigh fading channel were derived [26]. Acknowledging the lack of available spectrums in the utilization of Intelligent Transport Systems (ITS), researchers have suggested the opportunistic use of TVWS when a TVWS based internet connection is present, where a new metric, named the Channel Availability for Opportunistic Vehicular Access (CAFOVA), which is used to relate the channel occupancy of a TVWS based internet connection (eg. White-Fi), the speed of the vehicle, and the channel verification distance [27]. Improvement of waiting time for SUs of UHF and VHF spectrums has been proposed, such as the introduction of a middleware sublayer known as the dynamic queue regulator (DQR), into an existing Geolocation Database approach (GLDB), where the SU's waiting time is improved by upto 35.3% [28]. Other methods include the maintenance of a White Space Database (WSDB). In order to mitigate interference between broadband power line communication (BPLC) and TVWS, a BPLC network regulated by TVWS has been proposed for point-to-multipoint downlink communication. This method of integration helps to reduce the interference levels between these two methods of communication [29]. A testbed with cognitive radio enabled Time Division (TD)-LET has been proposed in order to inspect the dynamic spectrum management over TVWS [30].

Antenna designs that are fabricated for TVWS usage are almost always large in size, regardless of the type of antenna, due to its low operating frequency. This poses significant issues regarding convenience when installing in compact devices. Previous research has delved into the potential of using planar inverted-F antennas (PIFA) using magneto-dielectric materials for machine-to-machine communication [31], [32]. A system embedded antenna was fabricated with a high emphasis on portability, which covered a certain range (490 to 595 MHz) of the TVWS spectrum [33]. A tunable handset antenna was fabricated with modern microelectromechanical system tunable capacitors, which help to tune the antenna to the desired frequency in the TVWS band [34]. Another antenna designed for TVWS (albeit with limited bandwidth) is the rectangular loop UHF antenna, which is capable of an operating frequency from 596 to 733 MHz [35]. Modern day acceptable designs need to be ultra-wideband, which is defined by the Federal Communications Commission (FCC) as a radio system with its -10 dB signal being over 20% or wider than 500 MHz [36].

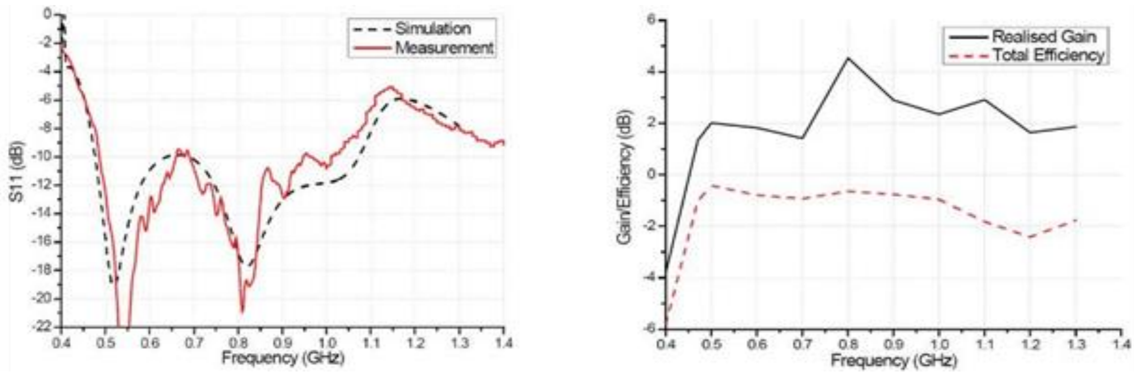
2. ANTENNA DESIGNS

2.1. Compact shorted printed monopole antenna

John & Amman published their patch antenna design for TVWS applications in 2013 [37]. Occupying 160 mm by 170 mm, this double sided FR4 substrate-based design comprises of a dielectric constant (ε_r) of 4.3. Figure 1(a) shows a diagram of the design, which has a rectangular ground plane and a curved rectangular patch design with a shorting stub. This curved patch also consists of a cut-out inside it. In order to further improve wideband impedance matching, there is a slightly extended portion of the ground plane which reaches the bottom of the patch.



