Progress In Electromagnetics Research, PIER 47, 75–85, 2004

COMPACT AND BROADBAND MICROSTRIP PATCH ANTENNA FOR THE 3G IMT-2000 HANDSETS APPLYING STYROFOAM AND SHORTING-POSTS

Y. J. Wang and C. K. Lee

School of Electrical & Electronic Engineering
Nanyang Technological University
Nanyang Avenue, Singapore 639798

Abstract—The objective of the paper is to develop a compact and broadband microstrip patch antenna for the IMT-2000 mobile handset application. By parasitically coupling two shorted semi-disc patches with a single shorting-post each and employing Styrofoam substrate with low dielectric constant, an overall impedance bandwidth of 17.8% has been achieved to cover the frequency spectra of 1.862–2.225 GHz. The overall dimension of this proposed antenna is 44.4 mm (length) × 37.8 mm (width) × 7 mm (thickness), and it would be suitable for the IMT-2000 mobile handset application. The typical antenna characteristics are presented and analysed theoretically and experimentally.

1. INTRODUCTION

Size miniaturization and broadband operation of microstrip patch antenna (MPA) [1–6] are increasingly essential in many practical applications, such as mobile cellular handsets, cordless phones, direct broadcast satellites (DBS), wireless local area networks (WLAN), global position satellites (GPS) and other next-generation wireless terminals.

The broad bandwidth of the MPA may be realized by the use of substrates with low dielectric constant and high thickness [3–8]. If substrate thickness is increased too much in an attempt to improve the bandwidth, spurious feed radiation and surface wave power will unfavorably be increased. Hence, a compromise between the dielectric constant, substrate thickness, and antenna bandwidth is to be considered.

The antenna physical sizes are an important factor in the design process [9] owing to the miniaturization of the modern mobile terminals. Any technique to miniaturize the sizes of the MPA has received much attention [10–15]. Electrical requirements for these mobile antennas are sufficient bandwidth, high efficiency, impedance matching, omni-directional radiation patterns, and minimum degradation by the presence of near objects, etc. In general, the size miniaturization of the normal MPA has been accomplished by loading [6, 19–21], which can take various forms, namely,

1) Use of high dielectric constant substrates or superstrata;
2) Modification of the basic patch shapes;
3) Use of short circuits, shorting-pins or shorting-posts; and
4) A combination of the above techniques.

Employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation. Modification of the basic patch shapes allows substantial size reduction; however, some of these shapes will cause the inefficient use of the available areas. In contrast, shorting-posts, which were regarded as a more efficient technique, were used in different arrangements to reduce the overall dimensions of the MPA. The detailed parameter study in [11–13] has disclosed the effects of substrate thickness, dielectric constant, cover layer, and sizes of feed and shorting-posts. Also in [15], the shorting-posts were modeled and analyzed as short pieces of transmission lines with series inductance and shunt capacitance.

On the other hand, the recent boom of the mobile cellular and cordless communications systems has created an ever-growing demand for low cost, small size, simple fabrication, easy integration, and high reliability antennas, as well as for multisystem (multiband) antennas that can operate at different bands or cover a wide frequency spectrum. The International Telecommunications Union (ITU) has been in the process of developing family-standards for the third generation (3G) global mobile system [16]: the International Mobile

