VOL. 10, NO 22, DECEMBER, 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN OF ELECTRICALLY SMALL TOP LOADED ANTENNAS FOR GPS APPLICATIONS

M. Venkata Narayana, Govardhani. Imamdi, Habibulla Khan, P. V. N. Lakshmi Durga, N. Sirisha, R. Praveen Kumar Reddy and Y. Chandan Krishna
Department of Electronics and Communication Engineering, KL University, Vaddeswaram, Andhra Pradesh, India
E-Mail: mvn@kluniversity.in

ABSTRACT

The design of small high frequency antennas continues to be a challenge while maintaining required bandwidth and low quality factor. Numerous methods are proposed to reduce the quality factor for small antennas. According to Wheeler and Chu limitation on quality factor the design should be in a way that the fields inside the spherical volume should be diminished. Generally for small antennas reactance will be very high. In this project we want to implement top loading approach to decrease Q value and tune the antenna at desired frequency. In this approach we used top loading for antenna in order to reduce its reactance. The top loading techniques which we implemented in this paper are loading using inductive loading, cap hat loading, and umbrella loading for helical antennas using ANSYS HFSS 13.0. The frequency of this antenna is designed at 1575.42 MHz which is operating frequency for GPS. GPS is used for tracking purposes. Q factor is greatly reduced by using these design approaches.

Keywords: small antennas, Q factor, top loading, helical antenna.

1. INTRODUCTION

Mobile communications are a prominence development of latest technology which has higher worth in telecommunications. They have shown a great advancement with new applications such as wireless LAN, wireless multimedia links, satellite mobile phones, two-way radios such as land mobile, remote monitoring, Bluetooth, ZigBee, GPS. Wireless communications and miniaturizing antennas for those applications became an important issue now-a-days. Small size, good radiation characteristics, wide bandwidth are important factors for any antenna. Mobiles became a necessity in every individual life. GPS is a tracking system is used for accurate location of a position and for surveying. Helix antenna used for construction of GPS system.GPS system operates at two bands L1 (1575.42MHz) and L2 (1227.60MHz) [5].Taking this application into account we tried to reduce the size of antenna. That is to consider the size of antenna with respect to wavelength which is the parameter influences radiation characteristics. The design challenges are mainly due to the tradeoffs involved in designing a small antenna with acceptable size so that it can satisfy required impedance and bandwidth at particular frequencies. Different approaches of shortening the helical antenna like meander line antenna [7] i.e. folding the antenna along its length and toroidal antenna are discussed in different papers.

This requires miniaturization of antenna with a method to design smallest possible antenna such that it maintains a reasonable compromise among volume, bandwidth, and efficiency. This paper presents a design methodology that uses inner volume efficiently in order to achieve self-resonances at very lower frequencies while maintaining performance constant with properties related to antenna height and volume. Helical antenna is mostly used for the purpose of GPS applications. Helix antenna is operated in two modes Normal mode and axial mode. In normal mode the radiation is normal to the axis. In axial mode radiation pattern coincide with helix axis. In axial mode helical antenna the current distribution changes for every 180 degrees so the current at opposite points will constitute for constructive interference and hence directive beam is achieved. As helical antennas are of travelling wave type they also provide wide bandwidth.

2. BASICS OF SMALL ANTENNAS

According to wheeler small antennas are those in which largest dimension is less than one-tenth of wave length (λ/10). The antenna should be confined within a sphere called radian sphere of radius r which is less than $\lambda/2\pi$ .Small antennas are those having Ka<1, where k=free space wave number $2\pi/\lambda$ and a is the radius of radian sphere. Quality factor is one of the important parameter that is to be considered for small antenna. Quality factor defines the amount of power which is radiated by an antenna. Q factor is high for electrically small antennas, as most of the power is absorbed in the antenna structure itself. The essential limitation for Q value according to Chu limit is defined as [15].