(a). Antenna design



(b) readings obtained from compact shorted printed monopole antenna for S11

(c) Gain/Efficiency

Figure 1. Diagram of the design [37]

The cut-out itself improves the lower operational frequency of the design, which is around 524 MHz. The curved shape of the cut-out aids in wide band impedance matching by adjusting internal capacitance. The researchers state that the addition of a cutout reduced the lower edge frequency by upto 54 MHz. The higher edge, on the other hand, exceeds the necessary range regardless of the existence of a cutout. The final design's simulations have shown satisfactory S11 response readings for the desired frequency range, as indicated in Figure 1 (b), along with the gain in Figure 1 (c). A good matching at -10 dB can be observed between 470 MHz and 1050 MHz, which occupies the TVWS frequency range.

Simulated readings have shown a decent match with the measured readings. It can be observed that there are two miniscule regions that go above -10 dB in between 650 MHz and 700MHz in the measured readings, which will not be of significant concern. Figure 3(c) shows the gain and total efficiency of the design. It can be observed that the gain is roughly 2 to 4 dBi, with maximum gain achieved at roughly 800 MHz. Radiation patterns have shown an omnidirectional antenna, which is useful in rural deployment.

2.2. Compact wideband omnidirectional UHF antenna

A UHF microstrip antenna was proposed in 2017 for the purpose of rural TVWS usage as well [38]. This form of antenna was a printed monopole. In order to improve the bandwidth, a pair of parasitic elements are introduced alone with a brief matching network. This was fabricated into an FR4 substrate consisting of a width of 30 mm and a height of 261 mm. The substrate is considerably thinner, at 0.8 mm and having a dielectric constant of 4.4. The rear end of the antenna consists of two parts, and the gap Wg between them helps to cause excitation (Figure 2 (a)). The final fabricated design has an aluminium fixture at the bottom, which is used to fasten the 50 Ω SMA connector. This connector will then be used to supply a signal connection to the feed line of the antenna. The researchers credit the large bandwidth potential, as seen in Figure 2 (b), to the parasitic elements introduced to the design.

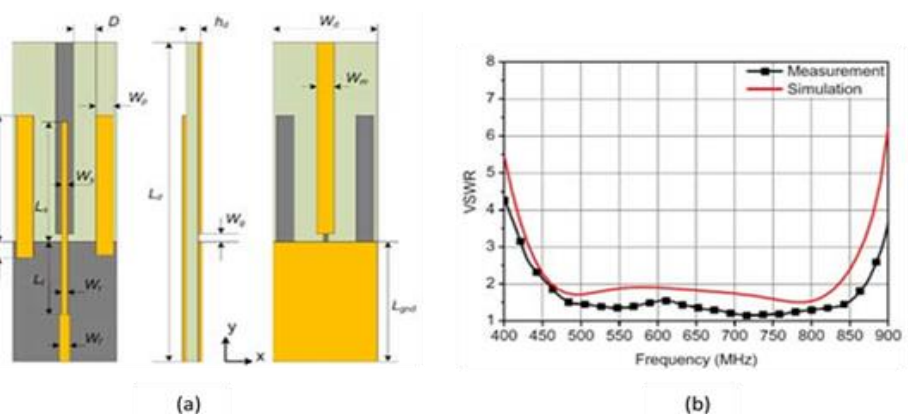


Figure 2. Design (a) and VSWR (b) of compact wideband omnidirectional antenna [38]

The final design successfully achieved a voltage standing wave ration (VSWR) less that 2 in the desired bandwidth, from 465 MHz to 870 MHz for simulation results, and 460 MHz to 870 MHz for measured readings (Figure 2 (b)). The minor differences could likely arise from the aluminium fixture that is installed onto the fabricated design. Anechoic chamber testing for radiation indicates slightly weaker measured readings compared to the simulated results, which can likely be credited to the cable connection and turntable attachment in the final stage of the design, with a rough gain of around 1 to 2 dBi throughout the required frequency range.