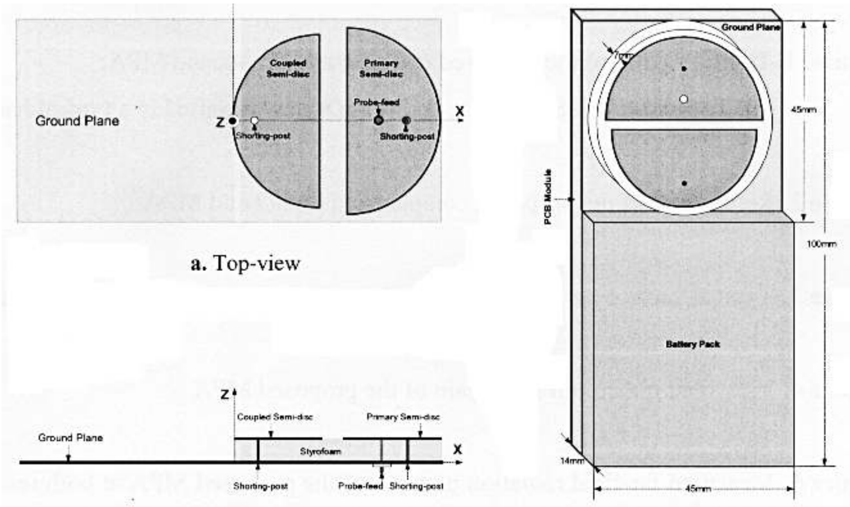
Telecommunications-2000 (IMT-2000) mobile communications system. The ITU at the 1992 World Administrative Radio-communications Conference (WARC 92) identified 230 MHz of frequency spectra that should be used as a world-wide basis by administrations wishing to implement the IMT-2000 systems [17]: The frequency spectra of 1.885–2.025 GHz and 2.110–2.200 GHz are to be used for both time division duplexing (TDD) and frequency division duplexing (FDD). It will be generally suitable for the IMT-2000 mobile antennas to satisfy the bandwidth in the frequency range of 1.885–2.200 GHz to fully cover both the up-link, 1.885–2.025 GHz and down-link, 2.110–2.200 GHz. This implies that about 15.4% impedance bandwidth (Return Loss ≤ -10 dB) is needed, if a single antenna is employed for both transmitting and receiving functions.

In this paper, to achieve a compact and broadband MPA for the IMT-2000 mobile handsets, both low dielectric constant substrate (Styrofoam) and two cylindrical shorting-posts are introduced to two parasitically-coupled semi-disc patches. More critical parameters and antenna performance will be discussed, as compared to those presented in [22]. This proposed dual-semi-disc MPA with a single probe-feed and a maximum dimension of 44.4 mm (length) $\times$ 37.8 mm (width) $\times$ 7 mm (thickness) exhibits an overall impedance bandwidth (Return Loss ≤ -10 dB or Voltage Standing Wave Ratio, VSWR $\leq 2:1$) of 17.8% from 1.862 GHz to 2.225 GHz. It fulfils the complete impedance bandwidth requirements for the IMT-2000 mobile handsets, whose frequency spectra are from 1.885 GHz to 2.200 GHz. Typical characteristics of the input impedance, input gain, surface currents and far-field radiation patterns of the proposed MPA are presented and analysed.

2. ANTENNA DESIGN

To theoretically predict the electrical performance of the compact and broadband MPA presented in this paper, a full-wave numerical method of moment (MoM) with potential integral equations was used. The solution was performed in the frequency-domain based on the exact Green's functions. In this design, a commercial software package, Ansoft Ensemble (Version 7.0.1) [18] was applied to simulate the typical characteristics of the proposed antenna.

The proposed dual-semi-disc MPA is presented in Figure 1, where its top-view, side-view and 3D (three-dimension)-view installed in a typical mobile handset are included. The antenna principally consists of a driven (primary) semi-disc patch of radius, R_1 with a single shorting-post, a coupled (secondary) semi-disc patch of smaller



b. Side-view **c.** 3D-view

Figure 1. Configuration of the proposed compact and broadband MPA: (a) Top-view, (b) Side-view, and (c) 3D-view installed in a typical handset.

radius, R_2 with a shorting-post, a single-layer Styrofoam substrate of thickness, t, and a probe-feed in the larger semi-disc patch. The two semi-disc patches are made of copper with the thickness of 0.1 mm and are parasitically coupled along their parallel diameter edges and are co-planarly (X-Y plane) located above the Styrofoam (expandable polystyrene) substrate with a relative (dielectric) permittivity of $\varepsilon_r = 1.03$.

The shorting-post of each semi-disc patch is located on its centreline (X-axis), while the probe-feed point is placed in the larger patch and is located between both shorting-posts. The coupling-spacing between both diameter edges of the two semi-disc patches is in the order of the substrate thickness. Theoretically, to reduce the manufacturing cost whilst maintaining the similar electrical performance, the Styrofoam substrate could be replaced by an air-filled substrate with a relative permittivity of $\varepsilon_r \approx 1$. However, the disadvantage in the case of the air-filled substrate is that several non-conductive spacers would be required to support both patches and, hence, lessen the mechanical robustness of the antenna.

