# Comparison of CAD for Rectangular Microstrip Antennas

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**Abstract.** *Calculations of several cases for rectangular microstrip antennas using more accurate cavity model have been compared with the conventional cavity calculations, expressions generated by curve fitting to full wave solutions and published experimental values for a variety of different substrate thickness and patch sizes with width to length ratio of 1.5 and with* $\varepsilon_r = 10.8$ *and* $\varepsilon_r = 2.33$.

## Keywords

CAD formulas, rectangular microstrip antennas, microwave antennas.

## 1. Introduction

The widespread use of printed circuits led to the idea of constructing radiating elements using the same technology. During the past twenty years, microstrip patch antennas experienced a great gain in popularity and have become a major research topic in both theoretical and applied electromagnetic fields. They are well known for their highly desirable physical characteristics such as low profile, lightweight, low cost, ruggedness, and conformability. Numerous researchers have investigated their basic characteristics and extensive efforts have also been devoted to the design of "frequency agile", "polarization agile", or dual-band microstrip antennas.

Although patch antennas appear simple and are easy to fabricate, obtaining electromagnetic fields, which satisfy all the boundary conditions, is a complicated task. For this reason, simplified approaches such as the transmission line model and the cavity model have been developed. The cavity model is particularly popular [1] - [3]. The basic idea of the cavity model is to treat the region between the patch and ground plane as a resonant leaky cavity. The simplified approaches allow the analysis as well as the design of rectangular microstrip patch antennas but the accuracy of those formulas is rather low.

On the other hand, the more accurate full-wave analysis [3] cannot be used for design because it is very time consuming. Therefore, new simple computer-aided design formulas for the rectangular microstrip patch antennas have been developed (MSANCAD program [4]), which use the cavity model but the more accurate models for open-end effect of microstrip lines and the effective permittivity are used.

One of the common methods of feeding a microstrip antenna is by means of a coaxial probe. The basic configuration is shown in Fig. 1, where a single metallic rectangular patch is printed on a grounded substrate. The patch is of length $a$, width $b$ and substrate thickness $h$. The dielectric substrate has a relative permittivity $\varepsilon_r$. The feed-point coordinates of the coaxial probe are $x_0$ and $y_0$. The value of $y_0 = b/2$ is chosen. In this case, the linear polarization is radiated and the dominant mode is $TM_{10}$.

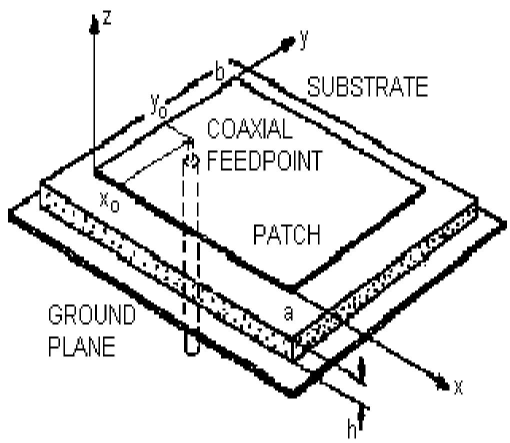


**Fig. 1.** Rectangular patch antenna fed by a coaxial probe.

## 2. Comparison of CAD Formulas and Experiments

The various rectangular patches have been calculated using MSANCAD program. The results have been compared with the conventional cavity calculations, expressions generated by curve fitting to full wave solutions and published experimental values. A variety of different substrate thickness and patch sizes with width to length ratio $b/a = 1.5$ and with $\varepsilon_r = 10.8$ (feed point with $x_0 = a/4$) and $\varepsilon_r = 2.33$ (feed point with $x_0 =$ 1.5 mm) as well as published comparisons [4] has been considered.

Some of the comparison results have been already published [4] for $\varepsilon_r$ = 2.2 and the relevant figures are not repeated here. Other results of the comparison are given in Fig. 2 to 7. The calculations using the above-described program MSANCAD are shown with the solid line. The conventional cavity method using program MSANT [5] and the program PATCHD [6] have been used for comparison.

The basis for the program PATCHD is a series of closed form expressions, which were generated by curve fitting to full wave solutions. As such the program PATCHD results include surface wave effects and are rigorous except for the fact that no feed model is included. However, there are limitations on some parameters: $0 \le \sqrt{(\varepsilon_r - 1)}\, h/\lambda_0 \le 0.2$, $1 \le \varepsilon_r \le 10$, and for rectangular patches $0.9 \le b/a \le 2$, and $0 \le h/a \le 0.2$.