$$Q = \eta \frac{1}{Ka} + \frac{1}{K^3a^3}$$

$$Q = [\eta \cdot \frac{1}{K^3a^3} + \frac{1}{Ka}].$$

ARPN Journal of Engineering and Applied Sciences

The quality factor should be greater than the lower limit which is derived by using the lower order mode. The quality factor and radius of the sphere are related by [2].

$$r= \frac{\lambda}{2\pi}\left(\frac{9}{2Q}\right)^{\frac{1}{3}}$$

To achieve Q close to essential limit, the volume of the sphere should be completely used. Directivity for small antennas is lower than normal antennas and the radiation is omnidirectional. Small antennas work at a frequency less than original frequency. As the operating frequency decreases the effective aperture decreases which decreases gain. Radiation resistance also decreases as the size is reduced. For small antennas reactance value dominates the resistance value. The reduction in size will also increase the Q factor, which reduces the bandwidth. Efficiency also reduces for small antennas because as size reduced losses in the antenna are increased.

3. MINIATURIZATION TECHNIQUES

In small antennas, the current distribution along the antenna varies linearly and becomes zero at the topmost. For this antennas most of the capacitance lies at the erect position of the antenna which is the reason for discharge of displacement current away from the antenna along its total length, so this decreases the amount of the current flowing inside the antenna.

Hence we will use different miniaturization techniques for uniform current distribution in the antenna while maintaining the same dimensions. Miniaturization in the antennas can be done through different methods like using lumped elements, high permeability materials, effect of the ground plane, optimizing geometry. Fractal approach is another technique followed for miniaturization of antenna.

In order to compensate the capacitance present in the antenna, we will give inductance to mitigate the effect caused in the current distribution by using lumped elements. Double negative materials which possess inductive nature are used to decrease the capacitance in order to make a resonant system. Using mirroring effect, the ground plane provides same characteristics just like as half wave dipole. By introducing the bends and slots, the effective current distribution in antenna increases. In this paper, top loading through lumped elements is used for antenna miniaturization. Sometimes the combination of inductance and capacitance lumped elements can be used.

4. TOP LOADING TECHNIQUES

The benefits of top loading are it increases current in the vertical portion of the antenna and this in turn increases radiation efficiency. Along with this another advantage is feed point reactance is reduced, which reduces the feed current which increases power management proficiency. Another advantage of top loading is to increase the effective height of the antenna for a given physical height. If cap hat is used as top loading Q factor is reduced. By using top loading, the effective length of antenna is increased. This is due to redistribution of capacitance in the total antenna design there by results a uniform distribution of current and radiation resistance increases. In this paper three types of top loading are used. They are top loading through inductive loading, cap hat loading and modified umbrella loading. These techniques are used to reduce the size of GPS antenna. Folding the antenna along its length also reduces the physical length of antenna. Drooping is another type of design to implement top loading. But the disadvantage with this type of loading is currents in antenna and top loading are in out of phase

5. DESIGN PROCEDURE

In this paper we implemented top loading concept for helical antennas. In most of applications to achieve circular polarization without the help of polarizer, axial mode is preferred and in this mode gain increases with increase in number of turns. Our antenna is designed to operate at frequency 1.575GHz using ANSYS HFSS 13. Antenna length is chosen as 1.8cm.But the resonant frequency is arond1575MHz. Helix dimensions are chosen as per formulas [5]. A general helix is formed by winding a wire around a cylinder. Each design is simulated by increasing number of turns. Return loss, gain and Vswr for each design are plotted.

