Fringing Field Effect on Patch Perimeter and Simple Co-related Design Formulae for Microstrip Antennas of Various Patch Shapes

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Abstract - *This paper presents a leap forward for finding physical dimensions of a microstrip antenna patch of any shape. A universal model (can be used for any patch shape) has been proposed for virtual extension in patch perimeter due to fringing fields in such antennas. The new model contains terms that are specific for geometrical shape of the patch. From this model, simple design formulae have been derived for various shapes of the microstrip antenna patch. Additionally it is very simple and straight forward to use. The model eliminates need to transform one shape into another for estimating patch dimensions. New formulae do not require "curve fitting of data" or computation of "effective dielectric constant" or "dynamic dielectric constant". The novelty of this paper is that for developing mathematical model for microstrip antennas, first a theory is propounded, formulae derived and then the results of the formulae are compared with empirical data to validate the formulae. Usually empirical data is plotted in the form of curves. Design models are then developed and fine tuned using curve fitting techniques. An expression has been proposed for estimating the constant of proportionality in the new model. The proposed theory also results in formulae for (i) the ratio of fringing area to physical area, (ii) the ratio of extension in patch perimeter to physical perimeter and also (iii) ratio of extension in critical dimension to physical critical dimension of the patch for different shapes.*

Key words: Design formula, Electrical thickness of substrate, Fringing field area, Microstrip antenna, Patch perimeter, Patch dimensions, Resonant frequency

1. INTRODUCTION

When microstrip antennas were designed using half-wavelength formulae there was a mismatch between designed and experimental values of the resonant frequency. This has been attributed to fringing fields in antenna. To account for this mismatch the concept of "extension in physical length" was introduced. Other researchers introduced the concept of "effective dielectric constant". Yet others used both the concepts. Dielectric constant of the antenna structure is an important parameter and its treatment varies from researcher to researcher. Dielectric constant, effective dielectric constant and dynamic dielectric constant all have been used in attempting to match one's theory with experimental results of someone else or of oneself. For the rectangular shape a formula for effective dielectric constant is in wide use that requires width of the rectangle (W) while the exercise is for estimating width W and length L of the rectangle. So a temporary value of W is calculated by assuming the effective dielectric constant to be average of the substrate dielectric constant (ε_r) and of the air. The purpose is to minimize the mismatch between the designed and measured (empirical) values of resonance frequencies. These concepts gave results reasonably accurately. For increasing the accuracy the concept of "dynamic effective dielectric constant" was brought-in. Analytical expressions were developed for rectangular shape. Other shapes were converted into equivalent rectangular patches and analyzed. The area of equivalent rectangular/circular shape was taken to be equal to the area of patch under consideration [1-10]. Yet, some researchers considered equivalent patch by keeping the perimeter of constant size between the two shapes [11-13]. The formulae became more and more complex and difficult to solve. Artificial Neural Network (ANN) models have been developed to match the results obtained by curve fitting formulae. The unknown coefficients of the model are determined by using genetic algorithm/ neural network. The ANN networks are trained to output desired results. Models are created (weights are assigned) to obtain the results that the author desires. This process led to different formulae for every shape of the patch. There is hardly any correlation between them. Attempts have been made to generalize the solution for microstrip antenna [2, 8, 14, and 15]. Even in these publications the discussion is focused on rectangular, circular and triangular shapes only. Elliptical and arbitrary shapes are rarely considered. Multilayer perceptrons network with 3 learning algorithms have been used [2]. The process of using ANN is cumbersome for simultaneous solutions for different patch shapes. In any ANN approach as the number of shapes (and therefore models) increase, the complexity of ANN increases. Auto-metric Graph Neural Network has been used for prediction of microstrip antenna dimension [16]. Characteristic Mode Analysis [17] and Machine Learning approaches [18, 19] have also been used for the same purpose. [15] has considered non-uniform fringing around vertices and edges. There is a need for simple formulae that quickly estimate dimensions of regular or irregular shaped microstrip antenna patch. This paper aims at developing simple formulae for estimating the critical dimension of the patch and correlating the formulae for different shapes. This work has been motivated by antenna designers who quickly want to know the physical dimensions of the antenna patch, up to the accuracy that is needed for fabrication. They face a dilemma because all formulae for increasing accuracy by modifying dielectric constant (effective value, dynamic value etc) require prior knowledge of patch dimensions. No formula is available for estimating dimensions of nonstandard/irregular shaped patches. Novelty of the present work is that dimensions of the antenna patch of any shape can be quickly estimated without the help of a computer. Further there is no need to convert the given shape into a known regular shape or to compute effective/dynamic dielectric constant. Basic structure of all microstrip patch antennas is same – the shape and size of the patch is designed to meet desired specifications. Therefore, there should be some relation between the design equations for different shapes of the patch. Little work has been done in this direction. This paper provides simple closed-form correlated formulae for determining, as accurately as is normally required, critical dimensions of microstrip antennas of various patch shapes. The dimension of the patch whose value is required for patch design has been termed as CRITICAL DIMENSION. Usually empirical data is plotted in the form of curves. Design models are then developed using curve fitting techniques. These are then fine tuned for better matching in different areas of the curve. The novelty of this paper is that for developing mathematical models for microstrip antennas, first a theory has been propounded, models derived and then the results of the models have been compared with available empirical data to validate the models.

