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Design Techniques of Super-Wideband Antenna–Existing and Future Prospective

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ABSTRACT With the recent advancement and phenomenal progress in the field of wireless communication technology, there is an ever increasing demand for high data rates and improved quality of service for the end users. In recent times various designs of super wideband antennas (SWB) fulfilling diverse objectives have been proposed for modern wireless networks. Design of compact and wideband antenna for high speed, high capacity, and secure wireless communications presents a challenging task for designers of fixed and mobile wireless communication systems. In this paper, a comprehensive review concerning antenna structures and the technologies adopted for design and analysis of SWB antennas for wireless application is reported. Comparative parameters in terms of electrical dimension, bandwidth, Fractional bandwidth (FB) and Bandwidth Dimension Ratio (BDR) are presented which introduces the researchers to the technical challenges in the design of a compact wideband antenna. This paper contributes to present existing novel approaches along with its adequacy in the design techniques. This review exercise will assist the researchers with valuable support for further research and to achieve better impedance matching, wide bandwidth, high gain and good efficiency along with well directive radiation characteristics.

INDEX TERMS Bandwidth dimension ratio, compact design, fractal antenna, monopole antenna, super wideband antenna.

I. INTRODUCTION

In the present modern era of wireless communication due to the increase in demands for higher data rate, capacity and resolution, the design of wideband antennas with enhanced radiation characteristics are capturing great importance [1], [2]. With the exponential growth of mobile systems toward the fifth-generation (5G), there is a great demand for compact, multiband and enhanced bandwidth antenna with high gain and good radiation efficiency [3]. The designed antenna should be compact in dimension to be integrated into portable wireless devices and RF circuits used for both civilian and military applications [4].

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In recent years, UWB systems have fascinated the new wireless world with its attractive features like multiband communication, high data rate and minimal requirement of operational energy [5]. According to the Federal Communication Commission (FCC) regulation, Ultrawide- band (UWB) antennas are functional over a frequency range of 3.1-10.6 GHz (ratio bandwidth of 3.4:1) for remote sensing, radar imaging and wireless personal area network applications [6], [7].

An appropriate UWB antenna should attain an absolute minimum bandwidth of 500 MHz or a minimum fractional bandwidth of 20% [8]. In spite of having a wide frequency range, UWB antennas are not suitable for a large number of communication systems. Even if the entire bandwidth of UWB (7.5 GHz) is used potentially, the maximum power that can be transmitted by UWB transmitter is 0.566 mW or even less. This amount of transmitted power is not even a fraction of transmitted power, required for applications falling under ISM bands. UWB antennas also exhibit slow adaptation rate and long signal acquisition time. Due to these issues UWB systems are restricted to use for indoor communication only. SWB antennas can play a crucial role to overcome the limitations of UWB communications. Present users of wireless personal area network emphasize a strong desire for SWB antenna as it is good enough for both short and long range communication [9]. SWB antennas can support a large number of wireless applications with a single device [10]. Also,in recent times, there is a demand for sensors in public surveillance domain that could provide extremely high data rate, large range, higher and better Doppler resolution to screening. To meet the aforesaid demand SWB radio technology could be the best key solution as it provides high resolution imaging, sensing and screening in free space as well as lossy medium [11].

SWB antenna supports high channel capacity and delivers voice and video transmission at a higher data rate. Due to its large bandwidth, SWB technology can be used for spectrum sensing in cognitive radios and it is suitable for various wireless frequency applications such as Amature Radio, Global Positioning System(GPS), Global System for Mobile communication (GSM), Personal communications service (PCS), Industrial, scientific and medical (ISM), Bluetooth, Wireless local area network (WLAN), Satellite communication systems, Defense systems, Doppler navigation aids, Radio astronomy, Aeronautical radio navigation [12].

SWB antenna does not have a predefined range of operating frequency. Antenna having bandwidth ratio 10:1 maintaining a return loss less than −10 dB and VSWR less than 2, over the entire range of operating frequency is considered as SWB antenna [11], [12]. This type of antenna can be used for both long and short range of communication. Factors that influence the wideband antenna designing are resistance to jamming, high data rate, transmission power, multipath performance etc. [5].

Miniaturization and wideband behavior of antenna can be achieved by fractal geometry techniques [13], [14]. This technique is based on self-similarity and space filling property [15]. Self-similarity leads to an increase in impedance bandwidth while its space filling property expands the electrical dimension of the antenna structure without affecting its physical dimension [16]. Various fractal configurations such as Koch structure, Sierpinski structure, Dragon structure, Minkowski curve, Hilbert curve and Fractal tree have been reported for reduction of size of the antenna [17], [18].

There are several factors which determine the performance of antenna such as gain, radiation pattern, directivity, polarization, return loss and bandwidth [19]. In antenna designing, the structure of radiator and ground plane, position of feed, and dielectric constant of substrate are optimized to achieve the desired antenna characteristics [20], [21].

Comparative analysis of different proposed antennas has been done in terms of Bandwidth dimension ratio (BDR) which illustrates the compactness and wideband properties of any proposed antenna [11], [22]. BDR measures the amount of fractional usable bandwidth provided per electrical unit area. A high value of BDR in antenna designing is desired to confirm wideband antenna characteristics with compact structure. BDR can be expressed as [38]

$$BDR = \frac{BW\%}{\lambda_{length} \times \lambda_{width}} \tag{1}$$

where λ_{length} and λ_{width} are the length and width of the antenna in terms of wavelength corresponding to the lower cut off frequency.

Antenna bandwidth is the range of frequency, over which the value of antenna performance parameters such as input impedance, beamwidth, radiation efficiency, polarization, gain, and sidelobe level is achieved within its standard acceptable limit [23]. In wireless communications system the antenna should have return loss less than −10 dB over its entire bandwidth [24], [25]. Bandwidth of the antenna can be determined in terms of fractional usable bandwidth and bandwidth ratio. Fractional usable bandwidth (FBW) is a measure of bandwith with respect to centre frequency whereas bandwidth ratio (RB) is a comparison of lower and upper frequency bound.SWB antenna needs to maintain a minimum bandwidth ratio of 10:1 [11]. FBW & RB can be calculated by following formulae [24] respectively.

$$FBW = \frac{(f_h - f_l)}{f_c} \times 100 \tag{2}$$

$$RB = \frac{f_h}{f_l} \tag{3}$$

where f_h and f_l are the higher and lower bound of bandwidth and f_c denotes the center frequency. Higher the FBW percentage, broader the bandwidth of antenna achieved.

To assure a reasonable comparison among the proposed SWB antennas, their performances characteristics in terms of bandwidth ratio, fractional usable bandwidth, electrical dimension and bandwidth dimension ratio are included and presented in Table 2 of Section 5. The research article aims to introduce the existing approaches and techniques of SWB antenna designing and to ease future research on SWB antenna designing by providing a direction for the decision on design aspects.

II. CONTRIBUTION

The main contributions of this paper are as follows.

- It provides an overview of contemporary techniques used for SWB antenna designs to achieve wide bandwidth operation with smaller dimension.
- The paper also describes the present challenges in achieving compact size, high gain and omnidirectional wideband antenna.

TABLE 1. Comprehensive survey on super wideband antenna design techniques.