(a) Loading using lumped elements

Generally small antennas have low radiation resistance and high capacitance at the feed. In order to cancel out the capacitance equivalent inductance should be used. One way to find out the capacitance of the antenna is to assume the antenna as an open circuited transmission line. According to transmission mode the helical antenna can be viewed as a transmission line. This is by equation

$$Z_{out} = \frac{-jZ_o}{\tan\theta}$$

Where Z_o is the characteristic impedance of helix which is equal to

$$Z_0=140\,\frac{c}{\lambda}.$$

From Z_o, reactance value is calculated and it is compensated by using equivalent inductance which is given by the formula

$$L = \frac{X_L}{2\pi f}$$

Radials are used as top loaded elements. They should be horizontal to the ground plane. Effectively covering the volume inside the radian sphere will also help in shifting the resonant frequency [6]. While increasing no of radials there will be shift in resonant frequency. In this

ARPN Journal of Engineering and Applied Sciences

paper we used five radials. The length of the radials should be 7/8th of length of the antenna. The resonant frequency is at 1575MHz. This type of design is implemented for1, 2, 3 turns and results are compared. 1, 2, 3 turns are implemented at a frequency 1575MHz frequency. Top loading using lumped elements can be seen in Figure-1. As the no of turns increases the electrical length increases which decreases so there will be a decrease in resonant frequency. But loading the inductance at the top does not give mechanical strength to the antenna. Another disadvantage with inductive loading is Q of the antenna increases which results narrow bandwidth. Different parameters are listed in Table-1.

Length of the antenna=1.8cm

Length of radials =1.35cm

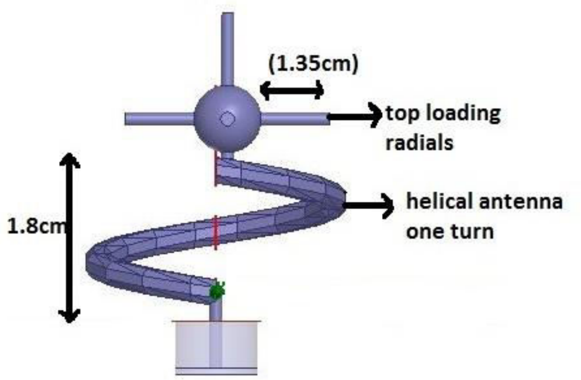

Figure-1. Top loading using lumped elements.

(b)Top loading using Cap Hats

Another way to reduce the capacitive reactance at the top of the antenna is to maintain capacitance at the top. This method provides extra capacitance from top to ground. An antenna without top loading has capacitance distributed only along the length and becomes zero at top. So the current flows away from the antenna. If a fraction of capacitance is added at the top then the displacement current flows along the top making the current distribution linear along the length of antenna. So the effective length of the antenna increases because current distribution at the top increases. This cap hat can take many configurations like ‘T’ shape at the top of antenna. A solid disc will provide

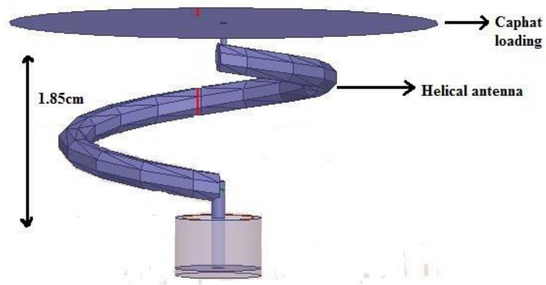

Figure-2. Top loading using cap hat.

the largest capacitance than any other structure. The cap hat reduces the use of inductor top loading and there by reduces Q of antenna. This type of loading is very efficient and it provides wider bandwidth. But radiation resistance is reduced cap hat loading can be viewed in Figure-2. In this type of design all turns are implemented at 1575MHz. Different parameters are listed as given in Table-2.

(c)Umbrella type loading

Another type of cap hat loading is umbrella type top loading. In this type of loading the radial wires are made to slope downwards. Radiation resistance can be maximized by employing cap hat at certain height from radiator. But sloping them with a greater angle beyond a limit will decrease the radiation resistance. Sloping angle is maintained as 50^{0} and the current distribution in antenna increases because the radials separate from each other and come abutting the ground. Materials that can be used for sloping wires are good conductors

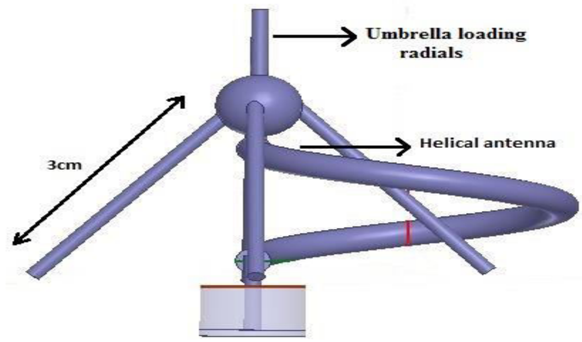

Figure-3. Top loading using umbrella design.