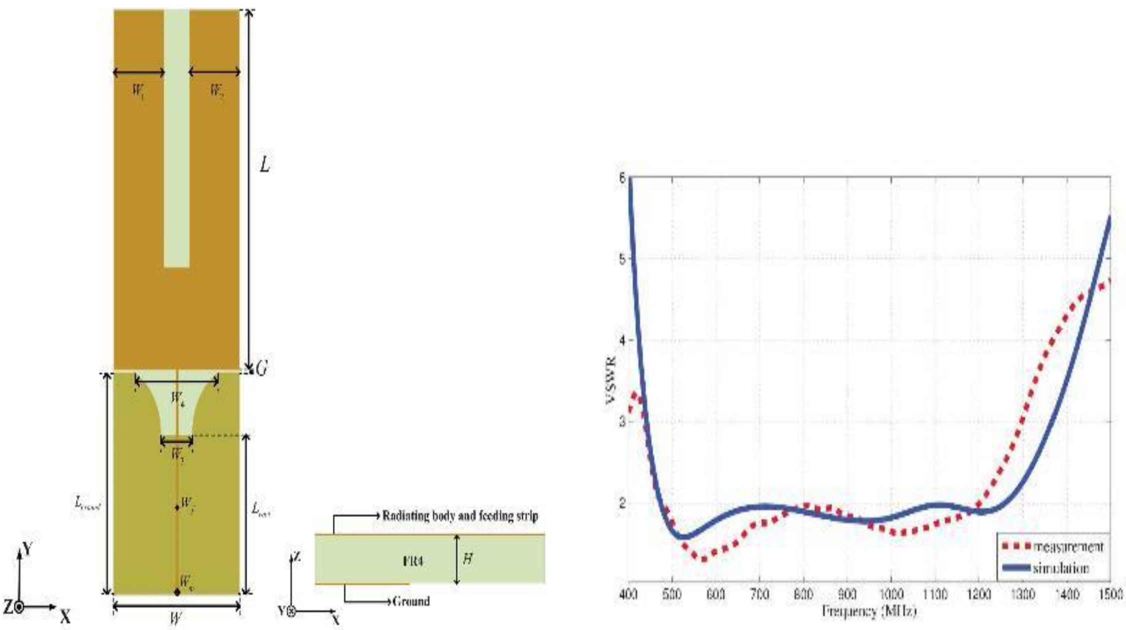
2.3. Compact low-profile UWB antenna with characteristic mode analysis

Characteristic mode analysis (CMA) is a method capable of providing physical insight into the working mechanism of antennas. This method is based on the theory of characteristic mode (TCM), which was designed by Garbacz in 1971 [39]. This was later improved upon by Harrington and Mautz [40], [41]. Zhang and Gao used this method in their ultra-wideband (UWB) antenna design which helped them to come up with a compact design for TVWS applications [42].

The design introduced has a thickness of 0.8 mm and utilizes an FR4 substrate, along with a ground plane. The antenna design comprises of a U-shaped structure, as seen in Figure 3 (a). The researchers utilized CMA initially on the radiating patch itself to understand its wideband properties. The length and width of the patch are selected and then the current for the first three modes is simulated in Figure 4 (a), along with the characteristic angles in Figure 4 (c).