2. BACKGROUND WORK

Conductor patch of microstrip antenna can have any shape and size. Perimeter as well as area of the patch appear to be enlarged due to fringing fields. For designing a microstrip antenna (MSA), substrate parameters (thickness h and dielectric constant ε_r) and operational parameter (resonant frequency f_r) are given. The designer has to estimate dimensions of the patch for the desired shape. The issue is then to find the physical dimensions of the patch that will result in the desired resonant frequency. Importance of substrate thickness normalized with respect to guide wave length has been demonstrated in [20]. This parameter has been termed as "electrical thickness" in literature [21]. In this paper it has been denoted by symbol H.

$$\mathrm{H} = \frac{h}{\lambda_g} = \frac{1}{c} f_r h \sqrt{\varepsilon_r} \qquad (1)$$

where c = $3*10^{10}$ cm/ sec is the speed of light in vacuum.

Here, h is physical thickness of substrate and λ_g is guide wavelength (wavelength in the dielectric material of the substrate). It has been shown earlier [20] that for rectangular microstrip antenna, extension in patch length (ΔL) is proportional to effective length (L_e) of the patch and electrical thickness of antenna substrate. Using this theory a known good design can be easily and quickly transformed from one substrate onto another substrate without going through elaborate computations. Procedure for such a transformation was also outlined. It has been also shown that for circular microstrip antenna [22] extension in physical radius is proportional to physical radius (r_p) of the patch and to the parameter H. This model gives good results without any iteration. For equilateral triangle [23] extension in side length is proportional to physical side length (S_p) of the patch and to the parameter H. This is based on the postulate [24] which states that "For a rectangular Microstrip antenna, extension (d) in physical length of the patch is directly proportional to the thickness (h) of antenna substrate and electrical length (L_e) of the patch and is inversely proportional to its width (W). The constant of proportionality (β) is independent of the resonant frequency (f_r), thickness (h) and dielectric constant (ε_r) of the substrate." In all these papers the constant of proportionality (β) has been assumed to be 1 and elliptical and other shapes have not been considered. The work reported here generalizes the theory to include all shapes of the patch and also suggests an expression for estimating β.

3. GENERALIZED POSTULATE – CORRELATED DESIGN FORMULAE

Earlier work [20, 22, 23, 24] had considered extension in critical dimensions of the patch – length and width of the rectangle, radius of the circle and sidelength of the triangle – that differs from one shape to another. For the sake of uniformity, this paper has considered perimeter of the patch since the perimeter is directly and simply related with the critical dimension for every shape. It can be easily observed that due to fringing fields, electrical extension is NOT confined to any particular dimension of the patch. The patch behaves as if its perimeter has been enlarged resulting in enlargement of its total area. In order to find common formulae, big data was created (using classical formulae). Data analysis indicates that extension in perimeter is directly proportional to physical perimeter for regular shapes of the patch. However the extent of dependence is related with the shape of the patch. Additionally, extension in perimeter of the patch is directly proportional to the electrical thickness of the substrate for various shapes of the patch. The extent of dependence is again dependent on the patch shape. It can therefore be postulated that "for a microstrip patch the extension in physical value of perimeter, due to fringing fields, is directly proportional to the physical perimeter itself and also to the electrical thickness of the antenna substrate." If the physical perimeter of the patch is P_p and its effective value is P_e then

$$P_e - P_p \ \alpha \ \mathrm{H} * P_p$$

or,

$$P_e = (1 + \beta \mathrm{H}) P_p \qquad (2)$$

where β is constant of proportionality.

3.1 Constant of Proportionality

β is a unique property of the shape of the patch. It has constant value for a given geometry of shape. Therefore, it is independent of the critical dimension of the patch. It is not a function of material parameters (h and ε_r) and operational parameter f_r. It is a dimensionless quantity. As perimeter increases, area of the closed shape also increases. However, the ratio (Perimeter/√(4*π*Area) remains constant for a given shape. A circle has the smallest perimeter for a given area of regular shape. This ratio has the value 1 for any circle. It is proposed that the constant of proportionality β may be set equal to this ratio

$$\beta = \frac{Perimeter}{\sqrt{4*\pi*Area}} \qquad (3)$$

Accordingly, for a regular polygon of N sides,

$$\beta = \sqrt{\frac{\tan\theta}{\theta}} \qquad (4)$$

where $\theta = \frac{\pi}{N}$, and angle θ is in radians.

