Programación Matemática y Software (2009)
Vol.1. Num. 2. Dirección de Reservas de Derecho: 04-2009-011611475800-102

Recibido: 10 de Noviembre del 2009 Aceptado: 05 de Diciembre del 2009
Publicado en línea: 30 de Diciembre del 2009

Pentagonal Microstrip Antenna Equivalent to a Circular Microstrip Antenna for GPS Operation Frequency

Margarita Tecpoyotl-Torres[1], J. G. Vera-Dimas[1], R. Vargas-Bernal[2], M. Torres-Cisneros[3], A. Zamudio-Lara[1] and V. Grimalsky[1]

[1] Center for Research of Engineering and Applied Sciences, (CIICAp)
Autonomous University of Morelos State (UAEM), 62209, Av. Universidad No. 1001, Col. Chamilpa, Cuernavaca, Mor., Mexico

[2]Instituto Tecnológico Superior de Irapuato, Electronics Department, C.P. 36821, Apdo. Postal 179, Ctra. Irapuato-Silao Km. 12.5. Irapuato, Guanajuato, México.

[3]Faculty of Mechanical, Electrical and Electronic Engineering, FIMEE, University of Guanajuato, Mexico

{tecpoyotl, gvera}@uaem.mx

Resumen. La antena pentagonal se diseña considerando su equivalencia en área a una antena de parche circular para la frecuencia de operación de GPS (Sistema de Posicionamiento Global, por sus siglas en inglés). La antena circular fue diseñada utilizando una simple ecuación de diseño, la cual requiere solamente de conocer la longitud de onda de grupo, la permitividad efectiva y la frecuencia de operación. Esta simple ecuación se recomienda para FR-4, para 1.57 GHz, entre otras frecuencias. Las simulaciones se realizan utilizando FEKO, un software basado en el Método de los Momentos (MoM). El bajo costo de la antena se basa en el material usado como substrato. El interés en la geometría pentagonal se debe a su relación con la razón dorada, un concepto matemático muy útil en ingeniería.

Abstract. The pentagonal antenna is designed as equivalent to a circular patch antenna for GPS (Global Positioning System) operation frequency. The circular antenna was designed with a simple design equation, which requires only knowing the group wavelength, the effective permittivity and the operation frequency. This equation is recommended for FR-4, among other frequencies, at the frequency used here. The simulations are realized using CADFEKO, software based on the Moment Method (MoM). The low cost of the antenna is based on the substrate material used. The interest in pentagonal geometry is due to its relationship with the golden ratio, a mathematical concept very useful for engineering.

Keywords: Patch antenna, circular polarization, FR-4, GPS.

1. Introduction

The circular patch antenna is one of the fundamental microstrip geometries. The methods used so far assumed an infinite size for the ground plane and substrate. The solutions are therefore approximated and lack of influence on the finite substrate and ground-plane dimensions [1]. The circular patch has a simple geometry and can operate on circular polarization. In this work, instead to use the common design equation [2]:

$$a=\frac{F}{\left\{1+\frac{2\times h}{\pi\times\varepsilon_r}\left[\ln\left(\frac{\pi\times F}{2\times h}\right)+1.7726\right]\right\}^{1/2}}. \qquad (1)$$

with $F=8.791x10^9/\sqrt{\varepsilon_r}$, where h is the substrate thickness, ε_r is the dielectric permittivity and f_0 is the operation frequency; or the approximation used in [3]:

$$a=\frac{1.841}{k_0\sqrt{\varepsilon_r}} \quad \text{with} \quad k_0=\frac{2\times\pi}{\lambda_0} \qquad (2)$$

We use a very simple and similar approach to the used equation for ring resonators (see Section 2). The simulations related with this purpose are provided in Section 2.

In Section 3, a pentagonal antenna designed to operate at the GPS operation frequency (1.57 GHz) and the corresponding simulations are presented. In Section 4, a comparison between pentagonal and circular patch antenna are discussed and finally, in Section 5 some concluding remarks are given.

2. Circular Patch Antenna

2.1 Design

As design equation, we use:

$$r=\frac{\lambda_g}{\pi}; \quad \text{with} \quad \lambda_g=\frac{c}{f_0\sqrt{\varepsilon_r}} \qquad (3)$$

where r is the patch radius, λ_g is wavelength of group, and c is the speed of light in vacuum. Equation (3) is very similar to the used equation for ring resonators [4]:

$$r=\frac{\lambda_g}{2\times\pi} \qquad (4)$$

The difference can be understood as a scaling of the radius into $r/2$.