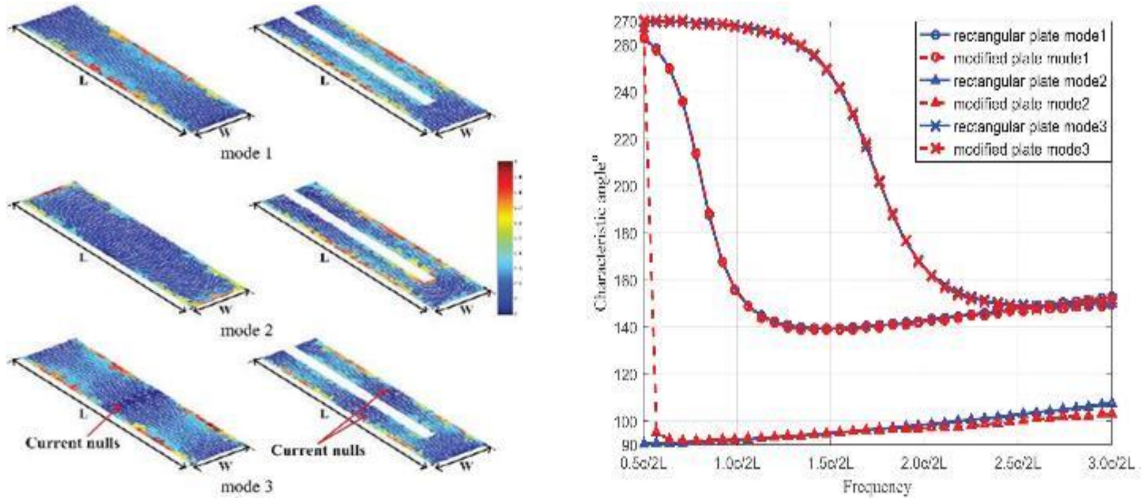
Mode 1 is characterized by the currents flowing along the long axis and Mode 2 shows those flowing along the short axis. Mode 3, which is a higher mode of mode 1, is where a current null is observed. Figure 4 (c) shows the characteristic angles of the rectangular plate in red and the modified plate in blue. This figure shows that modes 1 and 3 resonate at $c/2L$ and c/L, where c is the speed of light and L is half wavelength and one wavelength of resonant frequencies of modes 1 and 3. Due to the characteristic angles of modes 1 and 3 passing 'softly' through 180˚, a notable difference compared to mode 2, as seen in Figure 4 (c), the potential for wideband operation is high. The current strengths toward the center of the patch were weak, therefore it was removed, which introduced new modes, which are shown in Figure 4 (b).

The measured readings on the fabricated antenna have shown results similar to the simulated values. Figure 3 (b) shows the VSWR readings of the design, which indicate an impedance bandwidth less than 2 from 474 to 1260 MHz in simulations, and 474 to 1212 MHz in measured readings. The researchers justify the differences as factors arising from cable loss and fabrication imperfections.



(a) (b)

Figure 3. Design (a) and VSWR (b) of compact low profile UWB antenna with characteristic mode analysis [42]



(a) (b) (c)

Figure 4. Normalized current distributions on the unadjusted rectangular plate ((a) and (b)), in the modified rectangular plate, and the simulated characteristic angles of the first three modes of both designs (c) [42]

3. DISCUSSION

In the previous section, three distinctive TVWS designs have been identified and analyzed. Table 1s highlights the key factors of the three TVWS antenna designs. One very important characteristic of the reviewed designs is the ground plane that is reduced in size. As mentioned under section 2.3, current distributions of dominant modes tend to be concentrated in the area on the base of the radiation body. A similar behavior could likely explain the necessity for a shorter ground plane in most TVWS microstrip antennas. This behavior can be used to adjust the ground plane to obtain wideband characteristics in TVWS antennas, which is the observed case in the reviewed antenna designs. However, this alone is not the only method of achieving wideband characteristics, as observed by the curved ground plane in section 2.1 and the parasitic patches in section 2.2, which are credited with providing wideband characteristics to their respective designs. It is undoubtedly clear that the antennas in section 2.2 and 2.3 are smaller in size and thickness relative to the one in section 2.1. Despite this, they are able to obtain the full TVWS frequency range.

One of the few noticeable differences in the antenna's performance can be seen in section 2.1's slightly better gain. Due to its reasonable size coupled with good gain, this design has a better footing over the other fabrications. The application is crucial to identifying if an antenna is an appropriate design for the task. In some scenarios, the slimmer structure of antenna designs in sections 2.2 and 2.3 are more appealing, however, TVWS applications are usually in situations where longer distances exist between two nodes, with possible obstacles along the way. Due to these reasons, a higher gain is undoubtedly a more desirable trait, which makes the design in section 2.1 a very amiable one.

All three designs can be further improved in terms of their overall gain. One possible proven method of gain enhancement is the use of air as the substrate [43]. When placing the ground plain and antenna with an air-based gap, research has indicated the possibility of significantly improving the reflection coefficient.