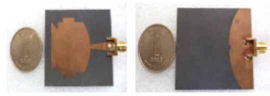
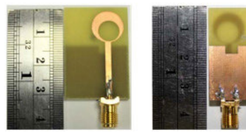
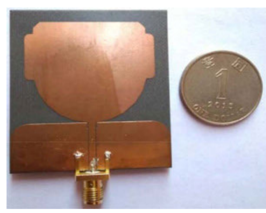
Ref.	Year	Design Methodology and Focus on Existing Study	Inferences	Structure Proposed
[35]	2017	Elliptical ground plane with notch and tapered microstrip feedline along with modification in conventional rectangular monopole antenna is proposed for super wideband application. The proposed antenna is designed by loading a circular base and including two stubs along the conventional rectangular monopole antenna which in turn provides good impedance bandwidth over the entire frequency range of 0.96-13.98 GHz with a bandwidth ratio of 14.56:1. The proposed antenna has the highest Bandwidth Dimension ratio of 7468.51.	The electrical dimension of the reported antenna is large i.e.0.16λ × 0.13λ. As the frequency increases, the gain increases while radiation efficiency decreases. Simulation results show maximum radiation efficiency of 58% at 2.5 GHz.	 **FIGURE 1 Modified rectangular monopole patch with notch loaded elliptical ground plane [35]**
[36]	2017	Authors proposed a crescent shaped radiating patch with a rectangular slotted partial ground, fed by microstrip line to achieve wide bandwidth of 2.5 GHz to 29.0 GHz with an overall dimension of 32 mm × 22 mm and bandwidth ratio of 11.6:1 which results in BDR of 3462.02. Minimum gain of 2 dBi at 7 GHz and Maximum gain of 6.10 dBi at 16 GHz is observed. Measured efficiency of 75% and simulated efficiency of 81% is achieved.	Gain of the proposed antenna varies over the entire range of frequency. Radiation Efficiency decreases at frequency above 7 GHz. Omni-directional pattern of the antenna becomes directive at frequencies above 14.5 GHz. Variation in isolation with respect to frequency and variation in group delay for both arrangements (side to side and face to face) with respect to frequency need to be addressed.	 **FIGURE 2 Crescent shaped radiator with rectangular slotted ground plane [36]**
[37]	2018	Partial circular monopole antenna with elliptical slot which enhances the lower operating frequency, which in turn increases the bandwidth dimension ratio to 6975.22, is proposed. In order to augment the impedance bandwidth and to reduce the coupling effect, tapered microstrip line feed with notch loaded elliptical ground plane is suggested. The proposed antenna achieves a frequency range of 0.96 GHz to 10.9 GHz with a bandwidth ratio of 11.35:1.	The impedance bandwidth of proposed antenna is less and a very low gain of 0.5 dBi is observed at the lowest resonant frequency. As well as efficiency of the proposed antenna needs to be further explored.	 **FIGURE 3 Segmented circular patch antenna with elliptical slot and notch loaded elliptical ground plane [37]**
[38]	2018	Authors presented a co-planner waveguide fed square monopole antenna which is modified by adding two stubs at the opposite side, which in turn increases the electrical length of monopole resulting in large BDR 7871.49.The designed antenna consists of semi-circular base which provides smoother impedance variation and helps in providing bandwidth greater than a decade. Corner truncated ground plane which creates capacitive coupling, which void the inductive effect created by modified radiator and thus provides the resistive impedance. The designed antenna operates at a frequency range of 0.95-13.8 GHz with a radiation efficiency of 80% and gain of 5.8 dBi at 13.8 GHz.	Negative gains are observed at lowest resonant frequency due to poor impedance matching at lower resonant frequency. Radiation efficiency is slightly decreasing as frequency increases which is due to the lossy nature of Rogers RT/Duroid 5880 substrate material and also due to the presence of losses in the surface wave.	 **FIGURE 4 CPW fed modified square monopole radiator [38]**
[39]	2017	Authors reported a 30 mm × 30 mm design of microstrip monopole antenna for band notch rejection by carving a rectangular slot on the patch radiator. Author proposed that impedance matching bandwidth and characteristics of radiation pattern can be enhanced by making use of tapered microstrip feed line and by employing modification in the lower edge of the patch. The average gain of proposed radiator is 5dbi. The proposed antenna has operating frequency over the range of 3-50 GHz having band-notch frequency from 4.85-5.83 GHz.	The presented antenna is incapable to cover the important lower frequency band such as L-band. Above 30GHz, the cross-polarization level increases. In order to ensure received pulse is the exact replica of transmitted pulse, time domain analysis needs to be further performed.	 **FIGURE 5 Tapered Microstrip fed rectangular slot monopole antenna [39]**

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

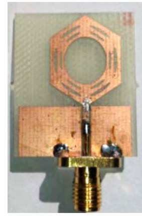
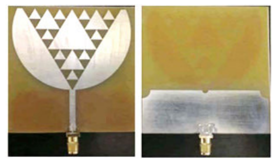
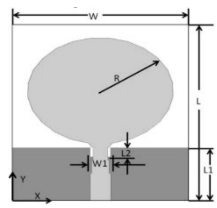
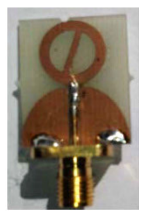
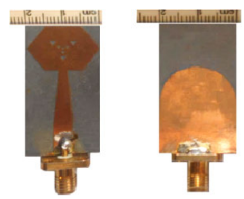
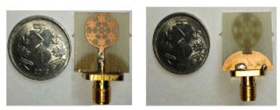
[40]	2016	A Compact fractal SWB antenna with CPW fed asymmetric ground plane is proposed.The proposed hexagonal shaped patch loaded antenna comprises of three iteration of circular slot to achieve operating frequency range from 2.75-71 GHz with a large bandwidth ratio of 25.82:1. Minimum gain of 4 dBi at 24 GHz and maximum gain of 12 dBi at 71 GHz is obtained.	At frequency above 10 GHz distorted omni-directional radiation patterns are observed, also impedance matching is not so good over the entire frequency band of operation. The future prospective of this research could be carried out to analyze antenna performance over the time domain.	 **FIGURE 6** **CPW fed Hexagonal shaped fractal SWB antenna with inscribed circle [40]**
[41]	2017	A complementary triangle Sierpinski geometry is proposed. In order to achieve coupling over the entire bandwidth semicircular sectors are enclosed on both sides of the radiating patch. Truncation in the ground plane is done to produce capacitive effect which in turn is used to nullify the inductive effect of patch resulting in an improved impedance matching by improving the return loss. It operates over a wide range of frequency 1.68-26 GHz with a bandwidth ratio of 15.47:1 and minimum gain of 0.5 dBi at 6 GHz and maximum gain of 5.5 dBi is obtained at 24 GHz.	Gain varies over the entire range of frequency. A higher gain deviation is noticed for the frequencies above 15 GHz due to reflection effects. Total efficiency decreases up to 50% with respect to frequency due to the high dielectric losses of the FR4 material that increases with frequency. The proposed antenna could not attain miniaturization. Time domain analysis of the presented antenna needs to be analyzed.	 **FIGURE 7** **Complementary triangular Sierpinski fractal antenna [41]**
[42]	2016	Circular shaped patch antenna with a rectangular slot ground plane fed by a microstrip feed line is presented to operate at a frequency range from 2.4-28.4 GHz with bandwidth ratio of 12:1.	Negative gains at lower frequencies are observed. Impedance bandwidth matching is not fairly good between 16-24 GHz which results in decrease in gain with increasing frequency above 16 GHz. Experimental validations needs to be accomplished to assess the performance of the antenna.	 **FIGURE 8** **Microstrip fed Circular shaped patch radiator [42]**
[43]	2016	In order to achieve wide bandwidth of 3.5-37.2 GHz a π-shaped radiator is designed with the modification of traditional elliptical monopole radiator and CPW fed ground plane. Simulation results shows minimum gain of 2 dBi at 3.5 GHz and maximum gain of 8 dBi at 37.2 GHz.	With increase in frequency, efficiency is observed to be decreased up to 55% due to improper impedance bandwidth matching at higher frequency and also due to varying performances of the radiating structure, substrate and SMA connector at different frequency. Fidelity factor for face to face configuration is less as compared to previous reported references. Less fidelity factor causes broadening of pulse and produces more distortion of the transmitted signal. Unstable radiation patterns are noticed at frequency greater than 10 GHz.	 **FIGURE 9** **CPW fed Phi-shaped monopole patch antenna [43]**
[44]	2015	Hexagonal-triangular fractal antenna with tapered microstrip feedline and modified partial ground which is an integration of semi-circular and rectangle shape has been presented to achieve wide frequency band from 3-35 GHz.	Low gains are observed in the range of 10-20 GHz. Impedance bandwidth matching is not fairly good at frequencies above 20 GHz.Also it does not support lower frequency bands. Isolation characteristics, efficiency and time domain analysis of the presented antenna needs to be further delve into.	 **FIGURE 10** **Hexagonal shaped triangular slot fractal antenna [44]**
[45]	2017	A Compact star-star fractal microstrip-fed monopole antenna with notch loaded semi-elliptical ground plane is designed and is investigated to operate over a wide frequency range of 4.6–52 GHz. Gain of 2 dBi at 4.6 GHz and 11 dBi at 52 GHz are observed.	The proposed antenna does not cover the lower range of frequencies. Time domain analysis to study the performance of antenna over the specified frequencies need to be carried out. Also, as the frequency is increased beyond 10 GHz; the patterns started	 **FIGURE 11** **Star fractal geometry patch antenna with semi-elliptical**

