

A Review and study of the design technique of Microstrip Patch Antenna Technology

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ABSTRACT

In this paper, study and survey of microstrip antenna elements is presented, with emphasis on theoretical and practical design techniques and material used, as previous study have been proved that material used play significant role in the performance such as gain, directivity, frequency of radiation. Available substrate materials are reviewed along with the relation between dielectric constant tolerance and resonant frequency of microstrip patches. Several theoretical analysis techniques are summarized. Practical procedures are given for both standard rectangular and circular patches. The quality, bandwidth, and efficiency factors of typical patch designs are discussed.

I. INTRODUCTION

The purposes of this paper are to describe analytical and experimental design approaches for microstrip antenna elements, and to provide a comprehensive survey of the state of microstrip antenna element technology.

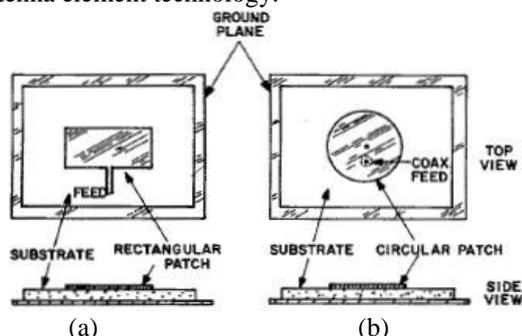


Fig1. (a) Rectangular microstrip patch antenna (b) Circular microstrip patch antenna

By contrast a microstrip device in its simplest form consists of a sandwich of two parallel conducting layers separated by a single thin dielectric substrate [1]. The lower conductor functions as a ground plane and the upper conductor may be a simple resonant rectangular or circular patch, a resonant dipole, or a monolithically printed array of patches or dipoles and the associated feed network.

II. MATERIALS FOR PRINTED CIRCUIT ANTENNAS

The propagation constant for a wave in the microstrip substrate must be accurately known in order to predict the resonant frequency, resonant resistance, and other antenna quantities. Antenna designers have found that the most sensitive parameter in microstrip antenna performance

estimation is the dielectric constant of the substrate material, and that the manufacturer's tolerance on ϵ_r is sometimes inadequate. The change in operating frequency of a thin substrate microstrip antenna due solely to a small tolerance-related change of the substrate dielectric constant may be expressed as

$$\frac{\Delta f}{f_0} = -0.5 \frac{\Delta \epsilon_r}{\epsilon_r} \quad \dots\dots 1$$

Where f_0 is the resonant frequency of a microstrip antenna assuming a magnetic wall boundary condition, ϵ_r is the relative dielectric constant, Δf is the change in resonant frequency, and $\Delta \epsilon_r$ is the change in relative dielectric constant.

Available Microwave Substrates

Polytetrafluoroethylene (PTFE) substrates reinforced with either glass woven web or glass random fiber are very commonly used because of their desirable electrical and mechanical properties, and because of a wide range of available thicknesses and sheet sizes.

Anisotropy

In order to obtain the necessary mechanical properties of PTFE, fill materials are introduced into the polymer matrix [2], [3]. This fill material is commonly glass fiber although it may also be a ceramic. In either case these filler materials take on preferred orientations during the manufacturing process.

Specialized Substrate Material

While the material most frequently used for printed antenna elements is PTFE, there are other materials used for specialized applications. Composite materials find applications where weight is important, such as for spacecraft antennas, or

where large physical separation between the antenna element and the ground plane is required. One such substrate consists of two thin layers of PTFE bonded on each side of hexcell material [3],[4]. Depending upon the thickness of the dielectric layers, the dielectric constant ranges from 1.17 to about 1.40 for a composite substrate thickness of 0.25 in. A second approach to achieve lightweight antenna structures is to support the radiating elements on dielectric spacers between the ground plane and the radiating element. If these spacers are placed at regions within the antenna where the electric field is small, the change in operating parameters from an air dielectric antenna will be small and can easily be computed using perturbation theory [5].