Table 1. Specifications of discussed microstrip antenna designs

Antenna Design	Dimensions (mm)	Substrate Thickness (mm)	Dielectric Constant (ε_r)	Bandwidth (MHz)	Gain (dBi)
2.1	160 x 170	1.52	4.3	470 – 1050	2 - 4
2.2	261 x 30	0.8	4.4	460 – 870	1 - 2
2.3	231 x 35	0.8	4.3	474 - 1212	1.4 – 1.9

4. CONCLUSION

This review paper has taken three TVWS microstrip antenna designs from various design approaches into consideration and discussion. All these designs, despite having slightly varying bandwidths, have been proven to be strong contenders in the field of TVWS compact antenna designs. They are compared regarding their gain, size, etc. and their usefulness is reviewed. A conclusion was arrived at, with the compact shorted printed monopole antenna from section 2.1 being the more preferable candidate. This decision was reached by considering its overall gain combined with a satisfactory antenna size. It should be noted that all three designs took varying approaches to achieve the wideband properties required by TVWS applications. The antenna design in section 2.1 credits its raised ground, 2.2 indicates that the higher bandwidth is achieved via the parasitic patches, and 2.3 achieves higher bandwidths through numerous methods, including the U-shaped radiation patch, which creates a capacitance. All these designs, however, are observed to use a small ground plane with a length that is significantly low. These points are useful for consideration in future antenna designs as well. This review paper will be a reference point for understanding the recent improvements done in TVWS microstrip antennas for various modern applications.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Sarawak Multimedia Authority (SMA) for financing this research through Sarawak Digital Economy Research Grant.

REFERENCES

[1] A. Kumar *et al.* (2016, July 2016) “Toward enabling broadband for a billion plus population with TV white spaces”. *IEEE Communications Magazine* 28-34.
[2] W. Kenyon, A. Mickelson, and A. Anderson, "A testbed for WiLDNet and white space," presented at the 2016 *IEEE Global Humanitarian Technology Conference (GHTC),* Seattle, WA, USA, 2016.
[3] M. A. I. M. Ariff, Y. L. Then, and F. S. Tay, "Establish Connection Between Remote Areas and City to Improve Healthcare Services," presented at the 2019 *International Conference on Green and Human Information Technology (ICGHIT)*, Kuala Lumpur, Malaysia, Malaysia, 15-17 Jan., 2019.
[4] Q. Zhang, X. Zhang, O. Holland, M. Dohler, J.-M. Chareau, and P. Chawdhry, "TV White Space Network Provisioning with Directional and Omni-Directional Terminal Antennas," presented at the 2016 *IEEE 84th Vehicular Technology Conference (VTC-Fall),* Montreal, QC, Canada, 18-21 Sept., 2016.
[5] C. A. Balanis, *Antenna theory: Analysis and design*. Wiley, 2016.
[6] G. A. Deschamps, "Microstrip Microwave Antennas," *Proc. 3rd USAF Symposium on Antennas*, 1953.
[7] R. Munson, "Conformal microstrip antennas and microstrip phased arrays," *IEEE Transactions on Antennas and Propagation* vol. 22, no. 1, Jan 1974.