TABLE 1. *(Continued.)* **Comprehensive survey on super wideband antenna design techniques.**

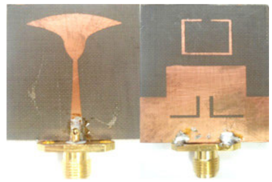
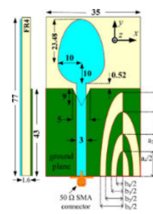
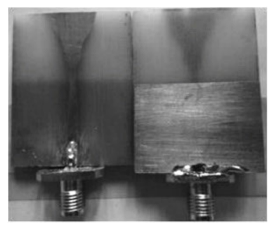
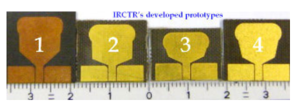
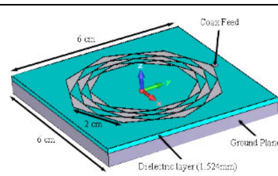
			achieving distorted omnidirectional nature in both planes. As reported these distortions at higher frequencies are due to the higher order modes and feed line radiation at those frequencies. Efficiency of the antenna need to be examined.	**notch loaded ground plane [45]**
[46]	2017	Band notch SWB antenna with tapered feedline has been designed. Band notch function has been achieved by placing C shaped parasitic element near the ground plane and by etching two L shaped slot on the ground plane. The proposed antenna provides a large impedance bandwidth with a bandwidth ratio of 111.1:1.	At frequency above 20 GHz, antenna generates multi-nulls in the E-plane and H-plane and also the cross-polarization level increases with higher frequencies. Negative gains are noticed at lower frequency.	 **FIGURE 12 Tapered radiating patch with chamfered ground plane band notched SWB antenna [46]**
[47]	2013	To attain wide impedance bandwidth of 2.18-44.5 GHz a novel design of circular-hexagonal fractal antenna with partial ground plane and asymmetrical patch towards the substrate has been introduced. The average gain of 4.38dBi is obtained. The presented antenna has a good efficiency over the entire range of frequency band, a large BDR of 2461 and high ratio bandwidth of 20.4:1.	Cross polarization level increases at higher frequencies and thus radiation characteristics become unstable at those frequencies. Also the performance of this antenna needs to be validated through time domain analysis.	 **FIGURE 13 Circular shaped metallic patch with hexagonal slot fractal antenna [47]**
[48]	2011	A microstrip fed line, asymmetrical ground plane loaded with triangular and a fractal complementary semi-elliptical slot is designed to provide a good impedance bandwidth from 1.44-18.8 GHz with a ratio bandwidth of 13.06:1 and BDR of 2735. It provides a gain of 1 dBi at 1.44 GHz to 7 dBi at 12 GHz.	Nevertheless, the major bottleneck of the designed antenna is its large size with an area of 2695 mm^2 and there is poor difference in its co and cross-polarization level even at lower frequencies. Even radiation characteristic are not stable over the operating frequency band. Reported study has not been assessed through efficiency, group delay and isolation parameter.	 **FIGURE 14 Egg shaped monopole radiator with asymmetrical ground plane [48]**
[49]	2014	Novel SWB monopole antenna design has been presented to obtain a broad impedance bandwidth from 2.5-80 GHz with a bandwidth ratio of 32:1 and measured gain of 2 dBi at 2.5 GHz and 6 dBi at 25 GHz. The proposed design consist of expanding tapered feed region and triangular tapered feeding line.	Variation in group delay is observed between 18 - 19 GHz due to improper impedance matching. Even at frequencies above 20 GHz the cross polarization level increases and few nulls are also observed. In spite of this, wide bandwidth of 77 GHz the presented antenna structure is not applicable for low frequency wireless application such as Global positioning System, Bluetooth, and Global system for mobile application.	 **FIGURE 15 Triangular tapered fed triangular shaped monopole radiator [49]**
[50]	2011	A novel SWB antenna with functional section block techniques is introduced to acquire the desired performance. The proposed antenna structure provides a broad bandwidth from 5 GHz till 150 GHz.	In spite of this wide impedance bandwidth, the designed antenna is not appropriate for low frequency band applications. Performance of the proposed antenna in terms of gain and efficiency needs to be analyzed.	 **FIGURE 16 SWB radiator with functional section block approach [50]**
[51]	2011	A fractal antenna based on second iteration of octagonal geometry has been presented to operate over the entire range of 10-50 GHz with a gain of 7 dBi at 10 GHz and 2 dBi at 40 GHz. Although it has wide bandwidth of 40 GHz yet it is not applicable for L Band(1-2 GHz),S band (2 to 4 GHz)and C(4 to 8 GHz) and UWB band applications. Also the size of the antenna is large(60 mm × 60 mm) which makes it difficult to be integrated in portable devices.	Lower Bandwidth ratio (5:01) and less BDR(33.25) are reported due to large electrical dimension of antenna. Impedance matching is not good at the lower range of frequency and gain decreases with increase in frequency. Moreover the performance of this antenna needs to be validated experimentally.	 **FIGURE 17 Octagonal circular fractal geometry microstrip radiator [51]**