This gives β = 1.286, 1.128, 1.075, 1.05 …… for an equilateral triangle (N = 3), a square (N=4), a pentagon (N=5), a hexagon (N=6) and so on and so forth. $\beta \rightarrow 1$ as $\theta \rightarrow 0$ i.e. N becomes very large. This is the case when the polygon becomes a circle. For any ellipse β = (1+m)/√(4m), where m = b/a is the ratio of minor axis (b) to major axis (a) of the ellipse. For a rectangle β = (1+ n)/√(nπ) where n=W/L is the ratio of width to length of the rectangle.

3.2 Design Formulae

For electrically thin substrates H is < 0.02. Therefore, $\beta H \ll 1$, using binomial theorem one gets

$$P_p = (1 - \beta H)P_e \qquad (5)$$

Substituting the values of β and of perimeter in terms of the critical dimension, it can be easily deduced that:

(i) For rectangular and square shapes:

physical length of the rectangle (L_p) is given by

$L_p = (1 - \beta H)L_e$ and effective length (L_e) is given by [2]

$$L_e = \frac{c}{2f_r\sqrt{\varepsilon_r}},$$

therefore $$L_p = \frac{15}{f_r\sqrt{\varepsilon_r}} - 0.5\beta h \qquad (6)$$

(ii) For equilateral triangular shapes:

physical sidelength (S_p) is given by

$S_p = (1 - \beta H)S_e$ and effective sidelength (S_e) is [2]

$$S_e = \frac{2c}{3f_r\sqrt{\varepsilon_r}},$$

therefore $$S_p = \frac{20}{f_r\sqrt{\varepsilon_r}} - \left(\frac{2}{3}\right)\beta h \qquad (7)$$

(iii) For circular shapes:

physical radius (r_p) is given by $r_p = (1 - \beta H)r_e$ and effective radius (r_e) is [2] $r_e = \frac{8.791}{f_r\sqrt{\varepsilon_r}}$,

therefore $$r_p = \frac{8.791}{f_r\sqrt{\varepsilon_r}} - 0.293\beta h \qquad (8)$$

(iv) For elliptical shapes:

physical semi major axis (a_p) is given by

$a_p = (1 - \beta H)a_e$. Since effective semi major axis (a_e) is [25] $a_e = \frac{c}{2\pi e f_r}\sqrt{\frac{q^{e,o}}{\varepsilon_r}}$,

$$\therefore a_p = \left(\frac{4.775\sqrt{q^{e,o}}}{e}\right)\frac{1}{f_r\sqrt{\varepsilon_r}} - \left(\frac{0.159\sqrt{q^{e,o}}}{e}\right)\beta h \qquad (9)$$

where

e = eccentricity of the elliptical patch

$q^{e,o}$ represents Approximated Mathieu function of the dominant ($TM^{e,o}$) mode

$q^e = -0.0049e + 3.7888e^2 - 0.7278e^3 + 2.2314e^4$

$q^o = -0.0063e + 3.8316e^2 - 1.1351e^3 + 5.2229e^4$

Above equations may be rewritten as

$$D_p = \frac{A}{f_r\sqrt{\varepsilon_r}} - Bh, \qquad (10)$$

where,

D_p is the Physical Critical Dimension (PCD)

A and B are constants that depend on the geometry of the patch.

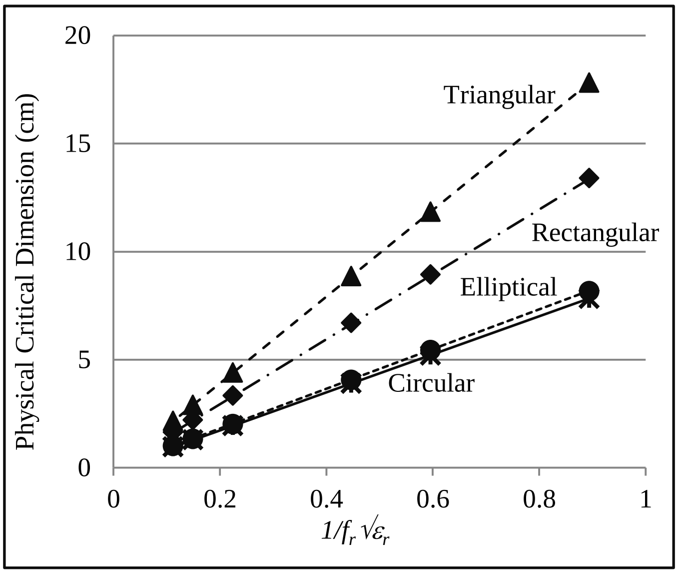
Equation (10) becomes the single universal design formula for determining critical design dimension of the patch of a microstrip antenna.