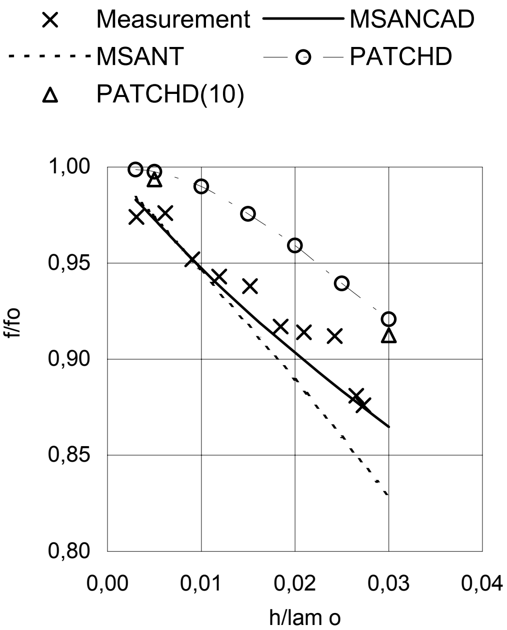


**Fig. 2.** Normalized resonance frequency versus the electrical thickness of the substrate.

The measurement results, which were obtained using a variety of different substrate thickness and patch sizes (with $b/a$ = 1.5), are shown with crosses. In Fig. 2 to 4, the measurements published in [3] with $\varepsilon_r$ = 10.8 and feed point with $x_0 = a/4$ are given. In Fig. 5 to 7, the measurements published in [7] with $\varepsilon_r$ = 2.33 and $x_0$ = 1.5 mm are given. Unfortunately, some parameters such as loss tangents are not given.

The normalized resonance frequency versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 2. We can see that the results are in agreement both with experimental and published calculation results using MSANCAD and MSANT. If the electrical thickness of the substrate of $h/\lambda_0$ is increased then the differences between MSANCAD and MSANT results are greater and MSANCAD calculations are better. The program PATCHD could not be used because $\varepsilon_r$ = 10.8 is out of limits. However, if PATCHD is used for $\varepsilon_r$ = 10.8, results are worse than MSANCAD and MSANT calculations and experiments. Even if the permissible value of $\varepsilon_r$ = 10 is used, the improvement is negligible (PATCHD10 for $\varepsilon_r$ = 10 versus PATCHD for $\varepsilon_r$ = 10.8 in Fig. 2).

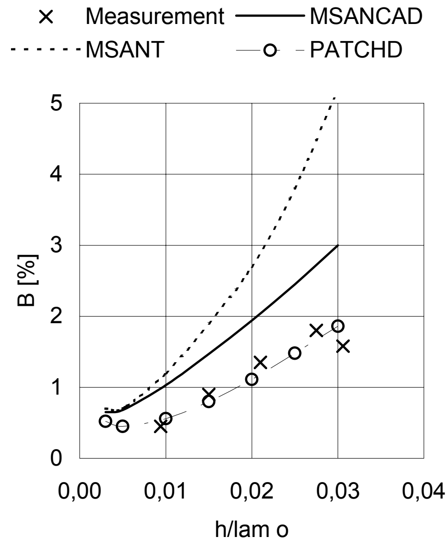


**Fig. 3.** The percentage bandwidth of a rectangular patch versus the electrical thickness of the substrate.

The percentage bandwidth of a rectangular patch versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 3. The value of $VSWR$ = 2 is considered for computation of impedance bandwidth. We can see that results of experiments and calculations are in agreement, if electrical thickness of the substrate $h/\lambda_0$ is low. If electrical thickness of the substrate $h/\lambda_0$ is increased, the differences between MSANCAD, MSANT and PATCHD and measurement results are greater. Even if the program PATCHD cannot be used due the above limitations, the results are better than the other calculations. However, the MSANCAD results are better than the MSANT results.