[8] J. Q. Howell, "Microstrip antennas," *IEEE Transactions on Antennas and Propagation,* vol. 23, no. 1, p. 4, 1975.
[9] D. M. Pozar, "Microstrip antennas," in *Proceedings of the IEEE*, 1992, vol. 80, no. 1, p. 13: IEEE.
[10] S. Elajoumi, A. Tajmouati, J. Zbitou, A. Errkik, A. M. Sanchez, and M. Latrach, "Bandwidth enhancement of compact microstrip rectangular antennas for UWB applications," *TELKOMNIKA*, vol. 17, no. 3, 2019.
[11] A. Hamdouni et al., "A low cost fractal CPW fed antenna for UWB applications with a circular radiating patch," *TELKOMNIKA*, vol. 18, no. 1, 2020.
[12] S. W. Oh, Y. Ma, M.-H. Tao, and E. C. Y. Peh, "An overview and comparison of TV White Space regulations worldwide," presented at the *International Conference on Frontiers of Communications, Networks and Applications (ICFCNA 2014 - Malaysia),* Kuala Lumpur, Malaysia, 3-5 Nov., 2014.
[13] M. Fadda, V. Popescu, M. Murroni, P. Angueira, and J. Morgade, "On the Feasibility of Unlicensed Communications in the TV White Space: Field Measurements in the UHF Band," *International Journal of Digital Multimedia Broadcasting,* vol. 2015, 2015.
[14] S. W. Oh, Y. Ma, M.-H. Tao, and E. C. Y. Peh, "An overview and comparison of TV White Space regulations worldwide," *presented at the International Conference on Frontiers of Communications, Networks and Applications (ICFCNA 2014 - Malaysia),* Kuala Lumpur, Malaysia, 3-5 Nov., 2014.
[15] M. Nekovee, T. Irnich, and J. Karlsson, "Worldwide trends in regulation of secondary access to white spaces using cognitive radio," *IEEE wireless communications,* vol. 19, no. 4, 2012.
[16] E. Trinidad and L. Materum, "Juxtaposition of Extant TV White Space Technologies for Long-Range Opportunistic Wireless Communications," *International Journal of Emerging Trends in Engineering Research,* vol. 7, no. 8, 8 August 2019.
[17] M. Nekovee, "A Survey of Cognitive Radio Access to TV White Spaces," *International Journal of Digital Multimedia Broadcasting,* vol. 2010, 2009.
[18] M. Fadda, M. Murroni, C. Perra, and V. Popescu, "TV white spaces exploitation for multimedia signal distribution," *Signal processing,* vol. 27, no. 8, 2012.
[19] R Sri Jagadeesh, C. Meghalatha, K. K. Chaitanya, and B. S. Ramanjaneyulu, "Efficient Spectrum Sensing and Decision making for Utilizing TV White Spaces," *International Journal of Recent Technology and Engineering,* vol. 7, no. 5S4, February 2019.
[20] Y. Ma, Y. Gao, A. Cavallaro, C. G. Parini, W. Zhang, and Y.-C. Liang, "Sparsity Independent Sub-Nyquist Rate Wideband Spectrum Sensing on Real-Time TV White Space," *IEEE transactions on vehicular technology,* vol. 66, no. 10, 2017.
[21] H.-S. Chen and W. Gao, "Spectrum Sensing for TV White Space in North America," *IEEE journal on selected areas in communications a publication of the IEEE Communications Society,* vol. 29, no. 2, 2011.
[22] D. Pineda and C. Hernandez, "Cognitive radio for TVWS usage," *TELKOMNIKA*, vol. 17, no. 6, 2019.