6. RESULTS AND DISCUSSIONS

Following are the results obtained for lumped element loading. One, two and three turns are implemented at 1.57GHz. It can be seen that the radiation pattern is directional with a reduced amount of side lobes. The maximum gain is obtained for 3 turn inductive loading 8.32 is along phi=170^{0} and theta=-6^{0}. Vswr observed for all the three designs is around 1-2. This type

ARPN Journal of Engineering and Applied Sciences

of design exhibited bandwidth of approximately 15MHz which is in the band of GPS frequency. But the disadvantage of inductive loading is that if the coil is used at the top of the antenna it doesn't give mechanical strength to the antenna.

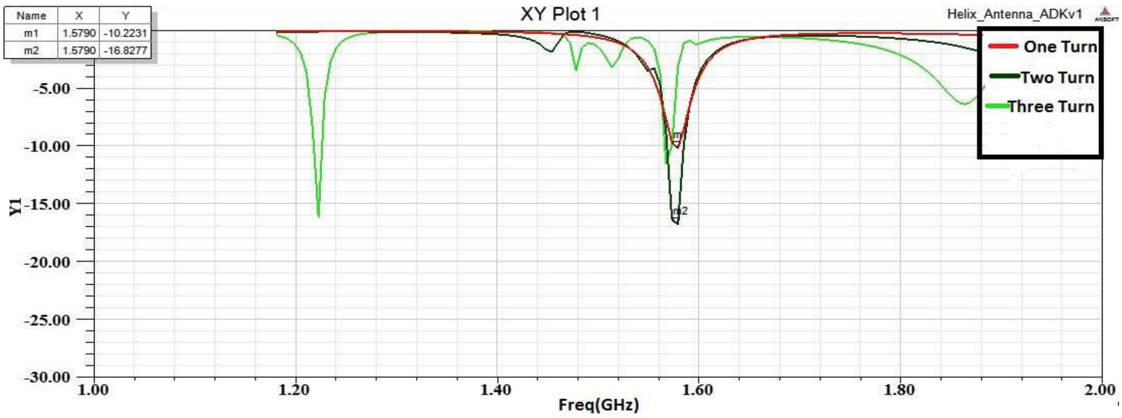

Figure-4. Return loss for lumped element loading.

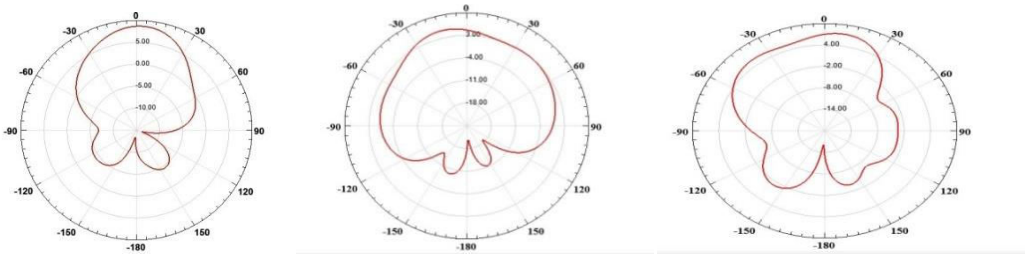

Figure-5. The above figure show the radiation pattern for inductive loading one, two, three turns.

