# การทำนายหาความถี่เรโซแนนซ์ของสายอากาศแบบไมโครสตริปรูปวงกลม

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## บทคัดย่อ

ในบทความนี้ได้นำค่าพารามิเตอร์โดยประมาณของสายส่งแบบไมโครสตริปมาใช้สำหรับทำนายหาความถี่เรโซแนนซ์ของสายอากาศแบบไมโครสตริปรูปวงกลม ซึ่งวิธีที่นำเสนอนี้สามารถที่จะคำนวณได้อย่างรวดเร็วด้วยเครื่องคำนวณทั่วไป ผลลัพธ์ที่คำนวณได้จากวิธีดังกล่าวยังมีความถูกต้องใกล้เคียงกับผลทางการวัดด้วย

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# Predicting the Resonant Frequency of Circular Microstrip Disk Antennas

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## Abstract

Approximate parameters of microstrip line are used to predict the resonant frequency of circular microstrip disk antennas. The present technique is computationally fast and efficient even on a desk calculator. The theoretical results are in good agreement with measured results.

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# Introduction

Several methods have been presented in the literature to calculate the resonant frequency of circular microstrip disk antenna by using the cavity model 11–71. However, these methods have complicated by the existence of fringing fields at edge of the disk, which the accuracy of the resonant frequency depends on the fringing capacitance. In this paper, an attempt has been made resolve the issues noted by carrying out a technique of the calculating the resonant frequency of circular microstrip disk antenna using the approximate parameters of a microstrip line. In theoretical section, the theoretical formulas of resonant frequency, effective permittivity, and effective radius are presented. Comparison with measurements is given in calculated and measured results section.

# Theory

The structure of a circular microstrip disk antenna is shown in Fig. **1.**

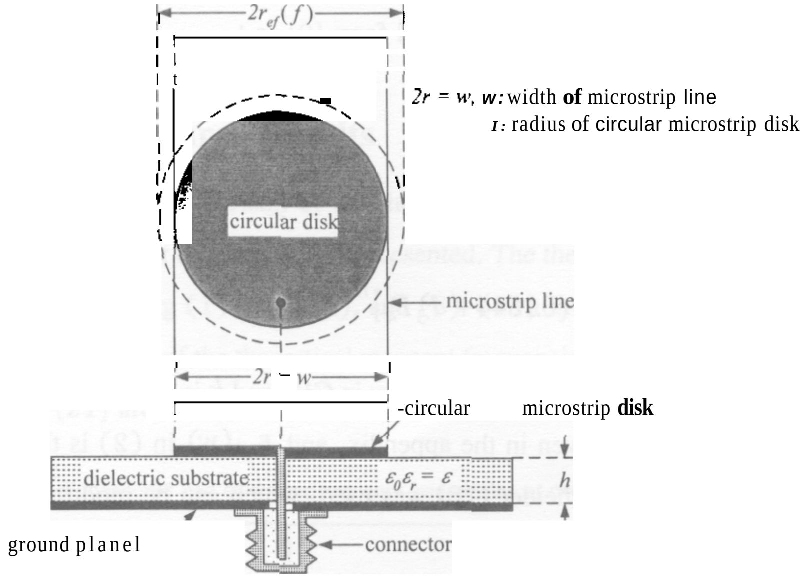


**Fig. 1** Structure of a circular microstrip **disk** antenna

The theory of the structure is obtained in three sections. Simple formula for the resonant frequency is obtained in the section A, and then the effective permittivity and the effective radius are obtained in the section B and C, respectively.

## A. Resonant Frequency

An analytic formula for the resonant frequency of **a** circular microstrip disk antenna can be obtained from Wolff [2], which is given the lowest resonant frequency in the simple formula as follows :

$$f_{11} = \frac{8.78745}{r_{ef}(f)\sqrt{\varepsilon_{ef}(f)}} \quad (1)$$

where $f_{11}$ is the resonant frequency of the dominant (fundamental) mode of a circular microstrip disk antenna in GHz

$r_{ef}(f)$ is the effective radius of circular disk with physical radius $r$ in cm.

$\varepsilon_{ef}(f)$ is the effective permittivity of dielectric substrate with relative permittivity $\varepsilon_r$

## B. Effective Permittivity

Several dispersion models for effective permittivity had been reported [8-16]. However, the results over a broad range tabulated in [17] were found that Kirschning and Jansen [9] and Kobayashi [10] models are the most consistently accurate results. In this paper, accuracy of the resonant frequency of the circular microstrip disk antenna can be fitted with experimental data by using the effective permittivity $\varepsilon_{ef}(f)$ in general form [9] as :

$$\varepsilon_{ef}(f) = \varepsilon_r - \frac{\varepsilon_r - \varepsilon_{ef}(w)}{1 + P(f)} \quad (2)$$

where

$$P(f) = P_1 P_2 \left[ f_0 h (0.1844 + P_3 P_4 \right]^{1.5763} \quad (3)$$

with $f_0 = 7.5/r\sqrt{\varepsilon_r}$, denoting the frequency in GHz and $h$ is the substrate thickness in cm. $P_1$, $P_2$, $P_3$, and $P_4$ in (3) are given in the appendix, and $\varepsilon_{ef}(w)$ in (2) is the zero frequency effective permittivity given by Schneider [18] was used, which can be modified for the circular microstrip disk as :

$$\varepsilon_{ef}(w) = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left(1 + \frac{6h}{r}\right)^{-0.555} \quad (4)$$