The equivalence between Equations (1) and (2) has been demonstrated (Table 1), also in this work, where we found a maximal difference of 0.1%, for several substrates materials and frequencies of operation.

Table 1. (a) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (2) (FR-4 Substrate).

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	10.9869	4.8831	2.7897	1.8312	0.7577
Equation (2)	10.9932	4.8859	2.7912	1.8322	0.7582

(b) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (2) (Silicon Substrate)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	6.4248	2.8555	1.6313	1.0708	0.4431
Equation (2)	6.4278	2.8568	1.6320	1.0713	0.4433

(c) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (2) (air medium)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	21.9618	9.7612	5.5766	3.6606	1.5148
Equation (2)	21.9865	9.7718	5.5824	3.6644	1.5163

On the other side, we also compared the results between Equations (1) and (3). The differences are from 8% up to 15% (Table 2).

The first difference corresponds to Silicon, showing a constant response in a wide frequency range. The last one corresponds to FR-4, for the case of high frequency (5.8 GHz), the difference was of 10%, while for the case of lower frequency (400 MHz) it was of 15%. In Air, the difference also remains approximately at a constant value (8.69%).

Table 2. (a) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (3) (FR-4 Substrate)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	10.9869	4.8831	2.7897	1.8312	0.7577
Equation (3)	12.1204	5.3869	3.1070	2.0600	0.8779

(b) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (3) (Silicon Substrate)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	6.4248	2.8555	1.6313	1.0708	0.4431
Equation (3)	6.9794	3.1020	1.8525	1.1632	0.4813

(c) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (3) (air medium)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	21.9618	9.7612	5.5766	3.6606	1.5148
Equation (3)	23.8732	10.6103	6.0615	3.9789	1.6464

For the case of FR-4:

$$\lambda_g \approx \frac{\lambda_0}{2} \qquad (5)$$

Then, Equation 3 can be replaced by:

$$r = \frac{\lambda_0}{2 \times \pi} \qquad (6)$$

This equation is really simple for practical design. Using this expression, the difference was reduced to 8,64 % (Table 3). This value remains almost constant for all analyzed frequencies, but only is valid for FR-4.

Table 3. (a) Comparison of sizes of the Circular Patch Antenna with Equation (1) and (6) (FR-4 Substrate)

Frequency / Radius (cm)	400 MHz	900 MHz	1.5754 GHz	2.4 GHz	5.8 GHz
Equation (1)	10.9869	4.8831	2.7897	1.8312	0.7577
Equation (6)	11.9366	5.3052	3.0308	1.9894	0.8232

On the other side, the size of the square ground plane is given by [3]:

$$L_g = 6h + r \quad . \qquad (7)$$

In order to demonstrate that our approximation, given in Equation (6), is useful, the design and simulation of a circular patch antenna for 1.5754 GHz (GPS signal frequency) were realized. The final sizes are shown in Table 4. The thickness of the FR-4 plate, used as substrate, is 1.6 mm.

Table 4. Sizes of the Circular Patch Antenna

Dimensions	Radius (m)	L_g(m)
Patch	0.0303	
Substrate		0.0399

For coaxial feeds, the location is usually selected to provide a good impedance match. In this case, this point is located near to the antenna center.

2.2 Simulation

The antenna was designed under the standard patch configuration for circular single-fed circularly polarized patch antennas. Our interest is to observe that the operation frequency remains very near to 1.57 GHz, as can be appreciated in Figure 1. The antenna gain was of 3.88 dB (Figure 2). The beam widths at phi=0 and phi=90 are of 100° and 95°, respectively (Figure 3 and 4), that means, almost a symmetrical radiation pattern. The back radiation in both cases was the same (-4.85 dB).

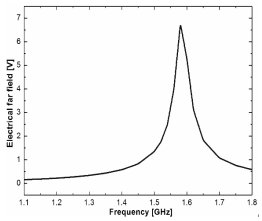

Figure 1. Electrical far field.

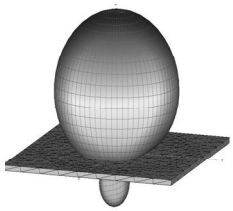

Figure 2. Patch antenna gain.

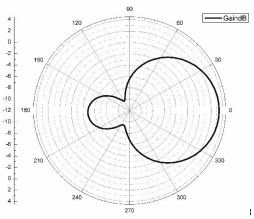

Figure 3. Beam width of patch antenna, at phi=0.