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

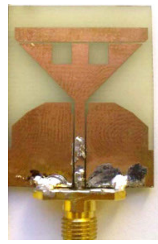
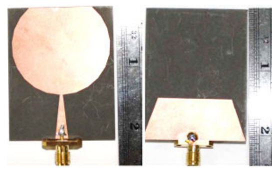
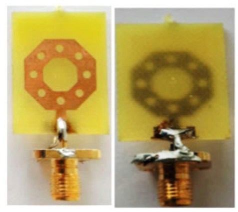
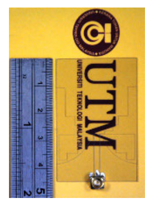
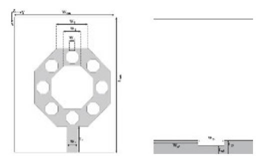
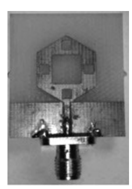
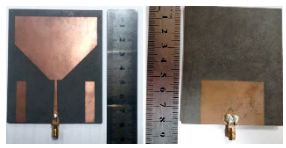
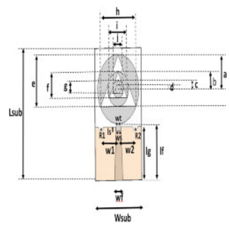
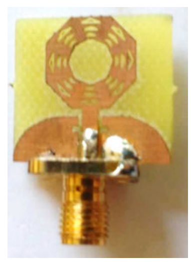
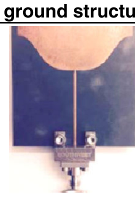
[52]	2015	Authors proposed a CPW fed monopole antenna. The proposed antenna consists of an inverted triangle above which includes two notches and a parasitic element of rectangular shape which is placed to improve the reflection coefficient at lower frequency. The ground plane contains slits notch at the sides which improves the impedance matching at higher frequency. The designed antenna operates over the frequency range of 3.06-35 GHz and provides a bandwidth ratio of 11.43.	The gain and efficiency of proposed antenna are not discussed. Time domain analysis has not been carried out to validate the antenna performance. Inconsistency between the measured and simulated result shows, poor impedance matching between 10 GHz to 20 GHz due to which omnidirectional radiation patterns are not recognized over the entire range of frequency and also at frequency above 10 GHz cross polarization level increases.	 **FIGURE 18** **CPW fed inverted triangular shaped patch antenna [52]**
[53]	2015	Semicircular shaped patch with trapezoid ground plane which is top rounded at the corner to achieve good impedance bandwidth matching is proposed. The proposed antenna is fed with tapered feedline to shift the lower operating frequency and to provide SWB characteristics. It covers frequency spectrum from 1.30 GHz to 20 GHz and provides a gain of 2 dBi at 1.3 GHz to 5 dBi at 20 GHz. Average efficiency of 98.8% is reported across the entire operating band.	Impedance matching is good only in the range of 4.90 GHz to 10.95 GHz. At frequency higher than 10 GHz current density is not evenly distributed on the patch and the ground plane, which results in increased level of cross polarization. Also the phase variation across the entire operating band is not linear, leading to pulse distortion. Gain fluctuations in between frequencies are also observed. Input impedance phase variation is not linear at 17.50 GHz which may lead to pulse distortion.	 **FIGURE 19** **Semicircular shaped radiator with partial trapezoidal shaped ground plane [53]**
[54]	2018	An octagonal shaped Sierpinski SWB antenna with single band-notch characteristics for C-band was designed by using the techniques of slot loading, symmetrical rectangular microstrip feedline and multiple notch-loaded reduced ground plane. The proposed antenna structure operates at 3.68 GHz to 31.61 GHz with band notch function for the frequency range of 7.86 GHz to 11.08 GHz with ratio bandwidth of 8.58:1.Increase in radiation efficiency from 93% to 99% up to 20 GHz is observed.	Above 20 GHz efficiency reduces to 70% due to lossy nature of FR4 substrate. Even negative gains are observed at lower operating frequency. Also proposed antenna has less bandwidth ratio as considered to the other references.	 **FIGURE 20** **Fractal geometry based octagonal Sierpinski antenna with defected ground structure [54]**
[55]	2014	A novel design of transparent antenna has been reported. Staircase approach on the rectangular patch is adopted to achieve wide bandwidth of 3.15 GHz to 32 GHz. The CPW fed partial ground is modified by quarter-circle slots to reduce the capacitance effect. In order to enhance the lower resonant frequencies and to increase the bandwidth, two symmetrical major and minor rectangular stubs were placed above quarter-circle slot ground by virtue of dual axis.	Gain varies over the entire range of frequencies and negative gains are observed throughout the bandwidth. Lower BWR is reported as compared to other references.	 **FIGURE 21Modified ground plane CPW fed staircase shaped patch antenna [55]**
[56]	2017	An octagonal shaped Sierpinski band rejection fractal antenna fed by asymmetrical rectangular microstrip for super wideband application is designed and analyzed. In order to increase the impedance bandwidth slot loading and truncation of partial ground method are utilized. The proposed antenna provides a wide impedance bandwidth of 3.87 GHz to 35 GHz with band notch from 7.24 GHz to 11.11 GHz.	Low gains are observed at lower operating frequency. Study has not been focused on efficiency of the proposed antenna. The designed antenna has not been experimentally validated.	 **FIGURE 22** **Band notched asymmetrically fed octagonal shaped Sierpinski fractal antenna [56]**
[57]	2016	A CPW fed Hexagonal shaped Sierpinski fractal antenna loaded with two iteration of square slot to achieve wide bandwidth from 3.4-37.4 GHz is designed and fabricated.	The reported antenna has large dimension of 30 mm × 28 mm which makes it difficult to be integrated in hand held devices. Also the efficiency of the proposed antenna decreases up to 45% with increase in frequency. This antenna could not support lower frequency range of application.	 **FIGURE 23** **Sierpinski hexagonal shaped fractal antenna with CPW feed [57]**

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

[58]	2014	In order to refine the performance bandwidth, triangular sectors are replaced with circular sectors in the proposed antenna. Full structure of circular sectors is utilized to directly match the impedance to 50 ohm feed line. By appropriately optimizing the geometrical parameters of the antenna, the bandwidth achieved is 1.0 GHz to 19.4 GHz.	The proposed antenna has lower bandwidth dimension ratio of 890.93 due to large electrical dimension of 135 mm × 135mm. Impedance matching over the entire range of frequency band is not good especially in the range of 9 GHz to 11 GHz as VSWR > 2 which results in poor return loss. Gain reduces with increase in frequency between 3 to 4.5 GHz and 6.5 to 8.5 GHz. Efficiency and time domain analysis of the design antenna needs to be explored.	 **FIGURE 24 Circular coupled sectorial loop radiator for SWB applications [58]**
[59]	2018	Bevel shaped radiator with tapered microstrip feed line is designed and analyzed to achieve SWB performance. Two ground plane on the top side and a partial ground plane on the bottom side are used to present wideband characteristics. The presented design provides a ratio bandwidth of 66:1 with an impedance bandwidth of 0.3-20 GHz. An average gain of 7 dBi is observed over the entire frequency range of 0.3-17 GHz.	Due to high dielectric losses gain decreases as the frequency increases above 17 GHz. In the radiation pattern of the proposed antenna a large amount of ripples are observed at frequency above 7.85 GHz. Also the electrical dimension of the proposed antenna is large (80 mm × 80 mm).The performance of the antenna needs to be evaluated using time domain analysis.	 **FIGURE 25 Bevel shaped patch radiator with modified ground plane [59]**
[60]	2018	A circular metallic patch nested with three iteration of apollonius circles is designed and analyzed. In order to greatly enhance the bandwidth, the ground plane is loaded with a rectangular notch and two semicircular notches. The antenna is fed by a tapered microstrip feedline to achieve better impedance matching over all around frequency range of 3 GHz to 60 GHz.	Although the peak gain increases with increasing frequency, however experimental design validation of the proposed antenna is not obtained. The designed antenna needs to be further examined for time domain analysis.	 **FIGURE 26 Circular shaped metallic patch with Apollonius fractal geometry [60]**
[61]	2016	An octagonal radiating patch loaded with four iteration of octagonal slot is designed to achieve impedance bandwidth of 0.3 -20 GHz. Good impedance matching over a wide frequency bandwidth is achieved by utilizing a pair of rectangular notch-loaded modified ground plane and coplanar waveguide feedline.	The peak gain increases linearly with increasing frequency, however maximum radiation efficiency obtained is 58% at 2.5 GHz. For the frequencies greater than 10 GHz, the radiation patterns become distorted and at some angles, the level of cross-polar patterns is greater than that of co-polar patterns due to excitation of hybrid modes at higher frequencies.	 **FIGURE 27 CPW fed octagonal shaped fractal radiator with defective ground structure [61]**
[62]	2018	Planar monopole SWB antenna based on Hanning window function is designed to provide wide bandwidth of 2.5 GHz to 110 GHz. In order to improve radiation and reduce reflection, microstrip line is narrowed down at the feeding point.	The gain is relatively flat up to 40 GHz. However according to the measured result impedance matching is not fairly good over the entire defined frequency range.	 **FIGURE 28 Hanning function based tapered microstrip monopole antenna [62]**