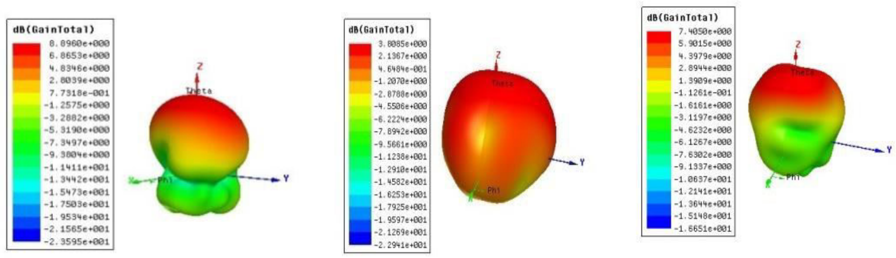

Figure-6. The above figure shows the 3D polar plot for inductive loading for one, two, three turns.

Following are the results obtained for capacitance hat loading. All the three turns are implemented for 1575MHz. the radiation pattern is omnidirectional. The maximum gain is 8.93 for three turn capacitance hat loading. It is observed that as the no of turns increase the gain increases as the electrical length of the antenna increases. Radiation pattern is directional. The bandwidth obtained from this type of loading.

ARPN Journal of Engineering and Applied Sciences

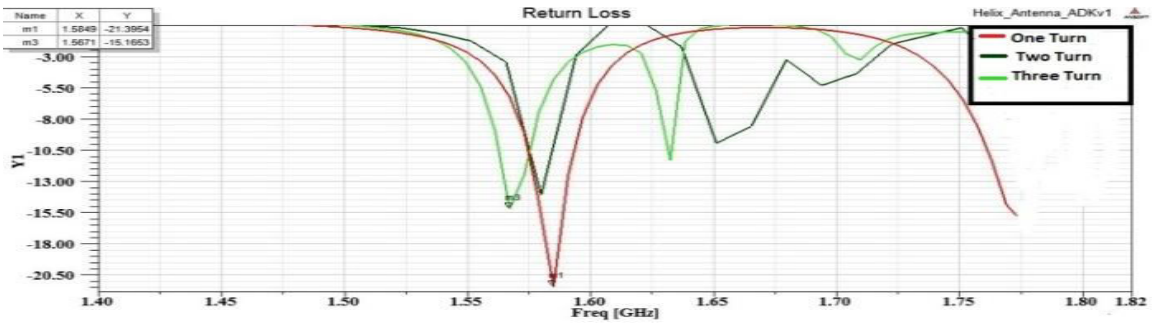

Figure-7. Return loss plot for capacitance hat loading.

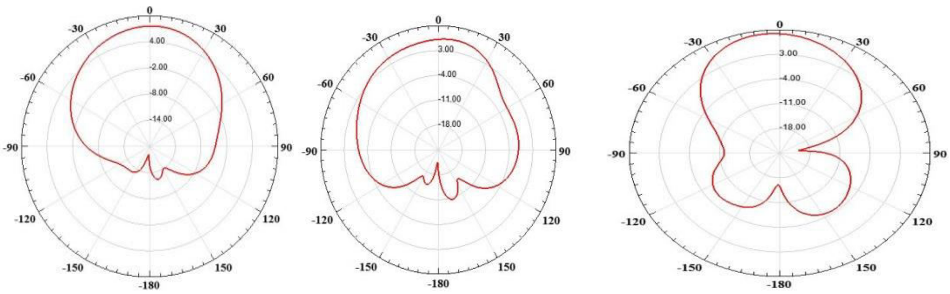

Figure-8. The above figure shows the radiation pattern for capacitance hat loading one, two, three turns.