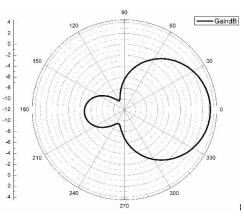

Figure 4. Beam width of patch antenna, at phi=90.

3. Pentagonal antenna

3.1 Design

Pentagonal geometry is one of the various shapes for microstrip antennas capable of circular polarization operation that has been reported in the literature [5]. The pentagonal antenna sizes calculation was made considering the invariance of the electrostatic energy below the pentagonal and circular patches, as it was realized in [6], for rectangular and circular ones, keeping constant areas.

The relationship between the circle patch (r_1) to the circle (r_2), where the pentagon patch is inscribed, in order to obtain equivalent areas is given by:

$$r_2^2 = \frac{\pi r_1^2}{2.37}. \quad (8)$$

Considering the radius length of the circle equal to 3.02 cm, the corresponding length of each side of the pentagon is 4.05 cm, and the apothem is equal to 2.79 cm, considering the cosines law and the Pythagoras theorem, respectively.

On the other hand, we also analyzed the case where the pentagon is inscribed, into a circle with a radius equal to the patch antenna. The simulations were also realized, considering a rectangular ground plane

separated from the edges of the pentagon in a length equal to 3*h*.

3.2 Simulation

Both cases of pentagonal patch were analyzed, the first one where the pentagonal patch is inscribed into a circle with a radius equal to the circular patch antenna, and the last one keeping the patches areas equivalents. As the last one give us better results, considering the symmetry of the electric far field around the operation frequency, we only present this case in this

section. Again, the operation frequency remains very near to 1.57 GHz (Figure 5), at 1.58 GHz. The antenna gain is of 3.43 dB (Figure 6), a little bit smaller than in the circular case.

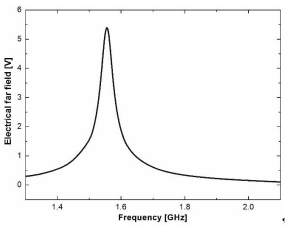

Figure 5. Electrical far field.

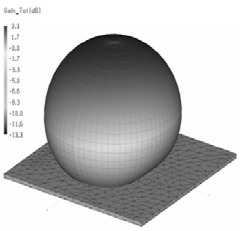

Figure 6. Patch antenna gain.

The beam widths at phi=0 and phi=90 are of 80° and 95°, respectively (Figure 7 and 8), showing a deviation of symmetry on the radiation pattern.

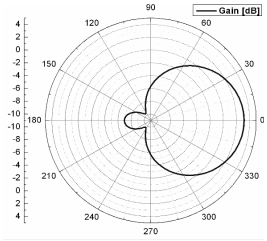

Figure 7. Beam width of patch antenna, at phi=0.

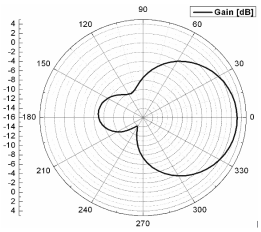

Figure 8. Beam width of patch antenna, at phi=90.

Finally in Figure 9, the return loss is presented considering a load of 50 Ω. As can be appreciated the corresponding bandwidth is of 650 MHz and the peak is obtained at 1.55 GHz, very near to the design operation frequency.

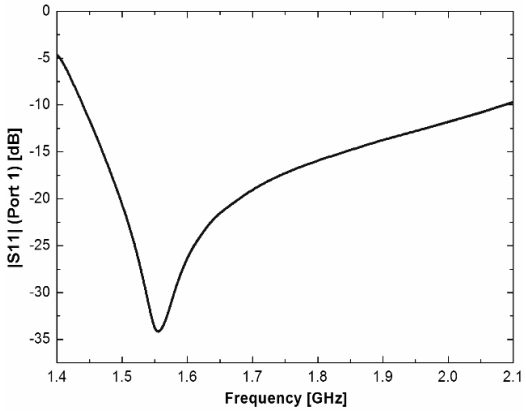

Figure 9. Return loss of the pentagonal antenna.

4. Comparison

The simulations of the gains of two cases where realized: 1) where the pentagonal radiating patch keeping equivalent the radius where it is inscribed and the circular patch,

and 2) where the circular and pentagonal patches have equivalent areas. The first case shows severe asymmetries in shape of the electric far field near to the operation frequency, and a smaller gain compared to the case of equivalent areas (Figure 10). Considering the pentagonal antenna of bigger gain, a comparison between the pentagonal case and the circular one was realized (Figure 11).