- Constraints and associated complications with the design of SWB antenna followed by a discussion of all relevant research articles are presented.

This paper is organized as follows. In Section III, parameters for the design of SWB antenna is discussed. Section IV, presents the key literature of SWB antenna.

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

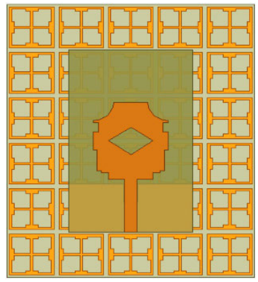
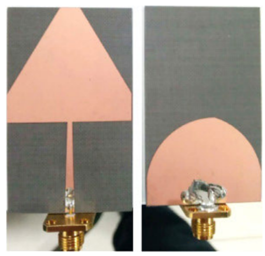
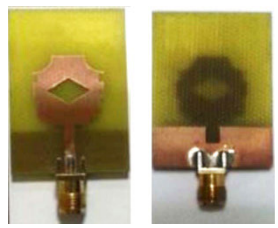
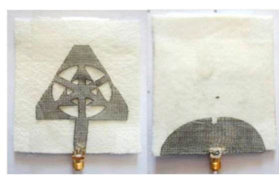
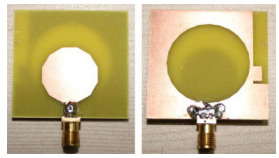
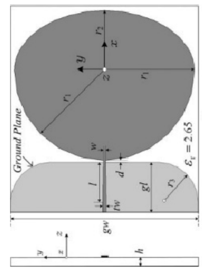
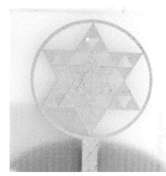
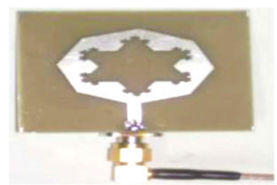
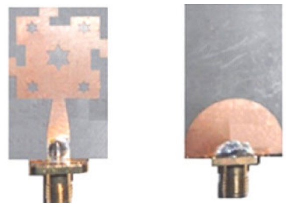
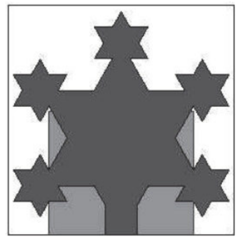
[63]	2018	Novel compact CPW-fed Semi-circular triangular antenna for Super Wide Band communication applications is proposed to achieve good impedance bandwidth from 4.9-25 GHz. The proposed structure provides an average gain of 4 dBi.	The reported antenna has less dimension of 15 mm × 20 mm.But this antenna could not support lower frequency range application such as L and S bands. Measured reflection coefficient in the frequency range between 4.9-7 GHz is-5 dB.	 **FIGURE 29 CPW fed semi-circular and triangular shaped antenna [63]**
[64]	2015	Radiating patch with diamond shape slot and modified edges using slits and corners truncations is presented. Gain of the antenna is enhanced over the entire frequency band from 3-20 GHz by using an FSS reflector. FSS array of 30 elements (i.e. 6 × 5) is placed below the antenna. Maximum gain enhancement is around 7.5 dB is achieved for the complete operational band.	Experimental design validation of the proposed antenna is not presented. Efficiency and time domain study needs to be carried out for the proposed antenna.	 **FIGURE 30 SWB patch antenna with frequency selective structure[64]**
[65]	2018	A Compact SWB trapezoid shaped radiator with a triangular tapered feedline and a semicircular ground plane is designed and investigated. The proposed antenna structure covers a wide frequency bandwidth from 1.42 GHz to 90 GHz and provides maximum gain of 7.67 dB at 23 GHz and the average gain of about 4.77 dB.	In spite of support for wide bandwidth, the omnidirectional radiation pattern becomes distorted at higher frequencies. At some angles, the level of cross-polar patterns is greater than that of co-polar patterns. The performance of the antenna needs to be analysed in time domain.	 **FIGURE 31 Trapezoid shaped patch antenna with semicircular ground plane [65]**
[66]	2015	A novel compact hut-shaped radiating patch with a diamond shaped slot at its center is designed for super wideband applications. To achieve the enhanced bandwidth, partial ground plane with a rectangular notch is proposed. The designed antenna operates in the frequency range of 0.92 GHz to 22.35 GHz and provides a bandwidth ratio of 24.8:1.	Gain degrades with increase in frequency from 2 GHz to 12 GHz. Efficiency of the design antenna has required to be explored.	 **FIGURE 32 Hut shaped patch antenna with diamond shaped slot for SWB applications[66]**
[67]	2015	A novel fractal textile antenna design based on genetic algorithm for SWB applications is proposed. In order to boost the radiation resistivity which improves the radiation power, gain and efficiency a fractal geometry consisting of triangular–circular patch with an elliptical ground plane is developed. The designed antenna provides a broad impedance bandwidth of 1.4 GHz to 20 GHz.	Antenna performances such as phase variation of the far-field and transient response in time-domain needs to be further explored to reveal the real ability of SWB antennas in receiving pulses**.**	 **FIGURE 33 Equilateral triangle with inscribed circle fractal geometry radiator with elliptical ground plane [67]**

