

Active Tuning and Miniaturization of Microstrip Antennas

¹⁾Ekram H. Bhuiyan, *Yong-Hee Park, Samir El-Ghazaly, ²⁾Vijay Nair, and
²⁾Herb Goronkin

Department of Electrical Engineering, Telecommunication Research Center,
Arizona State University, Tempe, AZ 85287-7206, USA

¹⁾ AT&T CORP., San Jose, CA 95131, USA

²⁾ Motorola Inc. Phoenix Corporate Research Laboratories,
2100 E Eliot Rd., Tempe, AZ 85284, USA

ABSTRACT — The objective of this paper is to introduce two aspects of printed planar antennas, miniaturization and tuning of the resonant frequency. When varactor diodes are used as capacitive loads for the antenna, it allows reducing the size of the antenna with an added feature of tunability. By varying the biasing voltage of the varactors, resonant frequency can be varied over wide range. Positions of the varactors also have influence on the resonant characteristics of the patch antenna. Various characteristics of patch antenna such as resonant frequency, input impedance, current distribution, cross polarization and radiation pattern for different varactor positions are studied using the full-wave Finite Difference Time Domain approach. Varactors are characterized by their equivalent circuits and incorporated as lumped elements in the Finite Difference Time Domain method. Now these patch antennas are under fabrication and will be measured to compare with results of simulation.

I. INTRODUCTION

The physical size of the radio communication equipments and electronic devices on which antennas are installed has been scaled down in the recent years, especially in mobile communications. Therefore, there is a demand for small size antennas with efficient electrical performance. In addition to the miniaturization, another desirable characteristic of modern antennas is wide-band operation, which has a single antenna to satisfy the frequency band requirements of different applications.

To meet the requirements of modern communication system, microstrip antenna is the most suitable antenna due to its smaller size, lightweight, low cost and ease of fabrication and integration with RF devices. A common technique for the miniaturization of microstrip patch antennas is reactive loading. In principle any reactive loading of the microstrip antenna will decrease the resonant frequency. Since the operating frequency of the patch is lowered when it is loaded, the effective area of the antenna is reduced compared to an unloaded patch antenna radiating at the same frequency. Loading also gives the tuning capability of the antenna. By changing the level of loading, resonance frequency of the microstrip antenna can be tuned over a wide range without significant variations in the performance of the antenna.

In this paper, a varactor loaded microstrip rectangular patch antenna is investigated. Varactor diodes are mounted between patch and ground plane. They are placed at different positions of patch. The different characteristics of patch antenna such as resonance frequency, input impedance, current distribution, cross polarization, and radiation pattern for these positions are studied using full-wave Finite Difference Time Domain (FDTD) method.

II. VARACTOR LOADED PATCH ANTENNA

The use of varactor diodes to improve the bandwidth of a microstrip patch was first reported by P. Bhartia and I. J. Bahl [1]. The mechanism, which causes the resonant frequency of this radiating element to vary with the applied bias level, can perhaps best be explained by considering

of a simplified transmission-line model of the structure. According to transmission line, the equivalent model of patch antenna can be represented by a simple R-L-C tank model [2].

A varactor is a semiconductor junction diode with a non-linear reverse-bias capacitance. The capacitance of the varactor decreases with the increasing reverse bias voltage. Placing a varactor between the patch and ground plane is equivalent to voltage-controlled capacitor being put parallel to the tank circuit of patch. By changing the reverse bias voltage, capacitance of the diode will be changed and thus tank circuit will tune out to the lower resonant frequency.

III. DESIGN AND FDTD ANALYSIS

A microstrip line at the center of the radiating edge feeds the antenna. Conductors of the antenna are assumed to be perfectly conducting and have zero thickness. Dielectric of the antenna is lossless. Moreover, The ground plane and the dielectric are considered to be infinite. Initially, the size of the patch is designed by the transmission line model and then rigorous FDTD method is applied to get the accurate analysis of the antenna. The Finite Difference Time Domain was first proposed by Yee in 1966 [3]. Varactors are characterized by their equivalent circuits and incorporated as lumped elements in the FDTD method [4]. Varactors are connected between the patch and ground plane through via holes. The antenna is designed for the operating frequency of approximately 4 GHz. It is designed on Duroid substrates with $\epsilon_r = 2.2$ and the thickness is taken as 1/32 inch i.e., 0.794 mm. Using design equations [5], the length of the patch is found 25.2 mm and the width of the antenna is taken 16.1 mm.