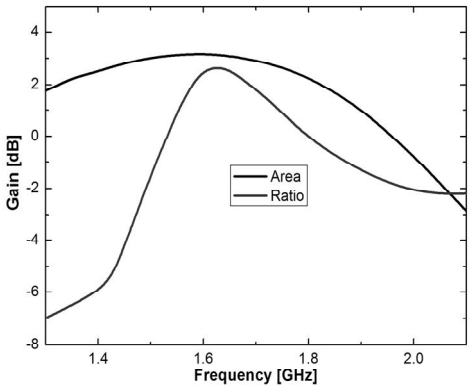

Figure 10. Gain of pentagonal antennas. In red, keeping an equivalent radio between the circular patch and the circle where the pentagonal patch is inscribed, and in black, keeping equivalent areas between the circle and the pentagonal patches.

As can be observed, in Figure 11, the pentagonal case shows a more defined symmetric curve considering at the center to the operation frequency, the same happen with the return loss and it is also almost imperceptible in the case of the electric far field. These facts constitute the main advantages of the pentagonal one, because the rest of the characteristics exhibit bigger symmetry in the case of the circular case.

Other advantage is the easier fabrication of straight sides instead of curves, which is even more economic for reducing costs of a complete GPS system.

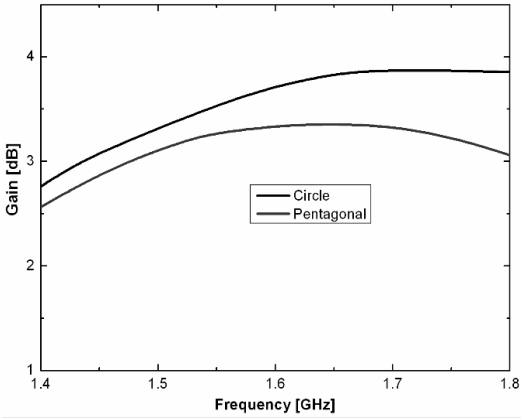

Figure 11. Gain of the pentagonal antenna (red) and of the circular one (black).

5. Conclusions

The approximation of the circular antenna design equation was enough ideal to obtain a circular patch antenna at GPS frequency with a satisfactory behavior, but for commercial purposes the substrate must be changed in order to obtain a bigger and competitive patch antenna gain.

As future work, it will be made prototypes with the sizes given by Equations (1) and (3), in order to observe its

experimental behavior and corroborate the result obtained in the corresponding simulation.

The asymmetries on the response of the pentagonal antenna could be reduced implementing a circular substrate instead of the rectangular one. The purposed solution here demonstrates that different strategies can be realized with the aim to reducing global costs.

The location of the feed point also affects to the gain value, which increases as it is separated from the origin, as a consequence of the adjusting on impedance.

Additionally, on the base of the pentagonal antenna, the implementation of a dual antenna is under analysis. This has the purpose to show the high applicability of the pentagonal geometry for diverse uses.

6. Acknowledgments.

Authors want to thank to EM Software & Systems (USA) Inc., for FEKO license. The authors want to knowledge the partial support of CONACyT under grant 90926-Y.

J. G. Vera-Dimas expresses his sincere thanks to CONACyT for the postgraduate scholarship under grant 270210/219230.

7. References

[1] P.J.B. Clarricoats, Y. Rahmat-Samii and J. R. Wait. Handbook of Microstrip Antennas. Vol. 1. Edited by J. R. James & P. S. Hall. Peter Peregrinus Ltd. (1989).

[2] Constantine Balanis. Antenna Theory: Analysis and Design. Third Edition,Wiley. (2005).

[3] Ramers H. Garg, Microstrip Antenna Design Handbook, Artech House, Norwood, MA, (2001).

[4] Jia- Sheng Hong and M. J. Lancaster. Microstrip Filters for RF/Microwave Applications. Wiley Series in Microwave and Optical Engineering. (2001).

[5] Garg, Bhartia, Bahl, Ittipiboon. Microstrip Antenna Design Handbook. Artech House. (2001).

[6] A. K. Verma and Nasimuddin. Analysis of Circular Microstrip Patch Antenna as an Equivalent Rectangular Microstrip Path Antenna on Iso/Anisotropic Thin Substrate. IEE Proc.-Microw. Antennas Propag. Vol. 150, No. 4, August (2003).