To satisfy the constrained volume of a typical mobile handset case, the physical dimension of the ground plane, made of copper with the thickness of 2 mm, is chosen to be 100 mm (length) $\times$ 45 mm (width).

This is to mimic a common shielding enclosure of the mobile handset with similar dimensions. The proposed antenna is conventionally positioned close to one end of the ground plane of a typical mobile handset.

The following mechanical parameters are optimized to realize the broadband operation suitable for the IMT-2000 mobile handsets: substrate thickness: $t = 6.9\,\text{mm}$; radii of the driven and secondary patches: $R_1 = 18.9\,\text{mm}$ and $R_2 = 18.2\,\text{mm}$; coupling-spacing: $\Delta = 7.3\,\text{mm}$; shorting-post location and radius of the driven semi-disc patch: $(x_{s1}, y_{s1}) = (36.5\,\text{mm}, 0)$ and $(r_{s1} = 0.7\,\text{mm})$; shorting-post location and radius of the secondary semi-disc patch: $(x_{s2}, y_{s2}) = (4.8\,\text{mm}, 0)$ and $(r_{s2} = 0.82\,\text{mm})$; probe-feed position: $(x_p, y_p) = (32.1\,\text{mm}, 0)$.

3. RESULTS AND ANALYSES

In the design of this probe-fed dual-semi-disc MPA incorporating two shorting-posts, there are a total of nine degrees of freedom for the antenna parameters with respect to the resonant frequencies and input impedance variations: the antenna thickness, the radii of both semi-disc patches, the positions and radii of both shorting-posts, the position and radius of the probe-feed. All the degrees of freedom should be optimized to achieve a broadband operation that covers the frequency spectra of IMT-2000 mobile systems with acceptable impedance matching. The simulation revealed that the resonant frequencies of the antenna were mainly determined by the antenna thickness and both semi-disc patch dimensions, while the impedance behavior was mostly controlled by the dimensions and positions of both the shorting-posts and probe-feed. Moreover, the simulation suggested that the coupling-spacing between both parallel diameter edges of the patches should be large enough, compared to the antenna thickness, to reduce the influence on the input impedance of interest.

The input impedance behaviour of the proposed MPA, both simulated and measured, is shown in Figure 2, where two different resonant frequencies of $f_1 = 1.887\,\text{GHz}$ and $f_2 = 2.109\,\text{GHz}$ are observed. The lower resonant frequency, $f_1 = 1.887\,\text{GHz}$ is roughly excited by the accumulative area of both semi-disc patches, and the higher resonant frequency, $f_2 = 2.109\,\text{GHz}$ is mainly activated by the smaller (secondary) semi-disc patch.

By optimising the aforementioned antenna parameters, the return losses between both resonant frequencies are favourably below $-10\,\text{dB}$. The overall impedance bandwidth (Return Loss $\leq -10\,\text{dB}$) is around 17.8% from 1.862 GHz to 2.225 GHz, which completely satisfies the frequency spectra of the IMT-2000 mobile systems of 1.885–2.200 GHz.

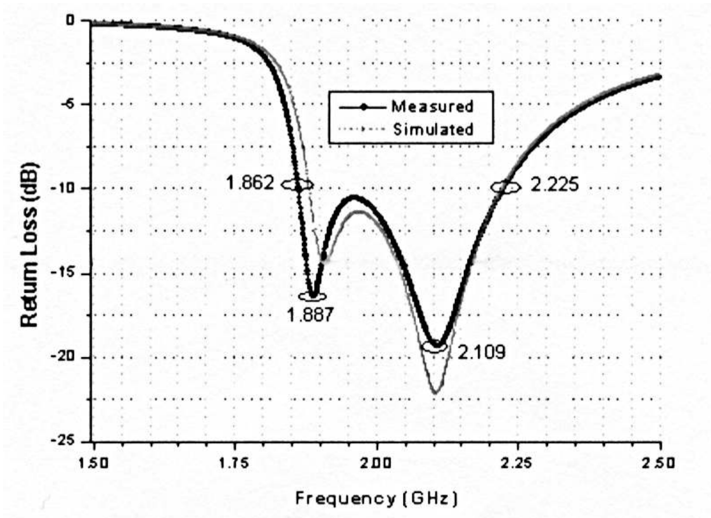


Figure 2. Return loss of the proposed compact and broadband MPA.