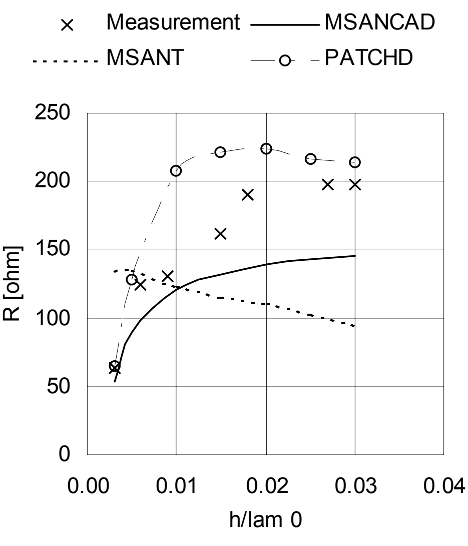


**Fig. 4.** The resonant input resistance of probe-fed rectangular patch versus the electrical thickness of the substrate.

The resonant input resistance of probe-fed rectangular patch versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 4. We can see that results of both experimental and published calculations are different.

If the electrical thickness of the substrate $h/\lambda_0$ is increased, the differences between MSANCAD, MSANT, PATCHD and measurement results are greater. However, the program PATCHD cannot be used due to the above limitations as $\varepsilon_r = 10.8$. The MSANCAD results are much better than the MSANT while measured results are spread between MSANCAD and PATCHD program results.

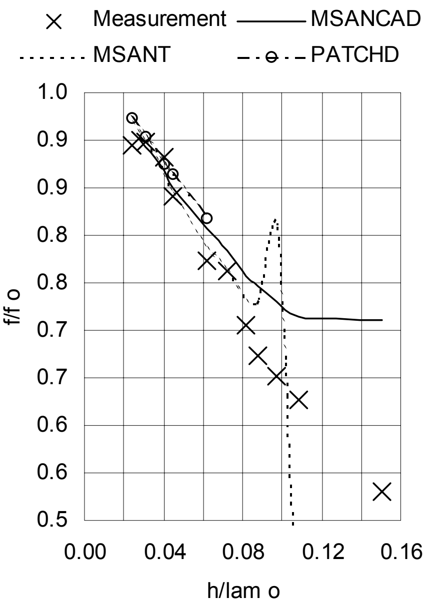


**Fig. 5** Normalized resonance frequency versus the electrical thickness of the substrate

The normalized resonance frequency $f/f_0$ versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 5. We can see that results are in agreement both with experimental and published calculation results, if the electrical thickness of the substrate $h/\lambda_0$ is less than approximately 0.08. If the electrical thickness of the substrate $h/\lambda_0$ is increased the differences between MSANCAD and MSANT results are greater and the program PATCHD cannot be used due to above given limitations. However, the range of utilization of MSANCAD is greater than PATCHD (due to above given limitations) and MSANT (see Fig. 5).

The percentage bandwidth of a rectangular patch versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 6. We can see that results of experiments and calculations are in agreement, if electrical thickness of the substrate $h/\lambda_0$ is low.

If the electrical thickness of the substrate $h/\lambda_0$ is high, the measurements and calculations of percentage bandwidths are different. If the electrical thickness of the substrate $h/\lambda_0$ is increased, the differences between MSANCAD, MSANT and PATCHD and measurement results are greater. The PATCHD program cannot be used for $h/\lambda_0$ greater than 0.06. However, the MSANCAD results are better than the MSANT results and the MSANCAD range of utilization is greater than PATCHD (due to above given limitations) and MSANT (see Fig. 6).

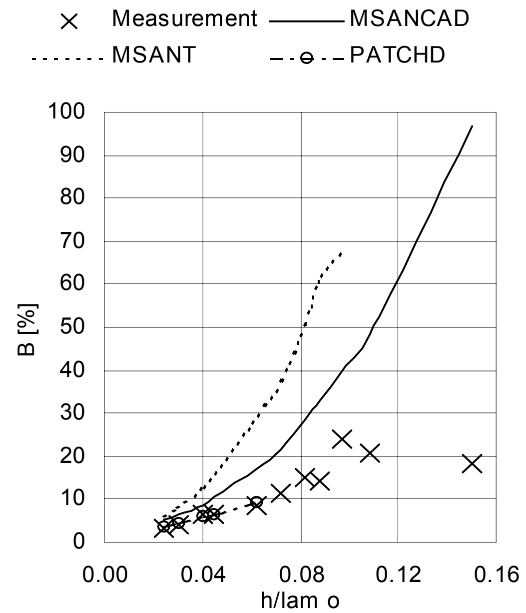


**Fig. 6.** The percentage bandwidth of a rectangular patch versus the electrical thickness of the substrate.

The resonant input resistance of probe-fed rectangular patch versus the electrical thickness of the substrate $h/\lambda_0$ is shown in Fig. 7. We can see that the results of published calculations are different. If electric thickness of the substrate $h/\lambda_0$ is increased, differences between MSANCAD, MSANT and PATCHD are greater. The MSANCAD range of utilization is greater than PATCHD (due to above given limitations) and MSANT (see Fig. 7). Unfortunately, the measured results are not available.