4. VALIDATION

Classical formulae were used to generate huge data. This was done for 5 regular shapes of the patch –Rectangle, Square, Equilateral Triangle, Circle and Ellipse. For every shape 7200 sets of substrate thickness (h), dielectric constant (ε_r) and resonant frequency (f_r) were used. Substrate thickness was varied from 0.05 cm to 0.3 cm in steps of 0.025 cm. For each value of h, ε_r was varied from 2 to 10 in steps of 1. For each value of ε_r the resonant frequency f_r was varied from 1 GHz to 10 GHz in steps of 1 GHz. Value of H varies in these data sets. Most of the classical formulae are for thin substrates (H < 0.02). This limit has been considered in computations. The data was analyzed to investigate relationship between the perimeter of the patch and its extension due to fringing fields and to validate the expressions for the physical critical dimensions. The new formulae have been validated by 4 different routes as mentioned below:

A. Validation Using Analysis Of Calculated Data

Equations (6), (7), (8) and (9) indicate that graphs between Physical Critical Dimensions (PCD) for rectangular, equilateral triangular, circular and elliptical shapes of antenna patch and $1/(f_r{*}\sqrt{\varepsilon_r})$ should be straight lines for constant value of h. Data for such graphs was computed and plotted (Chart-1). Unified values (values computed by new unified formulae) have been plotted as straight lines while classical values have been indicated by markers.



Chart– 1: Variation in PCD with $1/(f_r\sqrt{\varepsilon_r})$ keeping substrate thickness (h) constant

Chart-1 indicates that classical and unified values match very well. Moreover, classical data also shows relationship between PCD and $1/(f_r{*}\sqrt{\varepsilon_r})$ to be a straight line (for constant h) which is indicated by unified formulae. This validates the new theory. In Chart-2 maximum value of H is 0.03. The plot is for dielectric constant of 3.5 and resonant frequency of 1.5 GHz. Chart-2 indicates that classical and unified values match very well. Moreover, classical data also shows relationship between PCD and h to be a straight line (for constant $1/(f_r{*}\sqrt{\varepsilon_r})$) which is indicated by unified formulae. These graphs clearly validate the new theory.

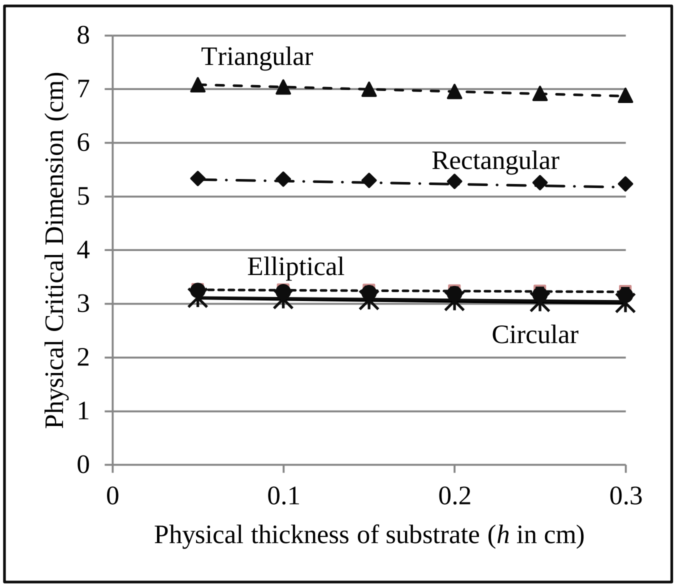


Chart-2: Variation in PCD with substrate thickness h for constant value of $1/(f_r{*}\sqrt{\varepsilon_r})$. The straight lines are plots of unified data and markers are corresponding data using classical formulae.

B. Validation Using Perimeter Ratio

For analyzing microstrip antennas of one shape equivalent rectangular or circular patches have been widely used. Some researchers considered equivalent patch by keeping the perimeter of constant size between the two shapes [11, 12, 13, and 24]. However, [13] considered a rectangle of equal perimeter for the circular patch while [11, 12, 26] used a circle whose circumference was equal to the perimeter of the triangle. Thus classical approaches tactically presumed that the effective perimeter to physical perimeter ratio is the same for all the shapes of the patch.