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

[68]	2018	A compact polygonal shaped patch antenna of 40 mm × 38 mm dimension which covers the frequency range of 2.25-11.05 GHz is designed. The ground plane consist of circular and rectangular shaped slot which helps to expand the bandwidth and gain of the designed antenna.	The peak gain of designed antenna is 5.05 dBi. However efficiency of the designed antenna drops with increase in frequency and even the performance of the antenna needs to be evaluated using time domain analysis.	 FIGURE 34 Polygonal shaped patch radiator with circular slotted ground plane[68]
[10]	2009	Elliptical shaped patch fed with tapered microstrip feedline is designed to exhibits extremely broad bandwidth from 640 MHz to 16 GHz. Two corners are rounded in the ground plane for bandwidth enhancement. Gain of the antenna evenly increases from 3 to 10 dBi with slight fluctuation.	The peak gain is high, but the antenna structure is large (150 mm × 150 mm) to be integrated into portable devices. Also for face to face configuration critical antenna characteristics such as antenna transfer function decreases substantially at frequency greater than 1.5 GHz, as a result the received signals undergo distortion. Hence in spite of extremely broad bandwidth only the spectrum in low frequency can be transmitted and received by the antennas	 FIGURE 35 Half circular and half elliptical patch with corner rounded ground plane[10]
[69]	2013	A compact star-triangular fractal monopole antenna is proposed, which is fed by a microstrip-feedline. The designed antenna is appropriate to cover from 0.5 GHz to 30 GHz frequency with a measured bandwidth ratio of 60:1.To achieve a good impedance matching semielliptical ground plane loaded with rectangular notch is introduced.	The gain is stable along 1–14 GHz of the antenna operating range. However fluctuation in gain are observed in intermediate frequency from 14 to 30 GHz.	 FIGURE 36 Star shaped fractal semi-elliptical ground plane monopole antenna [69]
[70]	2016	A compact octagonal shaped patch inscribed with Koch fractal geometry has been proposed to achieve wide bandwidth operation. The proposed fractal antenna design can be used in the frequency range of 2-30 GHz.	This antenna contained no validation experimentally. Gain, efficiency and time domain analysis has not been presented.	 FIGURE 37 Octagonal shaped patch with koch fractal geometry [70]
[71]	2013	A CPW fed propeller shaped monopole antenna for SWB application is presented. The designed antenna provides a wide bandwidth from 3 to 35 GHz with a ratio bandwidth of 11.6:1.	The gain of the antenna varies from 4dBi at 3 GHz to 6 dBi at 13 GHz. However at higher frequency due to dielectric loss of the substrate the gain gradually decreases to 3.9 dBi at 25 GHz.The designed antenna structure is not appropriate for L band wireless applications. The proposed antenna has fair impedance bandwidth however it suffers from lower BDR value (809) due to its large electrical dimensions.	 FIGURE 38 Propeller shaped monopole radiator with CPW feed [71]

Section V presents a comparison based on the performance characteristics in terms of bandwidth ratio, fractional usable bandwidth, electrical dimension and bandwidth dimension ratio. Section VI summarizes the contributions and interprets the observations. In Section VII, concluding remarks have been drawn from the aforesaid study.

TABLE 1. ***(Continued.)*** **Comprehensive survey on super wideband antenna design techniques.**

[72]	2014	A rectangular patch with Giusepe Peano fractal geometry on its boundary is designed to operate over a wide frequency range from 3 GHz to 26 GHz. In order to improve the current distribution in the exterior of the antenna, Sierpinski Koch snowflake slots of different size are further applied on the surface of patch. To achieve the wide impedance bandwidth the ground of proposed antenna consists of rectangle and semi-circle.	The proposed antenna structure is not suited for wireless applications such as GSM, GPS and Bluetooth. Radiation efficiency and time domain analysis needs to be carried out for the proposed antenna.	 FIGURE 39 Giusepe Peano fractal geometry radiator with combination of circular and rectangular ground plane [72]
[73]	2016	A snowflake structure is achieved using star shaped fractal antenna. The designed antenna is useful for 5G communication as it operates over the entire frequency range of 17.22 GHz to 180 GHz.The obtained peak gain of the proposed antenna is 10 dBi and average gain is 6.4 dBi.	Simulated structure is be fabricated and measured results need to be verified. In spite of operating over a wide bandwidth, the designed antenna does not support lower frequency range applications.	 FIGURE 40 Star snowflake structured fractal antenna[73]

III. PARAMETERS FOR DESIGN OF SWB ANTENNA

A. VSWR AND REFLECTION COEFFICIENT

As electromagnetic waves travel from the source to the antenna through the feedline and finally the antenna radiates electromagnetic waves in free space. In this process, EM waves may confront distinct impedance at each interface. Rely on the impedance mismatch part of some energy will get reflected back to the source producing a standing wave. Voltage standing Wave Ratio (VSWR) is the ratio of maximum to minimum voltage along the transmission line. Ideally, VSWR should be one [26], [27].

Reflection coefficient (S_{11}) is the ratio of reflected field to incident field. It measures how much of the incident energy is reflected back. Zero Reflection coefficients indicate perfect impedance matching between the source and the load which in turn results in unity standing wave ratio. Reflection coefficient must be lower than -10 dB in the entire band of frequency. In order to support wireless communication even in unfavorable and mobile environment, it is always a good practice to enable the bandwidth of the antenna considering below -14dB return-loss [28]. Reflection coefficient (S_{11}) and VSWR can be calculated through antenna input impedance as a function of frequency.

Expression for Reflection coefficient can be mentioned as [26], [27]

$$S_{11} = \frac{Z_L - Z_A}{Z_L + Z_A} \tag{4}$$

Z_A is the characteristics impedance of antenna and Z_L is the load impedance of the transmission line.

For a transmission line VSWR is defined as [26], [27]

$$VSWR = \frac{1 + |S_{11}|}{1 - |S_{11}|} \tag{5}$$

Return loss can be evaluated by following formula [28]

$$\text{Return Loss}, R_L = -20 \log_{10} |S_{11}| \text{ dB} \tag{6}$$

B. ISOLATION COEFFICIENT (S_{12})

It is an important parameter that measures the coupling in the structure of the antenna. A large value of isolation gives non-correlated transfer of signals at both the ports [28]. Isolation Coefficient (S_{12}) should be less than -13 dB over the entire frequency band. Isolation of a two port device can be calculated by following formula [29]

$$Isolation = -10 \log_{10} |S_{12}|^2 \text{ dB} \tag{7}$$

C. TIME DOMAIN ANALYSIS

SWB antenna transmits short duration pulses which are in the order of few hundreds of pico-seconds [30]. Time domain analysis is performed in-line to assure that the obtained pulse is a clone of the transmitted pulse [31]. So in order to validate the performance of SWB antenna in terms of time domain various parameters are evaluated such as fidelity factor, group delay and phase response [32]. In performing these analyses, two similar antennas separated by some distance are considered as transmitting and receiving antenna. To examine the performance of the system, two distant orientations (face to face and side to side) of transmitting and receiving antenna are taken into account. For time domain analysis it is considered that the transmitting antenna is excited with a Gaussian impulse signal [33].

TABLE 2. Comparison of existing super wideband antenna design based on various parameters.