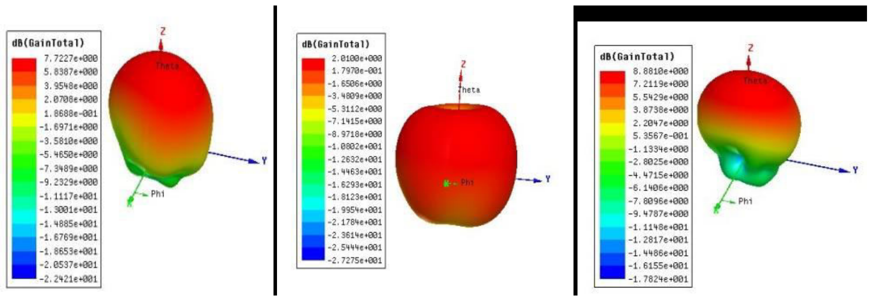

Figure-9. The above figure shows the 3D polar plots for capacitance hat loading one, two, three turns.

The following are the results obtained for umbrella type loading. All the three designs are implemented for 1575MHz. Maximum gain obtained is 9.163 obtained for three turn umbrella loading .In this case also as no of turns increase the gain increases. Radiation pattern is directional.

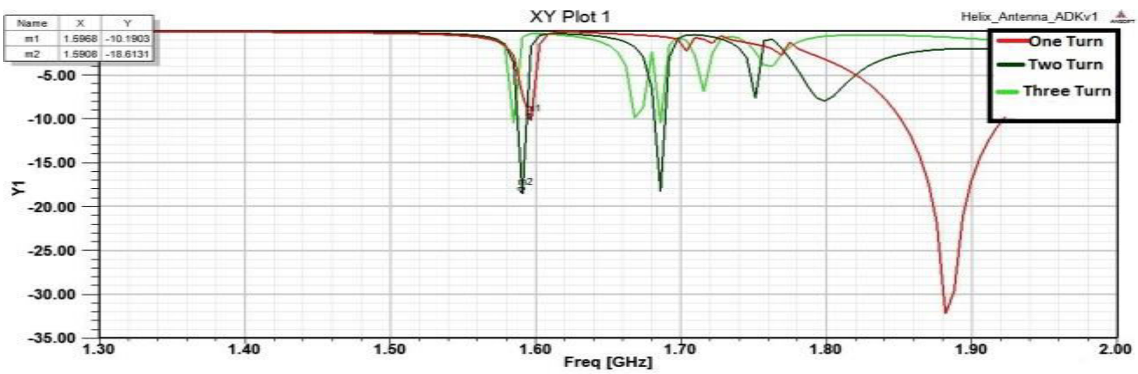

Figure-10. Return loss for umbrella loading.

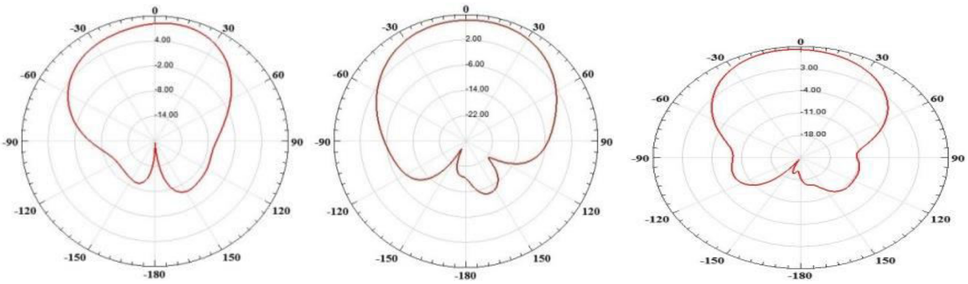

Figure-11. The above figure shows the radiation pattern for umbrella loading for one, two, three turns.

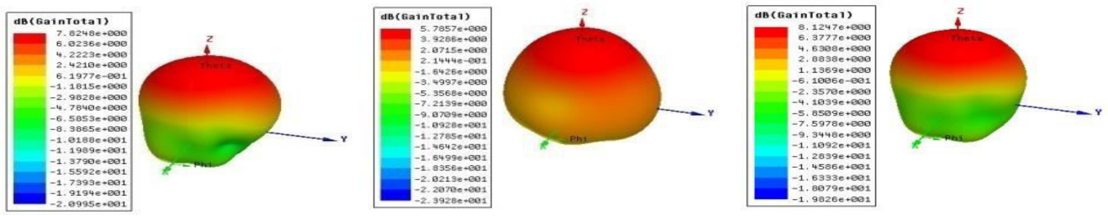

Figure-12. The above figure shows the 3D radiation pattern for Umbrella loading for one, two, three turns.