[23] A. Bourdena, E. Pallis, G. Kormentzas, and G. Mastorakis, "A prototype cognitive radio architecture for TVWS exploitation under the real time secondary spectrum market policy," *Physical communication,* vol. 10, 2014.
[24] M. Hassanein Rabah, Divitha Seetharamdoo, Rafik Addaci, and M. Berbineau, "Novel Miniature Extremely-Wide-Band Antenna with Stable Radiation Pattern for Spectrum Sensing Applications," *Antennas and wireless propagation letters,* vol. 14, 2015.
[25] D. Corral-De-Witt, S. Ahmed, F. Awin, J. L. Rojo-Álvarez, and K. Tepe, "An Accurate Probabilistic Model for TVWS Identification," *Applied sciences,* vol. 9, no. 20, 10 October 2019.
[26] M. M. Deshmukh, S. M. Zafaruddin, A. Mihovska, and R. Prasad, "Stochastic-Geometry Based Characterization of Aggregate Interference in TVWS Cognitive Radio Networks," *IEEE Systems Journal,* vol. 13, no. 3, 01 April 2019.
[27] A. Arteaga, S. Cespedes, and C. Azurdia-Meza, "Vehicular Communications Over TV White Spaces in the Presence of Secondary Users," *IEEE Access,* vol. 7, 2019.
[28] G. Atta-Boateng and P. O. Bobbie, "A Geolocation Database Middleware Sublayer for Minimizing Secondary User Waiting Times in TV White Space Spectrum Allocation," *Wireless personal communications,* 17 October 2019.
[29] M. Heggo, S. Sun, X. Zhu, and Y. Huang, "TV White Space Regulated Broadband Power Line Communication for Point-to-Multipoint Downlink IoT Networks: A Standard Perspective," *IEEE Internet of Things Journal,* vol. 6, no. 4, p. 6226, 16 October 2018.
[30] Y. Gao, Z. Qin, Z. Feng, Q. Zhang, O. Holland, and M. Dohler, "Scalable and Reliable IoT Enabled by Dynamic Spectrum Management for M2M in LTE-A," *IEEE internet of things journal,* vol. 3, no. 6, 2016.
[31] R. Ma, Y. Gao, Y. Wang, and C. Parini, "Circular co-planar inverted-F antenna for UHF Machine-to-Machine communications," presented at the 2015 *IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver*, BC, Canada, 19-24 July, 2015.
[32] Q. Zhang, Y. Gao, and C. Parini, "Miniaturized UHF Antenna using a magneto-dielectric superstrate for M2M communications," presented at the 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, Canada, 19-24 July, 2015.
[33] Y. Ma, "System Embedded Antenna for Portable TVWS Cognitive Radio Transceiver," *IEEE Antennas and Wireless Propagation Letters,* vol. 14, 08 October 2014.
[34] S. C. D. Barrio, E. Foroozanfard, A. Morris, and G. F. Pedersen, "Tunable Handset Antenna: Enhancing Efficiency on TV White Spaces," *IEEE transactions on antennas and propagation,* vol. 65, no. 4, 2017.
[35] Shine Let G, Christina V P F, Sam Prince T, and Benin Pratap C, "Rectangular Loop UHF Antenna for utilization of TVWS for Cognitive Radio Application," *International Journal of Innovative Technology and Exploring Engineering,* vol. 9, no. 1, 2019.
[36] Federal Communications Commission, "First report and order in the matter of revision of part 15 of the Commission's rules regarding ultra-wideband transmission systems," 2002.
[37] M. John and M. J. Ammann, "A compact shorted printed monopole antenna for TV white space trials," presented at the 2013 7th European Conference on Antennas and Propagation (EuCAP), Gothenburg, Sweden, 8-12 April, 2013.
[38] N. Wang, Y. Gao, and Q. Zeng, "Compact wideband omnidirectional UHF antenna for TV white space cognitive radio application," *AEU - International Journal of Electronics and Communications,* vol. 74, April 2017.
[39] R. J. Garbacz and R. H. Turpin, "A generalized expansion for radiated and scattered fields," *IEEE Transactions on Antennas and Propagation,* vol. 19, no. 3, May 1971.
[40] R. F. Harrington and J. R. Mautz, "Theory of characteristic modes for conducting bodies," *IEEE Transactions on Antennas and Propagation,* vol. 19, no. 5, Sept 1971.
[41] R. F. Harrington and J. R. Mautz, "Computation of characteristic modes for conducting bodies," *IEEE Transactions on Antennas and Propagation,* vol. 19, no. 5, 1970.
[42] Q. Zhang and Y. Gao, "Compact low-profile UWB antenna with characteristic mode analysis for UHF TV white space devices," *IET Microwaves, Antennas & Propagation,* vol. 11, no. 11, p. 7, 21 September 2017.
[43] H. Jaafar, M. T. Ali, S. Subahri, A. L. Yusof, and M. K. M. Salleh, "Improving gain performance by using air substrate at 5.8GHz," presented at the 2012 International Conference on Computer and Communication Engineering (ICCCE), Kuala Lumpur, Malaysia, 3-5 July, 2012.

BIOGRAPHIES OF AUTHORS

Chamath Kalanaka Vithanawasam received his Bachelor of Engineering (Honours) in Electrical and Electronics from Swinburne University of Technology Sarawak Campus in 2018 and is currently a master’s candidate in the same university. His research work includes microwave engineering, rural connectivity and antenna and wave propagation.

Yi Lung Then was born in Kuching, Sarawak, Malaysia in 1988. He is a registered chartered engineer with PhD in electrical engineering. Research areas involve instrumentation of electromagnetic wave propagation at microwave frequencies, development of microwave sensors for agricultural applications, renewable energy, and energy-harvesting.

Hieng Tiong Su received his BEng degree in Electrical and Electronic Engineering from the University of Liverpool and a PhD degree from the University of Birmingham, UK, in 1994 and 2001 respectively. After his PhD, he worked as a Research Fellow in the Department of Electronic, Electrical, and Computer Engineering, University of Birmingham. In 2006, Dr. Su joined Swinburne University of Technology Sarawak Campus, where he is currently the Dean of the Faculty of Engineering, Computing and Science. His research interests include wireless communication and the design of rf and microwave passive devices such as compact antenna and filters.