Ref	SIZE (mm^3)	Size in λ^2 (λ is free space wavelength calculated at lower frequency)	Freq. range (GHz)	BW (%)	Bandwidth Ratio	BDR	Substrate Material
[35]	52×42×0.94	0.16λ × 0.13 λ	0.96 - 13.98	174	14.56:1	7468.5	Rogers RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$
[36]	32×22×1.60	0.27 λ × 0.18 λ	2.5 - 29.0	168.25	11.6:1	3462.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[37]	52×42×1.575	0.17λ × 0.13λ	0.96 - 10.9	167.22	11.35:1	6975.2	Rogers RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$
[38]	52×46×1.6	0.17 λ × 0.13 λ	0.95 - 13.8	173.96	14.52:1	7871.4	Rogers RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$
[39]	30×30 × 1.6	0.3 λ × 0.3λ	3-50 (Band-notch is from 4.85-5.83)	177	16.66:1	1966.6	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[40]	28×27 ×1.6	0.256λ × 0.247λ	2.75-71	185	25.82:1	2912.2	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[41]	62×64×1.58	0.34λ × 0.36λ	1.68-26	175.72	15.47:1	1435.6	FR4, $\varepsilon_r = 4.08, \tan\delta = 0.019$
[42]	30×40×1.6	0.24λ × 0.32λ	2.4- 28.4	169	12:1	2200.5	Dielectric, $\varepsilon_r = 2.22, \tan\delta = 0.0009$
[43]	22×18.5× 1.6	0.2785λ × 0.234λ	3.5-37.2	164	10:1	2541.1	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[44]	20×33.3×1.57	0.35λ × 0.20λ	3-35	168	11.6:1	2400.0	Rogers RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$
[45]	19.7×19×1.6	0.30λ × 0.29λ	4.6 -52	168	11.31:1	1903.2	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[46]	30×40×0.787	0.09λ × 0.12λ	0.9 - 100 (Band-notch is from 4.7-6)	196	111.1:1	1814.8	RT/Duroid5870 $\varepsilon_r = 2.23, \tan\delta = 0.009$
[47]	31×45×1.575	0.33λ × 0.23λ	2.18 - 44.5	181.32	20.4 :1	2461.0	Rogers/Duroid 5870 $\varepsilon_r = 2.3, \tan\delta = 0.0012$
[48]	35×77 ×1.6	0.17λ × 0.37λ	1.44 -18.8	172	13.06: 1	2735.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[49]	40×30×1.6	0.33λ × 0.25λ	2.5 -80	187.88	32:1	2254.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.018$
[50]	16.55×15.72 ×0.787	0.27 λ × 0.26λ	5 - 150	187	30:1	2663.8	RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.0027$
[51]	60×60×1.524	2λ × 2λ	10 - 50	133	5:1	33.2	Rogers TMM $\varepsilon_r = 4.5, \tan\delta = 0.001$
[52]	32×26 × 1.6	0.326λ × 0.265λ	3.06 – 35	168	11.43:1	1944.6	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[53]	52.25×42×1.57	0.18λ × 0. 22λ	1.30 -20	175.58	15.38:1	4261.0	RT/Duroid 5870 $\varepsilon_r = 2.23, \tan\delta = 0.0012$
[54]	25×19×1.6	0.30 λ × 0.23λ	3.68 - 31.61 (Band-notch is from 7.86-11.0)	158	8.58:1	2289.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[55]	30×45×0.175	0.31λ × 0.46λ	3.15 -32	164	10.16:1	1102.9	Polyethylene terephthalate(AgHT-8) $\varepsilon_r = 3.24$
[56]	25×19×1.6	0.32λ × 0.245λ	3.87-35 (Band rejection is from 7.24-11.1)	160.40	9.04:1	2041.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[57]	30×28×1.6	0.32λ × 0.34λ	3.4 - 37.4	166.67	11:1	1531.8	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[58]	135×135×0.8	0.45λ × 0.45λ	1.0 - 19.4	180.40	19.4:1	890.9	FR4 , $\varepsilon_r = 4.4, \tan\delta = 0.025$
[59]	80×80×1.57	0.08λ × 0.08λ	0.3 - 20	194	66.6:1	3233.0	RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.0027$
[60]	19×31×1.6	0.19λ × 0.31λ	3 - 60	181	20:1	3073.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[61]	18.5×20×1.6	0.23 λ × 0.25λ	3.8 – 68	179	17.89:1	3015.0	FR4,$\varepsilon_r = 4.4, \tan\delta = 0.02$
[62]	40×50 ×0.254	0.33 λ × 0.416λ	2.5 – 110	191	44:1	1391.0	RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.0027$
[63]	15×20×1.6	0.23 λ × 0.31 λ	4.9 – 25	126	5.10:1	1767.0	FR4, $\varepsilon_r = 4.3, \tan\delta = 0.025$
[64]	40 × 25×1.6	0.4 λ × 0.25λ	3 - 20	147	6.66:1	1470.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[65]	57×34× 1	0.16λ × 0.27λ	1.42 - 90	193.70	63.38:1	4483.8	F4B ,$\varepsilon_r = 2.65, \tan\delta = 0.02$

TABLE 2. *(Continued.)* **Comparison of existing super wideband antenna design based on various parameters.**

[66]	40 × 25×1.6	0.12 λ × 0.07λ	0.92 - 22.35	184.5	24.8:1	20502.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[67]	60×80×2.5	0.28 λ × 0.285 λ	1.4 - 20	173.8	14.2:1	2178.0	Polyester Nonwoven Fabric $\varepsilon_r = 1.18, \tan\delta = 0.004$
[68]	40×38×1.6	0.30λ × 0.285λ	2.25 - 11.05	132.33	4.9:1	1547.7	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[10]	150×150 ×0.5	0.32 λ × 0.32 λ	0.64 - 16	184.6	25:1	1802.7	Dielectric, $\varepsilon_r = 2.65, \tan\delta = 0.001$
[69]	20×20×1	0.033 λ × 0.033 λ	0.5 - 30	193	60:1	175818	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[70]	50×54×1.6	0.33 λ × 0.36 λ	2 - 30	175	15:1	1473.0	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[71]	38×55×1.6	0.38 λ × 0.55 λ	3 - 35	168	11.6:1	803.8	FR4, $\varepsilon_r = 4.4, \tan\delta = 0.02$
[72]	22 x 33.4 x 1.57	0.35λ × 0.23λ	3 - 26	158	8.66:1	1962.7	RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$
[73]	20×20×0.787	1.148 λ × 1.148 λ	17.22 - 180	165	10.45:1	125.2	RT/Duroid 5880 $\varepsilon_r = 2.2, \tan\delta = 0.009$

Fidelity factor indicates the correlation or resemblance between the transmitted and received pulses. The equivalence between the normalized amplitude of transmitted and received pulse signal indicates the value of fidelity factor for that specific communication. Higher the value of fidelity factor lesser the distortion presents in the received pulse [34].

To analyze pulse distortion of a signal, time domain characteristics of an antenna are very important. Pulse distortion of a signal can be quantified by a parameter called Fidelity Factor (FF). FF is the maximum magnitude of the cross correlation of the radiated E-field and the input signal.

The normalized transmission signal pulse and reception signal pulse is defined by following equations [34] respectively.

$$\hat{T}_s(t) = \frac{T_s(t)}{\left[\int_{-\infty}^{\infty} |T_s(t)|^2\, dt\right]^{1/2}} \quad (8)$$

$$\hat{R}_s(t) = \frac{R_s(t)}{\left[\int_{-\infty}^{\infty} |R_s(t)|^2\, dt\right]^{1/2}} \quad (9)$$

where $T_s(t)$ is the transmitted pulse and $R_s(t)$ is the pulse at the receiving antenna port.

The cross-correlation between both signals is done at every point in time and the maximum value of this correlation is obtained when both pulses overlap.

The Fidelity Factor can be expressed by equation [34] mentioned as

$$FF = \max_{T} \int_{-\infty}^{\infty} \hat{T}_s(t)\,\hat{R}_s(t+\tau)dt \quad (10)$$

The value of FF lies between 0 and 1. When the value of FF is 1, the received signal pulse is exactly same as the input signal pulse at the transmitter without any system loss. If the value of FF is 0, then the received signal pulse is completely different from that of transmitter input signal. The received pulse becomes completely unrecognized if the FF value is less than 0.5.