According to the theory proposed in this paper for any microstrip antenna patch (2) is

$$\frac{Effective\ Perimeter}{Physical\ Perimeter} = (1 + \beta \mathrm{H})$$

Value of β should be taken for the concerned shape of the patch. Between various patch shapes considered, β varies from 1.0 to 1.286. Classical formulae are valid for thin substrates for which H < 0.02, Therefore (1+β H) varies from 1.02 to 1.0257. This means that the ratio

$$\frac{Effective\ Perimeter}{Physical\ Perimeter}$$

can be taken as equal for all shapes. Therefore match between classical approach and the new theory is excellent. This validates the theory proposed in this paper.

C. Validation Using Area Ratio

While some researchers considered equivalent patch by keeping the perimeter of constant size between the two shapes others preferred to keep the metalized area of the two shapes to be constant. For circular patch several variations have been used (a) width of the equivalent rectangle was taken to be equal to the diameter of the circle [1, 2, 3], (b) length of the equivalent rectangle was taken to be equal to the diameter of the circle [4] or (c) side of the equivalent square was taken to be equal to the square root of the area of the circle (square patch instead of a rectangular patch [5]). For triangular patch, [2, 3, 27] considered a rectangle of equal area, [28, 6] used square of equal area for the triangular patch. Garg and Long [7, 10] considered a circular patch of equal area for the triangular patch. For the elliptical patch, a circle of equal area was used by [8, 9]. Thus classical approaches tactically presumed that the effective area to physical area ratio is the same for all the shapes of the patch.

As per the theory proposed in this paper

$$\frac{Effective\ Area}{Physical\ Area} = (1 + \beta \mathrm{H})^2 \qquad (11)$$

For normally used shapes β varies only from 1.0 to 1.286. For electrically thin substrates $\mathrm{H} < 0.02$, $(1+\beta \mathrm{H})$ is in the range 1.02 to 1.0257 and $(1 + \beta \mathrm{H})^2$ is in the range 1.04 to 1.05 only. This means that the ratio

$$\frac{Effective\ Area}{Physical\ Area}$$

can be taken as equal for all the shapes. This again validates the new theory.

D. Validation By Comparison With Classical Data

Several thousand values of the physical critical dimensions were calculated using the new formulae as well as the classical formulae. These were compared and analyzed. Following [21], Average Relative Deviation (ARD) and Maximum Relative Deviation (MRD) were calculated.

$$ARD = \frac{1}{N}\sum_{i=1}^{N} \frac{|a_b - a_u|}{a_u}$$

$$MRD = max\left(\frac{|a_b - a_u|}{a_b}\right)$$

where a_b and a_u are respectively the benchmark physical critical dimension and the calculated physical critical dimension of the concerned patch. The results are given in Table-1 below:

The results are given for two values of electrical substrate thickness ($\mathrm{H} < 0.02$ and $\mathrm{H} < 0.03$). Percentage average deviations as well as maximum relative deviations are very small. Results for absolute differences are noted in Table-2. The matching of results is excellent. This validates the proposed theory and formulae.

Table-1: Percentage relative deviation between classical and new values of critical dimensions

Patch Shape	Critical Dimension	ARD		MRD	
		H <0.02	H <0.03	H <0.02	H <0.03
Rectangle	Length	0.30	0.40	0.93	1.28
Square	Side	0.29	0.39	0.89	1.21
Triangle	Side	0.28	0.33	0.92	1.10
Circle	Radius	1.10	1.34	3.18	4.11
Ellipse Even Mode	Semi-major axis	1.36	1.71	3.48	4.64
Ellipse Odd Mode	Semi-major axis	1.35	1.71	3.47	4.63

5. RESULTS AND DISCUSSIONS

Using the proposed formulae, values of PCD were calculated for several shapes of the patch. The results were compared with published experimental values. Few results are given in Table-3. For the patch shapes given in column (A), values of dielectric constant and substrate thickness are given in columns (B) and (C). Corresponding electrical thickness of substrate and experimental/published resonant frequencies are given in columns (D) and (E). Reference for this data is in column (F) which also mentions classic values of PCDs. Finally column (G) has the PCD values calculated by new formulae. Comparison of values in columns (F) and (G) shows that the matching of data is very good.

Simple as well as complicated design formulae are available for different shapes of the patch. Area and perimeter of the patch are inter-related and have been considered at various developmental stages. Due to fringing fields length as well as the width of the patch appear to be enlarged but efforts have been focused mainly on extension in physical critical dimension.