III. ANALYSIS TECHNIQUES FOR MICROSTRIP ELEMENTS

Transmission-Line Models

The simplest analytical description of a rectangular microstrip patch utilizes transmission-line theory and models the patch as two parallel radiating slots [6]. Each radiating edge of length a is modeled as a narrow slot radiating into a half-space, with a slot admittance given by

$$G_1 + jB_1 = \frac{a}{z_0} [1 + j(1 - 0.636 \ln k_0 w)] \quad \dots 2$$

Where λ_0 is the free-space wavelength, $z_0 = \sqrt{\mu_0/\epsilon_0}$, $k_0 = 2\pi/\lambda_0$, and w is the slot width, approximately equal to the substrate thickness t . Since the slots are identical, an identical expression holds for the admittance of slot 2. Assuming no field variation along the direction parallel to the radiating edge, the characteristic admittance is given by

$$Y_0 = a / (t z_0) \quad \dots 3$$

Where t is the substrate thickness and ϵ_r is the relative dielectric constant. Since it is desired to excite the slots 180° out of phase, the dimension b is set equal to slightly less than $\lambda_d/2$, where $\lambda_d = \lambda_0 / \sqrt{\epsilon_r}$, i.e., $b = 0.48\lambda_d$ to $0.49\lambda_d$. This slight reduction in resonant length is necessary because of the fringing fields at the radiating edges. By properly choosing this length reduction factor q , the admittance of slot 2 after transformation becomes [7]

$$G_2 + jB_2 = G_1 - jB_1 \quad \dots 4$$

So that the total input admittance at resonance becomes

$$Y_{in} = (G_1 + jB_1) + (G_2 + jB_2) = 2G_1 \quad \dots 5$$

In a typical design, $a = \lambda_0/2$ so that $G_1 = 0.00417$ mhos,

$$R_{in} = (1/2G_1) = 120 \quad \dots 6$$

The resonant frequency is found from

$$f_r = c / \lambda_d = qc/2b \quad \dots 7$$

The advantage of this model lies in its simplicity, i.e., the resonant frequency and input resistance are given by the simple formulas (6) and (7). The fringe factor q determines the accuracy of the resonant frequency and in practice is determined by measuring f_r for a rectangular patch on a given substrate. It is then assumed that the same q value holds for patches of other sizes on this same substrate and in the same general frequency range.

Modal-Expansion Cavity Models

Although the preceding transmission-line model is easy to use, it suffers from numerous disadvantages. It is only useful for patches of rectangular shape, the fringe factor q must be empirically determined, it ignores field variations along the radiating edge, it is not adaptable to inclusion of the feed, etc. These disadvantages are eliminated in the modal expansion analysis technique whereby the patch is viewed as a thin TM_z -mode cavity with magnetic walls [8],[9],[10]-[16].

This results in a much more accurate formulation for the input impedance, resonant frequency, etc, for both rectangular and circular patches at only a modest increase in mathematical complexity.

IV. DESIGN PROCEDURES FOR MICROSTRIP ANTENNAS

This section presents design procedures for rectangular and circular microstrip patch antennas. For patches of simple rectangular or circular shape, the theoretical models presented earlier are used to generate design curves.

Rectangular Microstrip Antennas

The design of a rectangular microstrip antenna begins by recognizing that the desired TM_{10} mode is excited by making the patch dimension b slightly less than one-half wavelength in the substrate, $\lambda_d = \lambda_0/\sqrt{\epsilon_r}$ thus causing the two parallel radiating edges of length a to behave effectively as a two element broadside array. The length a is chosen to be approximately $\lambda_0/2$ in a typical design. If there were no fringing, the resonant frequency would be given by $f_{r0} = c/(2b/\epsilon_r)$. However, in practice, the fringing capacitance effect associated with the radiating edges causes the effective distance between the radiating edges to be slightly greater than b , so that the actual resonant frequency is slightly less than f_{r0} by a factor q as discussed earlier.

Circular Microstrip Antennas

A circular microstrip patch of radius a and with a nonradiating zero- admittance wall has a dominant RF mode whose resonant frequency is given by $f_{r0} = ck_{10}' / (2\pi a \sqrt{\epsilon_r})$, where $k_{10}' = 1.84118$ [11]. In this case

the resonant wavelength in the dielectric is therefore $\lambda_{d0} = 3.413a$. The real resonant frequency f_r is therefore less than f_0 .