Group delay evaluates the phase distortion between the transmitted and received signals. The time required for a signal to travel from one antenna terminal to another antenna terminal gives the average group delay. It is mathematically computed as the negative derivative of phase response with respect to frequency and is specified as [34]

$$\tau_g(\omega) = -\frac{d\phi(\omega)}{d\omega} = -\frac{d\phi(\omega)}{2\pi df} \quad (11)$$

where φ denotes the phase response of the transmitted signal and ω represents the frequency in radians per second.

By observing at the antenna group delay, the phase linearity within the range of frequency of interest can be calculated. The phase response and group delay are associated with the antenna gain response. The group delay must be almost constant or its deviation should be less than 1 ns, which implies a linear phase response over the entire range of frequency. This linear phase response ensures transmission of pulse with minimum distortion.

IV. REVIEW OF SWB TECHNIQUES

To fulfill the requirement of broadband services, many bandwidth enhancement techniques have been introduced by various researchers which include suitable selection of substrate and feeding techniques. Bandwidth enhancement can also be obtained by overlapping of multiple resonances. Multiple overlapped resonance can be introduced by inserting slots in the patch and by modification in the ground plane and patch. Dimension of structures and locations of the slots should be optimized so as to introduce resonances in the frequency band.

To achieve good impedance matching between the feed and patch, an impedance matching network can be utilized. Lower portion of the patch near the feed can be trimmed linearly, stepped, circularly or exponentially to attain wide bandwidth operation. The impedance bandwidth of the antenna also relies on the ground plane due to coupling effect between the ground plane and the lower part of the radiator. The edge of the ground plane below the patch can be stepped, linear or exponentially tapered which leads to depletion of capacitance between the lower portion of the radiator and the ground plane.

In order to improve the impedance matching in SWB antennas, distinct variety of feeding techniques such as linearly tapered feed, symmetric and asymmetric coplanar waveguide feed are used. Wide bandwidth can also be achieved by applications of Fractal geometries in the patch. Table 1 includes the novel approaches adopted for the design of SWB antenna over the years.

V. COMPARISON OF EXISTING RESEARH BASED ON THE PERFORMANCE CHARACTERISTICS

All the antennas considered in Table 1, are compared on the basis of different design parameters and listed in Table 2. It is found that the dimension and substrate material have a great influence in the super wide band antenna designing.

VI. SUMMARY AND INTERPRETATION

In this review article, the antenna research targeting to super wide bandwidth has been addressed with sufficient number of relevant research articles. In TABLE 1, yearwise arrangement of super wide band antenna is made including their design methodology, main design focus and structural picture. Also inferences have been drawn for individual work illustrating some observations and research gaps. In TABLE 2, all relevant works are rigourously compared based on size of the structure, size in terms of wavelength, frequency range, percentage bandwidth, bandwidth ratio, BDR and substrate material used. Some interpretations can be made from this comparison table as mentioned below.

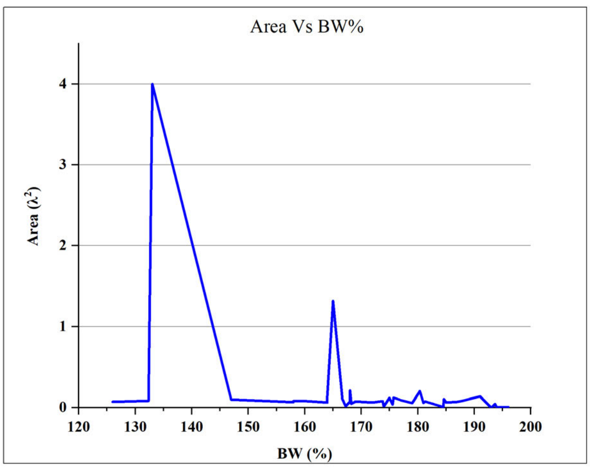


FIGURE 41. Area (λ2) Vs BW%.

1) As the antenna area reduces, bandwidth percentage increases. A graph has been drawn in Figure 41 to illustrate the relation between bandwidth percentage and antenna structure area. It can be concluded that bandwidth percentage is inversely related to antenna structure area.
2) Dielectric with relative permittivity around 2.2 and thickness 1.6 mm is the most suitable substrate for achieving high value of BDR for SWB antenna designing.

The utilisations of this review article can be expected for (i) referring different structures to achieve super wide band antenna; (ii) deciding the area of a new SWB antenna structure; (iii) choosing a substrate material to attain high BDR with SWB antenna.

VII. CONCLUSION

SWB antenna can support high data rate for voice and video transmission because of its greater channel capacity. Due to its large bandwidth, SWB technology can be used for spectrum sensing in cognitive radios, Amature Radio, Global Positioning System (GPS), Global System for Mobile communication (GSM), Personal communications service (PCS), Industrial, scientific and medical (ISM), Bluetooth, Wireless local area network (WLAN), Satellite communication systems applications, Defense systems, Doppler navigation aids, Radio astronomy, Aeronautical radio navigation. This article presents a comprehensive illustration of different design techniques for SWB antenna.

The detailed comparison tables in this article guides researchers in choosing geometries of antenna structure and material properties for desired gain, bandwidth and time domain response according to the applications of the system.

Considering the investigation carried out in this review article, the following discussions concerning the presented antennas can be highlighted.

- There is a necessity of compact wideband antenna with large bandwidth dimension ratio comprising less distortion, high gain, good efficiency and stable radiation pattern over the entire band.
- Proposed antennas need to follow the FCC guidelines on the restriction of power emission concerning the potential threats of human exposure to radio-frequency (RF) energy.
- SWB antenna should be designed in such a way that its ratio bandwidth should be greater than 10:1.

This review work provides an insight for understanding the trends of SWB antenna development. It also aims to provide a reference for research interest, in improving the SWB antenna design to achieve better overall performance and compact size for diverse wireless applications.

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Dr. Anguera was a member of the fractal team that received the European Information Technology Grand Prize, in 1998, for the applied science and engineering for the fractal-shaped antenna application to cellular telephony. Include 2003, He was a Finalist of the Best Doctoral Thesis on UMTS (Fractal and Broadband Techniques on Miniature, Multifrequency, and High-Directivity Microstrip Patch Antennas), prize promoted by Technology plan of UMTS promotion given by Telefónica Móviles España. New Faces of Engineering 2004 (promoted by the IEEE and the IEEE foundation). In 2004, he received the Best Doctoral Thesis (Ph.D.) in Network and BroadBand Services (XXIV Prize Edition Ingenieros de Telecomunicación) organized by Colegio Oficial de Ingenieros de Telecomunicación (COIT) and the Company ONO (national price). In 2011, he received the Alè Vinarossenc, recognition given by Fundació Caixa Vinaròs, Vinaròs, Spain. In 2014, together with four other Fractus inventors, he received the 2014 Finalist to European Patent Award. Several of his supervised students have been awarded by Best Bachelor and Master Thesis by the Spanish Ministry and other Spanish institutions. He is a Reviewer for several IEEE journals and others. He is an Associate Editor at *Electronics Letters* and an Editor of *International Journal on Antennas and Propagation* (IJAP) and *International Journal on Electronics and Communications*. His biography is listed in Who'sWho in the World, Who'sWho in Science and Engineering, Who'sWho in Emerging Leaders, and in IBC (International Biographical Center, Cambridge–England).

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