## C. Effective Radius

The characteristic impedance $Z_0(f)$ of microstrip line can be determined from the parallel-plate model [19]:

$$Z_0(f) = \frac{120\pi h}{2r_{ef}(f)\sqrt{\varepsilon_{ef}(f)}} \quad (5)$$

where $2r_{ef}(f) = w_{ef}(f)$ is the effective width of microstrip line.

In (5), we can determine the effective radius of the circular microstrip disk antenna as :

$$r_{ef}(f) = \frac{60\pi h}{Z_0(f)\sqrt{\varepsilon_{ef}(f)}} \quad (6)$$

To get more accurate calculated $f_{11}$, the characteristic impedance $Z_0(f)$ in (6) have adopted from James et al's formula *[20].* Substituting $Z_0(f)$ [20] in to (6), one obtains the simple and accurate expression for the effective radius $r_{ef}(f)$ as follows :

$$r_{ef}(f) = r + 0.441h + 0.082h\left[\frac{\varepsilon_{ef}(f)-1}{\varepsilon_{ef}^2(f)}\right] + h\left[\frac{\varepsilon_{ef}(f)+1}{2\pi\varepsilon_{ef}(f)}\right]\left[1.452 + \ln\left(\frac{r}{h}+0.94\right)\right] \quad (7)$$

where $r_{ef}(f)$ is the effective radius in cm with the physical radius *r* in cm. This expression can readily be handled by using a pocket calculator. **It** can also he incorporate in fairly extensive **CAD** routines which involve frequency - dependent expression for effective microstrip permittivity $\varepsilon_{ef}(f)$ (section **B).**

## Calculated and Measured Results

In this section, a comparison of the theoretical resonant frequencies of the fundamental mode with the measurement of Howell **[3] is** presented. The theoretical resonant frequencies which have been obtained by using **(1)-(4), (7),** and (8)-(11) in the appendix are shown in Table **I.** In Table **I,** the comparisons of the theoretical resonant frequencies among previous calculated results [2], **[3],** [6] and **[2l]** are shown.

**Table I Comparirons of measured and calculated resonant frequencies** of **circular microstrip disk antennas**

| **Dimensions & Parameters** | | | | **Resonant Frequencies (GHz)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| r **(cm)** | h (cm) | $\varepsilon_r$ – | $h/\lambda_d$ – | Measured [3] | Howell [3] | **Wolff & Knoppik** [2] | **Demeryd** [6] | **umprasert &Kiranon** 121] | **Present** Method |
| 3.493 | 0.1588 | 2.50 | 0.013 | 1.570 | 1.580 | 1.569 | 1.537 | 1.555 | 1.575 |
| 1.270 | 0.0794 | 2.59 | 0.018 | 4.070 | 4.290 | 4.267 | 4.159 | 4.175 | 4.074 |
| 3.493 | 0.3175 | 2.50 | 0.025 | 1.510 | 1.580 | 1.526 | 1.478 | 1.522 | 1.509 |
| 13.894 | 1.2700 | 2.70 | 0.026 | 0.378 | 0.387 | 0.362 | 0.350 | 0.370 | 0.374 |
| 4.950 | 0.2350 | 4.55 | 0.014 | 0.825 | 0.833 | 0.836 | 0.814 | 0.827 | 0.823 |
| 3.975 | 0.2350 | 4.55 | 0.017 | 1.030 | 1.037 | 1.042 | 1.009 | 1.027 | 1.028 |
| 2.990 | 0.2350 | 4.55 | 0.023 | 1.360 | 1.379 | 1.384 | 1.332 | 1.358 | 1.359 |
| 2.000 | 0.2350 | 4.55 | 0.034 | 2.003 | 2.061 | 2.067 | 1.965 | 2.009 | 2.004 |
| 1.040 | 0.2350 | 4.55 | 0.063 | 3.750 | 3.963 | 3.950 | 3.661 | 3.744 | 3.756 |
| 0.770 | 0.2350 | 4.55 | 0.083 | 4.945 | 5.353 | 5.308 | 4.848 | 4.938 | 4.948 |

## Conclusion

In conclusion, the results of the theoretical resonant frequency of the circular microstrip disk antenna based on the approximate parameters of the microstrip line have been presented. The technique has been successfully applied to the circular microstrip disk antenna. We have also applied this technique to the triangular and elliptical patches. Results on these and other patches will be reported soon. Thus, this technique is a useful tool and well suited for the microwave computer aided design (MCAD) on patch antennas and resonators.