The measured input impedances agree well with the simulated results for both resonant frequencies. The maximum planar dimension and thickness of the antenna is less than $0.28\lambda_1$ and $0.05\lambda_1$ respectively, where λ_1 is the wavelength of the lower resonant frequency, $f_1 = 1.887\,\text{GHz}$.

The vector representation of the surface current flow for both semi-disc patches is given in Figure 3. As can be seen, the current flow will periodically start from the probe-feed to both shorting-posts over the semi-disc patches (in the X-Y plane) and then return back to the probe-feed. The broadside direction of the current flow is along the X-axis. It is also observed from this current flow configuration that the perimeters of both semi-disc patches act as the radiating edges for the antenna.

The measured maximum input gain of the proposed antenna within the frequency spectra of interest is presented in Figure 4. The peak antenna gain reaches about 5.2 dBi at frequencies in the vicinity of both resonant frequencies. The gain variations up to 2.6 dB are observed towards both ends of the frequency spectra of interest.

Figure 5 shows the measured far-field radiation pattern characteristics (normalised) of the proposed MPA in both the E-plane (X-Z plane) and H-plane (Y-Z plane) for the two resonant frequencies of $f_1 = 1.887\,\text{GHz}$ and $f_2 = 2.109\,\text{GHz}$. There is a relatively deep null in the H-plane of E pattern at broadside ($\theta = 0$) for both

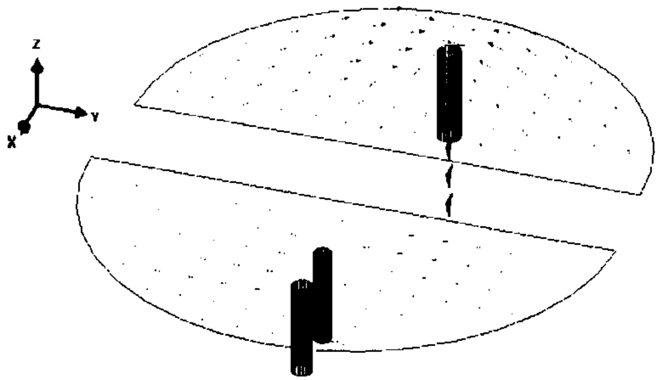


Figure 3. Typical surface current flow on both semi-disc patches (in the vector form).