Table-2: Average difference between classical and new values of PCD

Absolute difference between values of PCD calculated by classical formulae and new formulae				
	Rectangular	Triangular	Circular	Elliptical
Maximum (cm)	0.135	0.144	0.192	0.213
Average (cm)	0.0395	0.0256	0.0248	0.0349

Table-3: Comparison of new and classic published/ experimental results

Shape	ε_r	h (cm)	h/λ_g	f_r *(target)* (GHz)	PCD (cm)	
					Classic	Proposed in this paper
A	B	C	D	E	F	G
Rectangular	10.2	0.1270	0.031	2.260	2.0 [21]	2.005
Rectangular	2.5	0.1524	0.011	2.2	4.14 [14]	4.22
Rectangular	10.2	0.127	0.06	4.600	1.0 [2]	0.95
Rectangular	2.22	0.017	0.01	7.740	1.29 [2]	1.29
Triangular	2.32	0.078	0.006	1.489	8.7 [2]	8.75
Triangular	2.32	0.159	0.01	1.280	10 [10]	10.05
Circular	4.55	0.235	0.01	0.825	4.95 [3]	4.94
Circular	2.32	0.159	0.010	1.128	5.0 [1]	5.08
Elliptical e = 0.273 Even mode	2.48	0.1575	0.007	1.410	4 [25]	4.13
Elliptical e = 0.7 Odd mode	2.2	0.1524	0.013	2.535	3.065 [8]	2.97

Keeping in mind all the data, this paper has proposed a generalized postulate as follows: "For a microstrip patch the extension in physical value of perimeter, due to fringing fields, is directly proportional to the physical perimeter itself and also to the electrical thickness of the antenna substrate." The constant of proportionality is independent of the dielectric constant and thickness of the substrate material and resonant frequency. However it depends on the shape of the patch. Novelty of this thinking is that a **unified design formula** for all shapes of the patch for microstrip antennas has evolved. A formula for determining the constant of proportionality (β) for any shape of the patch has been proposed and used. This resulted in another novelty – simple and accurate formulae for determining value of physical critical dimensions of standard geometrical shapes of the patch. For the first time the ratio of width to length of the rectangular patch and the ratio minor axis to major axis of elliptical patch have been included in the design formulae. For the triangular patch the new formula is similar to that given by [29] {$S_{eff} = S + ph$} except that the uncertainty in the value of p has got removed. The formulae have been validated in 4 different ways. This validates the generalized postulate and the expression for the constant of proportionality. Another feature of this work is that no modification in the value of dielectric constant is required. Also there is no need to transform one shape of the patch into another shape for estimating the physical critical dimension. Equation (2) gives that for all shapes of the antenna patch

$$\frac{extension\ in\ patch\ perimeter}{physical\ patch\ perimeter} = \beta \mathrm{H}$$

And as a corollary

$$\frac{fringing\ area}{physical\ patch\ area} = 2\beta \mathrm{H}$$

Uncertainties in published data: Microstrip antennas are fabricated on commercially available laminates that are primarily meant for PCB. There may be variation in thickness and dielectric constant of the material across the laminate. While fabricating the antenna these are seldom measured. Typical values given by the vendor/supplier/ manufacturer of the laminate are used in calculations. Real dielectric constant value may be different from the vendor's nominal/typical value [8, 30]. The dielectric constant varies with resonant frequency in low-cost substrate materials like FR-4 typically used in microstrip antenna fabrication for general research. Numerical value of physical critical dimension is to be determined for the patch of a given shape. In published literature it is not mentioned that PCD values are actual values (measured on fabricated antenna) or design values or fabrication mask values. Certainly the earlier measurement results were not meant to be standards against which other results may be evaluated. The numerical values of PCD depend upon the formula used for its calculation. Calculation results from different formulae are expected to differ from each other. Basic formulae have been developed for the rectangular patch only. These include formulae for extensions in length and also in width of the rectangular patch. For the rectangular patch, actual value of W is always different from the assumed initial value of W and width to length ratio of the patch is not considered while computing effective dielectric constant has to be computed. While some people consider effective dielectric constant others do not.

6. CONCLUSION

Generalization of earlier postulate [24] has resulted in (2) to (11) as the new, simple co-related design formulae. These can be easily solved by ordinary calculator – computers are not needed for this work. This paper presents a leap forward for finding physical dimensions of a microstrip antenna patch of any shape. Main issue is to estimate virtual extensions in dimensions due to fringing fields. Classically virtual extension in patch dimension (due to fringing fields) has been related with non-radiating dimension of the patch and substrate parameters (dielectric constant and physical thickness) but not with the dimension under consideration. Some researchers have presumed this extension to be equal to the physical thickness of the antenna substrate and then developed formulae for matching theoretical and experimental values of dimensions or resonant frequencies. Novelty of present work is that virtual extension in patch perimeter has been directly related with physical perimeter itself and the electrical thickness of the substrate. This has resulted in another novelty — dimensions of the antenna patch of any shape can be quickly estimated without the help of a computer. Yet another novelty is that for developing mathematical model for microstrip antennas, first a theory is propounded, formulae derived and then the results of the formulae are compared with empirical data to validate the formulae. This model eliminates the need to transform one shape into another for estimating patch dimensions. The proposed theory also results in formulae for the ratio of fringing area to physical area, for the ratio of extension in patch perimeter to physical perimeter and also for ratio of extension in critical dimension to physical critical dimension of the patch for different shapes. Novelty of this approach is that a unified design formula for all shapes of the patch for microstrip antennas has evolved. A formula for determining the constant of proportionality for any shape of the patch has been proposed and used.