## Appendix

### Effective Permittivity for Resonant Frequency

The following expressions for the effective permittivity of Kirschning and Jansen [9], originally derived for microstrip lines, are necessary to accommodate resonant frequency of circular microstrip disk antenna.

$$P_1 = 0.27488 + \frac{20r}{h}\left[0.6315 + 0.525/(1+0.0157 f_0 h)^{20}\right] - 0.065683 e^{-\frac{175.03r}{h}} \quad (8)$$

$$P_2 = 0.33622\left(1 - e^{-0.03442\varepsilon_r}\right) \quad (9)$$

$$P_3 = 0.0363 e^{-\left(\frac{92r}{h}\right)}\left[1 - e^{-\left(\frac{f_0 h}{38.7}\right)^{4.97}}\right] \quad (10)$$

$$P_4 = 1 + 2.751\left[1 - e^{-\left(\frac{\varepsilon_r}{15.916}\right)^{8}}\right] \quad (11)$$

Here $h$ and $r$ are in centimeters, and $f_0$ is in gigahertz.

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## References


1. Itoh, T. and Mittra, R., 1973, "A new method for calculating the capacitance of a circular disk for microwave integrated circuits," *IEEE* Trans. Microwave *Theory* Tech., pp. 431 - 432.
2. Wolff, I. and Knoppik, N., 1974, "Rectangular and circular microstrip disk capacitors and resonators," *IEEE* Trans. Microwave Theory Tech., Vol. MTT-22, No. 10, pp. 857-864.
3. Howell, J. Q., 1975, "Microstrip antenna," *IEEE* Trans. Antennas Propagat., pp. 90-93.
4. Borkar, S. R. and Yang, R. **F.** H., 1975, "Capacitance of a circular disk for applications in microwave integrated circuits," *IEEE* Trans. Microwave Theory Tech., **pp.** 588-591.
5. Shen, **L.** C., Long, **S.** A,, Allerding, M. R., and Walton, M. D., 1977, "Resonant frequency of a circular disc, printed-circuit antenna," *IEEE* Trans. Antennas Propagat., pp. 595-596.
6. Derneryd, A. G., 1978, "Microstrip disc antenna covers multiple frequencies," Microwave *J.*,pp. 77 - 79.
7. Chew, **W.** C. and Kong, J. A., 1980, "Effects of fringing fields on the capacitance of circular microstrip disk," *IEEE* Trans. Microwave Theory Tech., Vol. MTT-28, **pp.** 98-104.
8. Edwards, T. C. and Owens, R. P., 1976, "2-18 **GHz** dispersion measurements on 10-100 Ω microstrip lines on sapphire," *IEEE* Trans. Microwave Theory Tech., VoI. MTT-24, pp. 506 - 513.
9. Kirschning, M. and Jansen, R. H., 1982, "Accurate model for effective dielectric constant with validity up to millimeter-wave frequencies," Electron Lett., Vol. 18, **pp.** 272 - 273.
10. Kobayashi, M., 1988, **"A** dispersion formula satisfying recent requirements in microstrip CAD." *IEEE* Trans. Microwave Theory Tech., Vol. 36, pp. 1246-1250.
11. Yamashita, E., Atsuki, K., and Ueda, T., 1979, "An accurate dispersion formula of microstrip lines for computer-aided design of microwave integrated circuits," *IEEE* Trans. Microwave Theory Tech., Vol. MTT-27, pp. 1036-1038.

12. Hammerstad, E. and Jensen, O., 1980, "Accurate models for microstrip computer aided design." *IEEE MTT-S* Int. Microwave Symp. Dig., Washington, **pp.** 407-409.

13. Pramanick, P. and Bhartia, P., 1983, "An accurate description of dispersion in microstrip," Microwave *J.*, pp. 89–92.

14. Getsinter, **W.** J., 1973, "Microstrip dispersion model," *IEEE* Trans. Microwave Theory Tech., Vol. MTT–21, pp. 34–39.

15. Carlin, H. **J.**, 1973, **"A** simplified circuit model for microstrip," *EEE Trans.* Microwave Theory Tech., Vol. MTT–21, **pp.** 589–591.

16. Schneider, M. V., 1972, "Microstrip dispersion," Proc. *IEEE*, Vol. *60*, pp. 144-146.

17. York, **R.** A. and Compton, R. C., 1990, "Experimental evaluation of existing CAD models for microstrip dispersion," *IEEE* Trans. Microwave Theory Tech., Vol. MTT-38, NO. 3, pp. 327-328.

18. Schneider, M. V., 1969, "Microstrip lines for microwave integrated circuits," Bell Syst. Tech. *J.*, Vol. 48, pp. 1422-1444.

19. Owens, R. P., 1976, "Predicted frequency dependence of microstrip characteristic impedance using the planar–waveguide model," Electron. Lett., pp. 269–270.

20. James, J. **R.,** Henderson, A. and Hall, P. S., 1982, "Microstrip antenna performance is determined by substrate constraints," Microwave System News, **pp.** 73–84.

21. Kumprasert, N. and Kiranon, W., 1995, "Simple and accurate formula for the resonant frequency of the circular microstrip disk antenna," *IEEE* Trans. Antennas Propagat., Vol. AP–43, No. 11, pp. 1331-1333.