Performance Parameter:

The usual goal of an antenna design is to produce an antenna system which has high efficiency and large bandwidth. However, these parameters are interrelated and one does not have complete freedom to independently set these parameters. The stored energy in the cavity region, including that energy stored in the fringing fields around the structure, may be calculated and then compared with the various losses to compute the Q factor associated with each. The steps required to perform these loss calculations were outlined previously. There are four loss mechanisms to be considered, namely, radiation, the loss associated with surface wave propagation on a dielectric coated conductor, the loss due to heating in the conducting elements and the ground plane, and the loss due to heating within the dielectric medium. The total Q of the antenna is given by

$$1/Q = 1/Q_{rad} + 1/Q_{sw} + 1/Q_{di} + 1/Q_{cu} \quad \dots 8$$

The term involving Q_{sw} associated with the surface wave is negligible for thin substrates. For thicker substrates, techniques are available to estimate the surface wave contribution [17],[14]. The Q factors may then be calculated assuming that energy stored in the fringing fields is negligible, and the field distribution within the cavity region does not depend on thickness. Formulas for the Q factors due to conductor loss and dielectric loss for circular microstrip antennas have been obtained [18], [19]. It can be shown that these relationships apply in general to thin microstrip antennas of arbitrary shape, i.e.,

$$Q_{di} = 1/\tan \delta \quad \dots 9$$

$$Q_{cu} = t/d_s \quad \dots 10$$

Where $d_s = (\pi f \mu \delta)^{-1/2}$ is the skin depth associated with the conductor. Providing that the field distribution along the radiating aperture or within the cavity region of the antenna does not change as the thickness is varied, it can be shown that the radiation quality factor Q_{rad} has the following form:

$$Q_{rad} = (2w \sigma / tG/l) \quad \dots 11$$

Where G/l is the conductance per unit length of the radiating aperture.

Bandwidth as referred to microstrip antennas may take one of several meanings. The usual definition of the bandwidth, $\Delta f = Q/f_0$ is not extremely useful by itself. There is usually an impedance matching network between the antenna radiating element and its input port which must be considered.

A more meaningful measure of bandwidth is that band of frequencies where the input VSWR is less than a specified value, usually 2:1, assuming that a unity VSWR is obtained at the design frequency. The bandwidth may then be expressed in terms of Q and maximum allowable VSWR as follows [20]

$$BW = [VSWR - 1] / Q \sqrt{VSWR} \quad \dots 12$$

The antenna efficiency (power radiated/power input) may be calculated.

$$\eta = Q / Q_{rad} \quad \dots 13$$

Antenna engineers usually express this as the antenna loss, i.e., $10 \log (1/\eta)$, in decibels. Since the copper loss increases with increasing frequency, there is more loss for an X-band patch than for an L-band patch of the same electrical size.

V. CONCLUSION

This paper has provided a comprehensive review of the state of microstrip antenna element technology as it exists in 1981. Most practical microstrip antenna designs use either the rectangular or circular patch, although other configurations such as the open-circuit microstrip radiator or the microstrip dipole are being used with increasing success. Design procedures and graphical presentations of typical microstrip patch performance data have been discussed, with emphasis on the rectangular and circular patches. The microstrip antenna has typical bandwidths from one to six percent, although greater bandwidths may be achieved by using increased substrate thickness or larger patch sizes. Exclusive of the problems in microstrip arrays, there is a critical need for attention to the development of key improvements in the microstrip element itself. The first and most pressing of these is the need for better substrate dielectric constant tolerance control, as discussed. The second is the need for more detailed attention to rigorous solutions for the radiating wall admittance for various microstrip antenna geometries, including electrically thicker substrates, since this is crucial to improving design procedures and formulas. The third requirement is for the development of a larger class of layered microstrip element configurations which can be used for the design of multi frequency elements. Related to this is the need for more design approaches which can produce greater bandwidth. Finally, but certainly not the least of these, is the need for greatly expanded efforts in the development of monolithically integrated microstrip elements and associated active components.