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REFERENCES

[1] A. K. Verma and Nasimuddin, “Analysis of circular microstrip antenna on thick substrate”, *Journal of Microwaves and Optoelectronics*, Vol. 2, No. 5, pp 30, July 2002

[2] K. Guney, S. Sagiroglu and M. Erler, “Generalized neural method to determine resonant frequencies of various microstrip antennas”, *Int J RF and Microwave Comp Aid Eng* 12:131-139, 2002, doi: 10.1002/mmce.10006

[3] K. P. Ray and Girish Kumar, “Determination of the resonant frequencies of microstrip antennas”, *Microwave and Opt Technol Lett* Vol. 23, No. 2, pp 114, 1999; Corpus ID: 110690410

[4] Z. Rostamy,“ Determination of resonance frequency of dominant and higher order modes in thin and thick circular microstrip patch antennas with superstrate by MWM”, *International Journal of Engineering, section ‘Transactions A: Basics’* Vol. 16, No. 4, pp 359, 2003

[5] A. Mishra, G. B. Janvale, B. V. Pawar and P. M. Patil, “The design of circular microstrip patch antenna by using quasi-newton algorithm of ANN”, *J Electromagnetic Analysis and Applications,* Vol. 2, pp 444, 2010
doi: 10.4236/jemaa.2010.27058

[6] D. Karaboga, K. Guney, N. Karaboga and A. Kaplan, “Simple and accurate effective side length expression obtained by using a modified genetic algorithm for the resonant frequency of an equilateral triangular microstrip antenna” *International. J. of ELECTRONICS,* VOL. 83, NO. 1, pp 99, 1997;
doi: 10.1080/002072197135698

[7] R. Garg and S. A. Long, “An improved formula for the resonant frequencies of the triangular microstrip patch antenna” *IEEE Transactions on Antenna and Propagation* Vol. 36, No. 4, pp 570, 1988; doi: 10.1109/8.1148

[8] P. Mythili and A. Das, “Simple approach to determine resonant frequencies of microstrip antennas” *IEE Proc. Microw. Antennas Propagation* Vol. 145, No. 2, pp 159, 1998

[9] S. Gurel and E. Yazgan, “New computation of the resonant frequency of a tunable equilateral triangular microstrip patch”, *IEEE Trans. on MTT,* Vol. 48, No. 3, pp 334, 2000

[10] N. Kumprasert and W. Kiranon, “Simple and accurate formula for the resonant frequency of the equilateral triangular microstrip patch antenna, *IEEE Trans on Antennas and Propagation,* Vol. 42, No. 8, pp. 1178, 1994

[11] E. Aydm and S. Can, “Modified resonant frequency computation for tunable equilateral triangular microstrip patch”, *IEICE Electronics Express*, Vol 7, No. 7, pp 500, 2010

[12] K. Y. Kapusuz , H. Tora and S. Can, “Neural network based estimation of resonant frequency of an equilateral triangular microstrip patch antenna”, *Tehnicki Vjesnik* Vol 20, N0. 6 pp 955, 2013

[13] D. Guha and J. Y. Siddiqui, “Resonant frequency of circular microstrip antenna covered with dielectric superstrate”, *IEEE Trans. Antennas and Propagation,* Vol 51, No. 7, pp 1649 , 2003

[14] T. Khan and A. De, “A generalized ANN model for analyzing and synthesizing rectangular, circular and triangular microstrip antennas”, *Chinese J. of Engineering* Vol. 2013, Article ID 647191, doi:10.1155/2013/647191

[15] D. Shri Gyan and K. P. Ray, “Generalized formulation for resonance frequency of even polygonal microstrip antennas”, *Electromagnetics* Vol. 42, No. 2, pp 102, 2022
doi: 10.1080/02726343.2022.2067964

[16] D. Prabhakar, P. Karunakar, S. V. Rama Rao and K. Srinivas, "Prediction of microstrip antenna dimension using optimized auto-metric graph neural network" *Intelligent Systems with Applications* Vol. 21, pp 200326, 2024,

doi: 10.1016/j.iswa.2024.200326

[17] B. Q. Elias, A. A. Al-Hadi, P. Akkaraekthalin and P. J. Soh, "A dimension estimation method for rigid and flexible planar antennas based on characteristic mode analysis" *Electronics* Vol. 11, pp 3585, 2022 doi.org/10.3390/electronics11213585