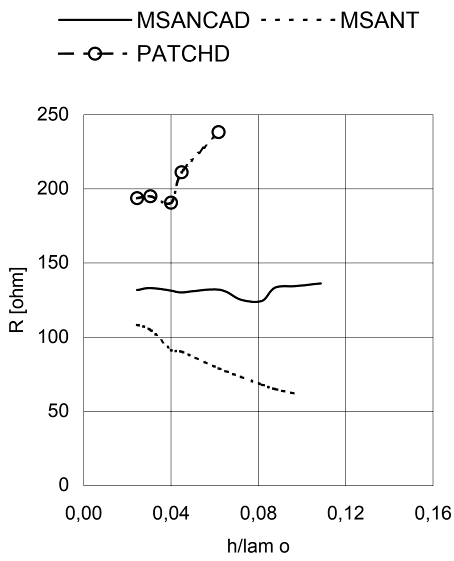


**Fig. 7.** The resonant input resistance of probe-fed rectangular patch versus the electrical thickness of the substrate.

# 3. Conclusions

Various simple CAD formulas for a rectangular patch antenna have been presented (see [1] to [4]). The method [4] uses the cavity model with the more accurate models for open-end effect of microstrip lines and the effective permittivity. That allows increasing the calculation resonant frequency accuracy. Moreover, the reliability of calculation considering the ratio *h*/*a* is higher than for the usual cavity model MSANT [5]. Because of the relative simplicity of the model [4], the analysis as well as the design of rectangular microstrip patch antennas can be performed.

The comparison using the program MSANCAD [4] with the conventional cavity method using program MSANT [5] and the program PATCHD [6] have been done. The measurement results, which were obtained by using a variety of different substrate thickness and patch sizes (with *b*/*a* = 1.5), are shown with crosses. In Fig. 2 to 4, the measurements published in [3] with $\varepsilon_r = 10.8$ are given. In Fig. 5 to 7, the measurements published in [7] with $\varepsilon_r = 2.33$ are given.

We can conclude that the calculations of normalized resonance, bandwidth and resonant input resistance are in agreement with experiments, when the electrical thickness of the substrate $h/\lambda_0$ is low. For higher values of $h/\lambda_0$, the experiments and calculations are different. The MSANCAD results are sometimes better than the PATCHD results especially for resonant frequency, when $\varepsilon_r = 10.8$ or $\varepsilon_r = 10$ are used (the upper limit of PATCHD is $\varepsilon_r = 10$), and for resonant input resistance for $\varepsilon_r = 10.8$ and $\varepsilon_r = 2.2$ (see [4]). The PATCHD results are always better for bandwidth calculations, even if $\varepsilon_r = 10.8$ (which is slightly greater than the upper limit $\varepsilon_r = 10$) is used. The MSANCAD range of utilization is greater than PATCHD (due to several limitations given above) and MSANT (for higher values of $h/\lambda_0$, the MSANT program results are quite unexpected such as negative resonant frequency or negative resonant input resistance). The MSANCAD results are always better than the MSANT results, which is demonstrated especially for resonant input resistance, when the input resistance calculated by MSANT decreases for the increasing electrical thickness of the substrate $h/\lambda_0$. However, we can see in Fig. 4 and 7 as well as in Fig. 4 of the paper [4] that the typical dependence for experimental results and the calculations using MSANCAD and PATCHED is increasing for the increasing electrical thickness of the substrate $h/\lambda_0$.

The comparison of CAD tools for the analysis of planar antennas is generally necessary to recognize the limitations and errors of these tools. It is clear that the comparison of three CAD tools with measurement is very useful. However, any comparison is limited and cannot be generally viewed as a proof of credibility of these methods. The full-wave analysis tools are very popular recently. The paper, which compares the full-wave analysis tools with the given CAD formulas, is under preparation.

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