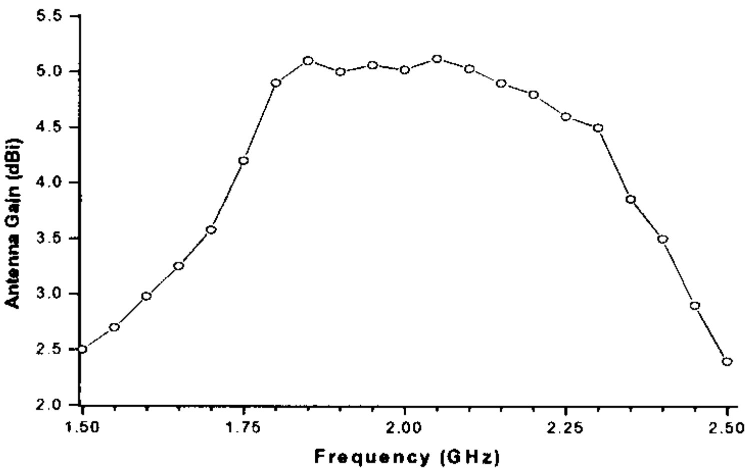
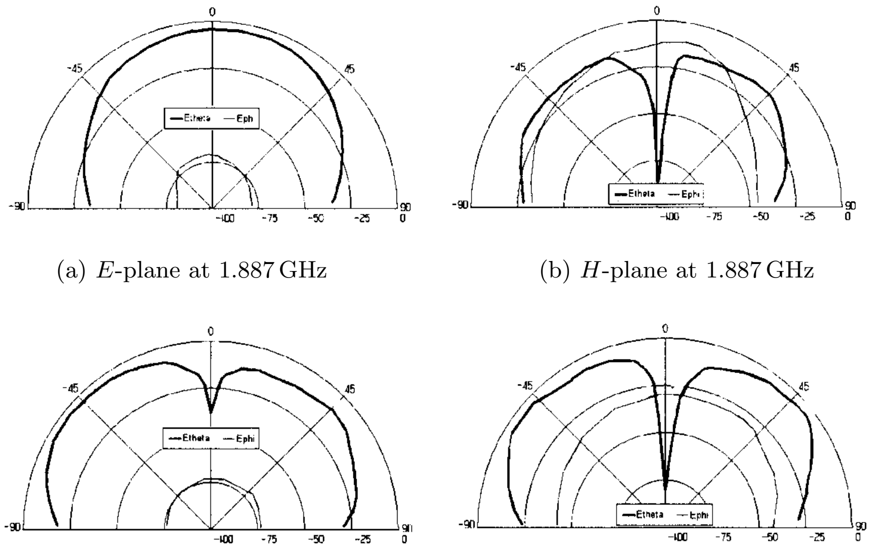


Figure 4. Measured maximum input gain of the proposed MPA.

resonant frequencies. This may be due to the unsymmetrical structure of the proposed MPA and the introduction of the shorting-posts in the structure. The E_ϕ patterns at both resonant frequencies are similar to omni-directional patterns. Although the antenna cross-polarisation in the H-plane of E_θ is relatively high, it will not be a major concern for the mobile handset application, since most of the electric fields will diffract off the edges of the small and limited handset ground plane. Furthermore, the normal mobile handsets will be encountered with



(a) E-plane at 1.887 GHz

(b) H-plane at 1.887 GHz

(c) E-plane at 2.109 GHz

(d) H-plane at 2.109 GHz

Figure 5. Measured far-field radiation patterns of the proposed MPA at both resonant frequencies in the E-plane (X-Y plane) and H-plane (Y-Z plane).

all kinds of possible polarisation due to the multi-path propagation mechanism related to the mobile cellular systems.

It should also be noted that the return losses within the frequency spectra of interest will become lower (i.e., better impedance matching) when the hand of the user is placed over the proposed antenna, while the resonant frequencies only shift slightly away from their original values. This may be due to the loading effect of the hand, which makes the impedance matching of the antenna even better. In this sense, the proposed antenna would be preferable to normal external antennas like dipole or helix. In addition, the radiating semi-disc patches are placed above the ground plane, which in some part will screen the radiation towards the head of the user. However, both resonant frequencies will decay significantly when the hand directly touches the patches. To mitigate such environment effects, a suitable plastic housing for the antenna is desirable for the practical application.

4. CONCLUSIONS

A compact and broadband microstrip patch antenna with a single probe-feed has been investigated. By incorporating low dielectric constant substrate and electromagnetically coupling two similar shorted semi-disc patches, an overall impedance bandwidth (Return Loss $\leq -10\,\mathrm{dB}$) of 17.8% has been realised within the frequency spectra from 1.862 GHz to 2.225 GHz, which fully satisfy the IMT-2000 frequency spectra of 1.885–2.200 GHz for both the up-link and down-link. The mechanical configuration and the typical electrical characteristics, such as impedance behaviour, input gain, surface current flow, and far-field radiation patterns, of the proposed antenna are addressed and discussed theoretically and experimentally. It would be suitable for the IMT-2000 mobile handset application.