[18] M. A. Haque, N. Sarker, N. Singh, S. Singh, M. A. Rahman, M.N. Hasan, M. Islam, M. A. Zakariya,L. C. Paul, A. H. Sharker, G. E. M. Abro, M. Hannan and Ripon Pk "Dual band antenna design and prediction of resonance frequency using machine learning approaches", *Applied Sciences* Vol. 12, pp 10505, 2022,

doi: 10.3390/app122010505

[19] Q. Wu, W. Chen, C. Yu, H. Wang and W. Hong, "Machine-learning-assisted optimization for antenna geometry design", *IEEE Trans. AP* Vol. AP-72, N0. 3, pp 2083, 2024

[20] D. Mathur, S. K. Bhatnagar, and V. Sahula, "Quick estimation of rectangular patch antenna dimensions based on equivalent design concept", *IEEE Antennas And Wireless Prop. Lett,* Vol. 13, pp 1469, 2014

doi: 10.1109/LAWP.2014.2334362

[21] Z. Wang, X. Li, S. Fang and Y. Liu, "An accurate edge extension formula for calculating resonant frequency of electrically thin and thick rectangular patch antennas with and without air gaps" *IEEE Access* June 3, 2016.

doi: 10.1109/ACCESS.2016.2565684

[22] S. K. Bhatnagar, "New model for effect of fringing fields on radius of circular microstrip antenna" *SKIT Research Journal* Vol 11 Issue Proc.-1 (2021),

doi: 10.47904/IJSKIT.11.3.2021.25-28

[23] S. K. Bhatnagar, "New design formulae for equilateral triangular microstrip antenna", *International Research J. of Engg. and Technology* Vol. 07, issue 11, pp 946 , 2020

[24] S. K. Bhatnagar, "A new approach for designing rectangular micro strip antenna", *Proc. Of "National Conference on Recent Trends in Microwave Techniques and Applications, Microwave – 2012"*, University of Rajasthan, Jaipur, 30 July -1 Aug, 2012

[25] A. Mahamdi, S. Benkouda and S. Bedra, "Fast and accurate model to determine the resonant characteristics of elliptical microstrip patch antenna" , *Intl. Conf. on Adv. Syst. and Emergent Technologies (IC-ASET),* 2019

[26] D. Guha and J. Y. Siddiqui, "Resonant frequency of equilateral triangular microstrip antenna with and without air gap", *IEEE Trans. Antenna and Propagation,* Vol 52, No. 8, pp 2174, 2004
doi: 10.1109/TAP.2004.832504

[27] Nasimuddin, K. Esselle and A. K. Verma, "Resonance frequency of an equilateral triangular microstrip antenna", *Microwave and Optical Tech. Letts.* Vol. 47, No. 5, pp 485, 2005

[28] K. Guney, "Resonant frequency of a triangular microstrip antenna", *Microwave and optical technology letters,* vol. 6, No. 9, pp 555, Jul 1993

[29] J. Helszajn and. S. James, "Planar triangular resonators with magnetic walls" *IEEE Trans.MTT* Vol. MTT-26, No. 2, pp 95, 1978

[30] O. O. Molina and F. Lopez-Giraldo, "A simple model to compute the characteristic parameters of a slotted rectangular microstrip patch antenna", *Electronics* Vol. 11, pp 129, 2022;
doi: 10.3390/electronics 1111010129

BIOGRAPHIES

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Dr. S. K. Bhatnagar was born in Beawar, Rajasthan (India) on 15 June 1943. He is an Emeritus Scientist of CSIR - Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani, Rajasthan, India. He was key person in developing SPACE Qualified Hybrid Micro Circuits (HMC), Silicon Planar Technology and Bipolar Integrated Circuits in India. He was engaged in R & D of semiconductor devices in CEERI, Pilani for 38 years. He retired as Scientist in Director's Grade

He was Director (Research) and Professor in Electronics and Communication Engineering Department at Swami Keshvanand Institute of Technology (SKIT), Jaipur, Rajasthan, India. He has also guided Ph.D. students at Malaviya National Institute of Technology (MNIT), Jaipur. He has given new formulae and new concept for microstrip antennas.

He has more than 100 publications, 26 Research Reports, and 8 patents to his credit. He won prestigious Independence Day 1990 Prize Award (National Award given by NRDC) for Invention entitled “Hybrid Thick Film Microcircuits” and A.N. Chatterjee Memorial Award 1990 (Indian Cryogenics Council) for developmental work on Superconductors apart from many other awards. He has the unique distinction of getting four consecutive merit promotions.

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