Table-1. The properties for inductive loading.

No. of turns	Resonant frequency	Return loss	Vswr	Q_{lb}	Quality factor	Gain
1	1.579	-10.23	1.89	2.05	4.6	8.7151
2	1.590	-12.11	1.65	2.03	4.4	5.3036
3	1.567	-11.55	1.71	2.09	4.6	8.32

Table-2. The properties for capacitive loading.

No. of turns	Resonant frequency	Return loss	Vswr	Q_{lb}	Quality factor	Gain
1	1.5849	-21.3	1.99	2.04	4.566	7.65
2	1.5790	-10.43	1.8	2.03	4.625	7.7
3	1.5671	-15.16	1.4	2.08	4.679	8.93

Table-3. The properties for umbrella type loading.

No. of turns	Resonant frequency	Return loss	Vswr	Q_{lb}	Q	Gain
1	1.5968	-10.19	1.89	2.32	6.605	8.14
2	1.590	-18.6	1.89	2.33	6.61	8.394
3	1.5849	-10.5	1.8	2.34	6.66	9.163

7. CONCLUSIONS

From the three designs obtained it can be observed that inductive loading is not worthy, because losses are included by the use of loading coils. Capacitance hat is the best among the top loading. Solid disc provides the best capacitance than all other structures. It gives optimized gain and Q. Umbrella loading is difficult to construct but gives good gain. As the turns increases resonant frequency reduces and quality factor increases. All the designs are optimized to a good Q factor and exhibited good gain and radiation pattern is directional.

REFERENCES

[1] Ibrahim Turki Nassar. 2010. Small antennas design for 2.4GHz applications. University of south Florida.

[2] Steven. R. Best. Optimization of bandwidth of electrically small planar antennas.

[3] Davorbonefacic, Juraj Bartolic. Small antennas miniaturization techniques and applications. ISSN1848-3380.

[4] A quadrafilar helical antenna for low elevation GPS applications. Senglee Foo CAL Microwave journal.com/articles/2229.

[5] Walter R. Gulley. Construction details for a GPS helical antenna.

[6] James M. Baker, Madgy F. 2015. Iskander new design approach for electrically small high frequency antennas. IEEE Antenna and Wireless Propagation Letters. Vol. 14.

[7] C.C. Hsu, H.H. Song. 2013. Design, fabrication and characterization of a dual-band electrically small meander line monopole antenna for wireless communications. International Journal of Electromagnetic and Applications. 3(2): 27-34.

[8] Automatika.korema.hr/index.php/automatika/article/view/164/204.

[9] K. Sarabandi, R. Azadegan, H. Mosallaei and J. Harvey. Antenna Miniaturization Techniques for Applications in Compact Wireless Transceivers. Proceedings/ProcGA02/papers/p2037.

[10] Small antenna design text book by Douglas Miron, 1st edition.

[11] Optimization of umbrella top-loaded shunt-fed monopole antenna for MF digital radio using WIPL-D Microwave software Vladimir V. Petrović, Senior Member IEEE, Jovan V. Surutka.

[12] Richard W. Ziolkwski. 2008. An efficient, electrically small antenna designed for VHF and UHF applications. Antennas and wireless propagation letters. IEEE. Volume 7.

[13] 2005. Design and performance of an electrically small slot loop antenna with a miniaturized superconducting matching circuit. Y. Tsutsumi, H. Kanaya and K. Yoshida. Applied superconductivity. IEEE transactions. 15(2).

[14] Design Guide Lines for Small Antennas R. Fenwick Antenna and propagations IEEE transactions. 13: 379-383.

[15] Oleksy S. Kim. 2012. Minimum Radiation Quality Factor. Antenna and Propagations. IEEE transactions.