Margarita Tecpoyotl Torres received the Mathematician degree from the University of Puebla (UAP), Mexico, in 1991. In this University, she was graduated as Electronic Engineer in 1993. She received the M.Sc. and Ph.D. degrees in Electronics from National Institute of Astrophysics, Optics and Electronics (INAOE), México, in 1997 and 1999, respectively. Dr. Tecpoyotl works, since 1999, at CIICAp of the UAEM, Mexico, where she is currently titular professor. She has been visiting research scientist in University of Bristol (2001), UK. Her main research interest includes MEMS, Antenna design, and Microwave devices, and the development of educational programs. She has currently two patents under revision. She holds the status of National Researcher (SNI) in Mexico since 2002, (level 1). From 1999-2002, she was Candidate of SNI.

José Gerardo Vera Dimas was born in Morelia, Michoacán, Mexico, on January 3rd, 1984. He is graduated from the Technologic of Morelia as Electronic Engineer. Member IEEE since January 2005. Commit member of VII and VIII ROPEC. He received the award "EGRETEC 2009" by the Association of Graduates from the Technological Institute of Morelia. Nowadays he is student of master degree in CIICAp at UAEM.

Rafael Vargas Bernal was born in Irapuato, Guanajuato, Mexico, in 1972. He received the Communications and Electronics Engineering degree from the University of Guanajuato, Mexico, in 1995, the M.Sc. and Ph.D. degrees from INAOE, Mexico, in 1997 and 2000, respectively. Dr. Vargas-Bernal works, since 2002, at Instituto Tecnológico Superior de Irapuato, Mexico, where he is currently a full professor. His main research interests are MEMS, RF, sensors, and computer-aided design (CAD). He is technical reviewer in IEEE Latin America Transactions since 2004 and technical reviewer of standards in SEMI International Standards since 2006.

Miguel Torres Cisneros obtained his Engineering Degree in Electronics at the Universidad de Guanajuato in 1988, his M. Sc. degree from the Centro de Investigaciones en Óptica (CIO) in 1991 and his Ph. D.cum Laude in Sciences from INAOE in 1997. He has been visiting

research scientist in Dayton University (2002) and the University of Central Florida (UCF) in 2009. He has been professor at the Tech. of Monterrey and the Universidad de las Américas, and Titular Researcher at the Universidad de Guanajuato since 14 years, where he is involved with the NanoBioPhotonics Group, the Patents Group, and the Design and Manufacture Cell, Electronics & Mechatronics Programs. He has published over hundred scientific papers and holds 2 patents. He holds the status of National Researcher (SNI) in Mexico since 1992, (level 2) and obtained recognition as outstanding professor PROMEP since1999. He was president of the Mexican Academy for Optics in 1999 and become a regular member of the Mexican Academy of Sciences in 2006.

Dr. Alvaro Zamudio Lara received the Industrial Engineering degree in Electronics from the Instituto Tecnologico de Veracruz (1994), and The Masters (1997) and Ph.D. (2005) from INAOE. He currently works at CIICAp at UAEM, in the area of Electrical Engineering. His research is mainly focused on Digital Design with FPGA's and microcontrollers. He belongs to the National System of Researchers of Mexico since 2006 (level I).

Volodymyr Grimalsky received the M.Sc. and Ph.D. degrees in Physics from Kiev National University, Kiev, Ukraine, in 1982 and 1986, respectively. Dr. Grimalsky worked during 1985 – 1997 at the Radiophysics Faculty of Kiev National University as the Research Scientist, where he was engaged in the millimeter wave device physics. In 1997, Dr. Grimalsky was the Invited Researcher at the Large Millimeter Telescope Project in INAOE, Mexico. During 1997-1999, he was Senior Research Scientist at Space Research Institute, Kiev, Ukraine. During 2000 -2006, Dr. Grimalsky was the Titular Researcher at the Electronics Department, INAOE, Mexico. Since 2006, he is the Titular Researcher at CIICAp, UAEM, Cuernavaca, Mexico. His research interests include electromagnetic and acoustic wave interactions with semiconductors and plasmas, millimeter wave and terahertz devices, electromagnetic monitoring of seismic and volcanic phenomena. He has more than 120 papers in refereed journals. He is member of National System of Investigators (SNI) in Mexico (level 2) and the Member of IEEE.

View publication stats