To analyze the effects on performance of the antenna for different positions of varactors, several configurations are considered as shown in Fig. 1. For the configuration (a), microstrip line is fed slightly right side of the center to provide the space for varactors. To change the loading, capacitances of the diodes are changed from zero to 5pF.

V. RESULTS

Different characteristics such as resonance frequency, current distribution, input impedance, and radiation patterns are calculated for all of these configurations except Fig.1 (f). It is found that resonant frequency does not changed significantly for this configuration, and therefore, is not studied further. Fig. 2. shows $|S_{11}|$ and current distribution of unloaded patch antenna and four-corners-loaded patch antenna with 2 pF capacitance.

A. Resonant Frequency

Resonance frequency is defined as the frequency at which scattering parameter $|S_{11}|$ is maximum. The resonant frequencies for all configurations of the varactor loading are summarized in Fig. 3.

From the Fig. 3, it is clear that the position of the diodes have strong influence on the resonance frequency. When varactor is placed at the radiating edges, it gives reduction of the resonance frequency with loading. This is mainly because diodes can change the resonant length of the antenna. The variation of the resonant frequency with the loading level is quite evident and thus confirming the ability of the varactors to provide tunability of the antenna. For 5pF loading in the four corners of the patch, 63% change of resonant frequency is found.

B. Input Impedance

Input impedance of the antenna is of great important when bandwidth and power transfer are considered. Matching between the feed line and input impedance of the antenna determines the amount of power transferred to the antenna for radiation. The resonance impedance of the linearly polarized rectangular microstrip antenna is maximum at the radiating edge, which is found 308 ohms for the unloaded patch. The input impedances for all configurations of the varactor loading are summarized in Fig. 4.

Input impedance increases in case of back corners loading of antenna, Fig. 1(b). When antenna is loaded in the opposite of the feed position, diodes draw the current from the antenna towards

the backside, which reduces the current density in the feed side. Thus, input impedance becomes higher with the increase of the capacitances. Maximum decrease of the input impedance is found in front corners loading case. Electrical length of this configuration of the patch antenna increases only in the feeding edge. As a result, feeding point of this configuration is closer to the center of the antenna than the other configurations and therefore more reduction in the input impedance results.

The effect of the input impedance along the radiating side is also investigated as shown in Fig. 5 - 6. The feeding position of the microstrip line to the patch is shifted from the center to the corners for case Fig. 1 (a) and case Fig. 1 (e) for 1pF loading. It is found that impedance is minimum at the farthest point from loading edges and increases towards the loading edges. This effect can be explained according to the cross polarized currents of the patch. From Fig. 5(b) and Fig. 6(b), currents have $\hat{x}$ components at the loading edge. Usually for resonance this current has maximum at the loading edge and decreases far from the loading edge. This may cause the impedance to be higher at loading edge.

C. Radiation Pattern

Radiation patterns for both E - plane and H - plane are calculated for the each of the loading configurations of the patch antenna, to determine its radiation characteristics, which include beam width, beam shape, directivity etc. No significant changes are found in the patterns for capacitive loading of the antenna. The radiation pattern follows almost that of the conventional patch without loading. Although H - plane characteristics do not change much, E - plane beam width increases with decreasing the resonant frequency. Thus, directivity of the antenna decreases slightly. This increase of the beam width is due to the cross polarization introduced by the loading of the antenna. Asymmetry of the feeding and loading points of the antenna cause this cross polarization. Diagonal corners loading shows the maximum beam width of 90° . Although, cross polarization level is high, this configuration shows higher bandwidth of resonant frequency than the other two diodes loading configurations. The four corners loading shows the highest 37% of the change of the resonant frequency. Radiation pattern is also closer to the original patch for this configuration. These patch antennas are now under fabrication and will be tested to compare with simulation.

V. CONCLUSION

This paper presented a comprehensive analysis of the use of varactor diodes to change the operating frequency of the microstrip patch antenna. A full-wave finite difference time domain method is used to investigate the patch antenna. The effects of biasing of the varactors as well as the positioning of the diodes on the patch are examined.