REFERENCES

[1] *Reference Data for Radio Engineers*, 5th ed. Indianapolis, IN: Howard W. Sams, Oct. 1968, ch. 22, pp. 25-27.

- [2] T. E. Nowicki, "Microwave substrates, present and future," in *Proc. Workshop Printed Circuit Antenna Tech.*, New Mexico State Univ., Las Cruces, Oct. 1979, pp. 26/1-22.
- [3] L. R. Murphy, "SEASAT and SIR-A microstrip antennas," in *Proc. Workshop Printed Circuit Antenna Tech.*, New Mexico State Univ., Las Cruces, Oct. 1979, pp. 18/1-20.
- [4] K. R. Carver, "Description of a composite hexcell microstrip antenna," private communication to J. W. Mink, Dec. 1979
- [5] R. F. Harrington, *Time-Harmonic Electromagnetic Waves*. New York: McGraw-Hill, 1961.
- [6] R. E. Munson, "Conformal microstrip antennas and microstrip phased arrays," *ZEEE Trans. Antennas Propagat.*, vol. AP-22, no. 1, pp. 74-77, Jan. 1974.
- [7] A. G. Derneryd, "A theoretical investigation of the rectangular microstrip antenna," *IEEE Trans. Antennas Propagat.*, vol. AP-26, no. 4, pp. 532-535, July 1978.
- [8] Y. T. Lo, D. D. Harrison, D. Solomon, G. A. Deschamps, and F.R. Ore, "Study of microstrip antennas, microstrip phased arrays, and microstrip feed networks," Rome Air Development Center, Tech. Rep. TR-77-406, Oct. 21, 1977.
- [9] K. R. Carver and E. L. Coffey, "Theoretical investigation of the microstrip antenna," Physic. and Sci. Lab., New Mexico State Univ., Las Cruces, Tech. Rep. PT-00929, Jan. 23, 1979.
- [10] K. R. Carver, "A modal expansion theory for the microstrip antenna," in *Dig. Znt. Symp. Antennas Propagat. Soc.*, Seattle, WA, June 1979, pp. 101-104.
- [11] K. R. Carver, "Practical analytical techniques for the microstrip antenna," in *Proc. Workshop Printed CircuAitn renna Tech.*, New Mexico State Univ., Las Cruces, Oct. 1979, pp. 7/1-20.
- [12] Y.T. LO, D. Solomon, and W. F. Richards, "Theory and experiment on microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-27, no. 2, pp. 137-145, Mar. 1979.
- [13] W. F. Richards and Y. T. Lo, "An improved theory for microstrip antennas and applications," in *Dig. Int. Symp. Antennas Propagat. Soc.*, Seattle, WA, June 1979, pp. 113-116.
- [14] W. F. Richards, Y. T. Lo, P. Simon, and D. D. Harrison, "Theory and applications for microstrip antennas," in *Proc. Workshop Printed Circuit Antenna Tech.*, New Mexico State Univ., Las Cruces, Oct. 1979, pp. 8/1-23.
- [15] A. R. Van de Capelle, "Theoretical investigations of microstrip antennas," in *Proc. Workshop Printed Circuit Antenna Tech.*, New Mexico State Univ., Las Cruces, Oct. 1979, pp. 11/1-8.
- [16] E. Van Lil, R. Van Loock, and A. Van de Capelle, "Design models for rectangular microstrip resonator antennas," in *Dig. Int. Symp. Antennas Propagat. Soc.*, College Park, MD, May 1978, pp. 264-267.
- [17] R. J. Collier and P. D. White, "Surface waves in microstrip circuits," in *Proc. 6th European Micro. Conf.*, 1976, pp. 632-636.
- [18] A. G. Derneryd and A. G. Lind, "Extended analysis of rectangular microstrip resonator antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-27, no. 6, pp. 846-849, Nov. 1979.
- [19] E. Belohoubek and E. Denlinger. "Loss considerations for microstrip resonators," *IEEE Trans. Microwave Theory Technol.*, vol. MTT-23, pp. 522-526, June 1975
- [20] A. G. Derneryd, "The circular microstrip antenna element," in *Proc. Int'l. Conf. Antennas Propagation (IEE)*, Part 1. Nov. 1978. pp. 307-310.