Varactor loaded microstrip antenna shows quite practical antenna characteristics, indicating that it is feasible to use varactor diodes to reduce the size of the antenna, and also to tune the antenna over a wide band. Although cross polarization level increases with decrease of frequency, for mobile handset, direction of the signal arrival is not a fixed and so cross polarization is not a great concern. Broad beam of patch antenna also make it suitable for mobile communications. In many applications, low directivity of a single patch element is not adequate. However, this limitation is overcome by grouping a number of identical radiating elements to form a periodic array, which can provide a high directivity.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and support of Motorola - University Partnerships in Research (UPR) program

REFERENCES

- [1] P. Bhartia and I. J. Bahl, "Frequency agile microstrip antennas," *Microwave Journal*, vol. 25, no.10 pp. 67-70, Oct. 1982.

- [2] R. B. Waterhouse and N.V. Shuley, "Frequency agile microstrip rectangular patches using varactor diodes," IEEE Antenna and Propagation Society International Symposium Digest, vol. 4, pp. 2188-2191, 1992.
- [3] K. E. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," IEEE Trans. Antennas and Propagat., vol. AP-14, pp. 302-307, May 1996.
- [4] W. Sui, D. A. Christensen and C. H. Durney, "Extending the two-dimensional FDTD method to hybrid electromagnetic systems with active and passive lumped elements," IEEE Trans. Microwave Theory tech., vol. 40, pp. 724-730, April 1992.
- [5] J. Bahl and P. Bhartia, *Microstrip Antennas*, Dedham, MA, Artech House, 1980.

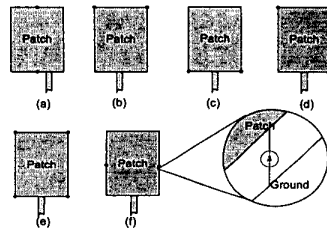


Fig. 1. Different configurations for the varactor loading of the patch antenna. (a) Front and back centers loading. (b) Back centers loading. (c) Front centers loading. (d) Diagonal corners loading. (e) Four corners loading. (f) Left and right centers loading patch antenna.

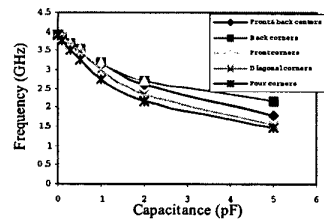


Fig. 3. Variations of resonance frequency of the varactor-loaded patch antenna with capacitances of diodes.

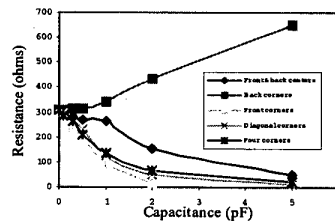
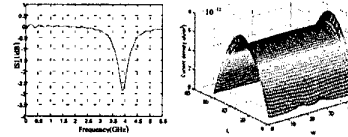
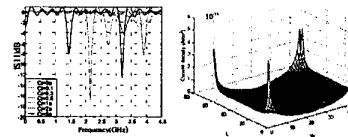


Fig. 4. Input impedance of the varactor-loaded patch with the variation of the capacitance.



(a) Unloaded patch antenna.



(b) Four corners loaded patch antenna as shown in Fig. 2(e).

Fig. 2. $|S_{11}|$ and current distributions

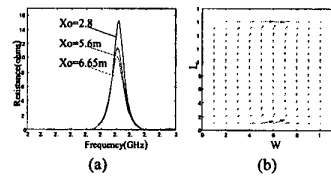


Fig. 5. (a) Input resistances with different feeding point and (b) Vector plot of the current distribution for front back centers loaded patch antenna. x_0 is the distance of the feed point from the center of the edge.

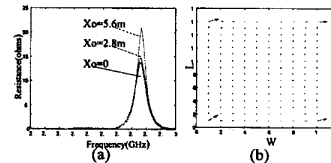


Fig. 6. (a) Input resistances with different feeding point and (b) Vector plot of the current distribution for four corners loaded patch antenna. x_0 is the distance of the feed point from the center of the edge.