REFERENCES

1. Bahl, I. J. and P. Bhartia, *Microstrip Antennas*, Artech House, Norwood, MA, 1980.
2. Gupta, K. C. and A. Benalla (eds.), *Microstrip Antenna Design*, Artech House, Norwood, MA, 1988.
3. Waterhouse, R. B., "Broadband stacked shorted patch," *Electron. Lett.*, Vol. 35, No. 2, 98–100, Jan. 1999.
4. Pozar, D. M., "Microstrip antennas," *IEEE Proc.*, Vol. 80, 79–91, Jan. 1992.
5. James, J. R., P. S. Hall, and C. Wood, *Microstrip Antennas Theory and Design*, Peter Peregrinus, London, 1981.
6. James, J. R. and P. S. Hall, *Handbook of Microstrip Antennas*, Peter Peregrinus, London, 1989.
7. Fujmoto, K. and J. R. James (eds.), *Mobile Antenna Systems Handbook*, Artech House, Norwood, MA, 1989.
8. Rowley, J. T. and R. B. Waterhouse, "Performance of shorted microstrip patch antennas for mobile communications handsets at 1800 MHz," *IEEE Trans. Antennas Propagat.*, Vol. 47, No. 5, 815–822, May 1999.
9. Slobodzian, P. and R. Borowiec, "Microstrip antenna for cellular and wireless communication systems," *Microwave Opt. Tech. Lett.*, Vol. 34, No. 5, 380–384, Sept. 5, 2002.
10. Delaveaud, C., P. Leveque, and B. Jecko, "New kind of microstrip antenna: the monopolar wire-patch antenna," *Electron. Lett.*, Vol. 30, 1–2, Jan. 1994.

11. Waterhouse, R. B., "Small microstrip patch antenna," *Electron. Lett.*, Vol. 31, 604–605, Apr. 1995.
12. Waterhouse, R. B., S. D. Targoniski, and D. M. Kokotoff, "Design and performance of small printed antennas," *IEEE Trans. Antennas Propagat.*, Vol. 46, No. 11, 1629–1633, Nov. 1998.
13. Waterhouse, R. B. and D. M. Kokotoff, "Novel technique to improve manufacturing ease of shorted patches," *Microwave Opt. Tech. Lett.*, 37–40, Jan. 1998.
14. Kan, H. K. and R. B. Waterhouse, "Size reduction technique for shorted patches," *Electron. Lett.*, Vol. 35, No. 12, 948–949, Jan. 1999.
15. Sanad, M., "Effect of the shorting posts on short circuit microstrip antennas," *Proc. IEEE Antennas Propag. Symp.*, 794–797, Seattle, WA, Jun. 1994.
16. *IMT-2000*, Radio Communication Bureau, Vol. 1997, M Series-Part 2.
17. Mistry, P. M., "Third generation cellular (3G): W-CDMA & TD-CDMA," *Proc. of 1998 WESCON Conf.*, 227–231, Anaheim, CA, USA, Sept. 15–17, 1998.
18. *Ansoft Ensemble 7.0.1, Planar EM Simulation Software for RF & Wireless Design*, Ansoft Corporation, 2001.
19. Wang, K. L., C. L. Tang, and H. T. Chen, "A compact meandered circular microstrip antenna with a shorting pin," *Microwave Opt. Tech. Lett.*, Vol. 15, Issue 3, 147–149, 1997.
20. Wang, Y. J. and C. K. Lee, "Design of dual-frequency microstrip patch antennas and application for IMT-2000 mobile handsets," *Progress in Electromagnetics Research*, Vol. 36, 265–278, 2002.
21. Kuo, Y. L. and K. L. Wang, "Coplanar waveguide-fed folded kinverted F antenna for UMTS application," *Microwave Opt. Tech. Lett.*, Vol. 32, Issue 5, 364–366, 2002.
22. Wang, Y. J., C. K. Lee, W. J. Koh, and Y. B. Gan, "Design of small and broadband internal antennas for IMT-2000 mobile handsets."

Y. J. Wang received B.Sc. (Best Hons) from Physics Department of Xiamen University, P. R. China in 1992, and M.Eng. (by research) in Electrical and Electronic Engineering from Nanyang Technological University, Singapore in 2000. From 1992 to 1998 he was an electrical engineer/a senior electrical engineer and assistant to General Manager at China Import and Export Commodities Inspection Bureau (CCIB), Fujian, P. R. China. Since November 2000, he has been working with DSO (Defence Science Organisation) National Laboratories, Singapore as a member of technical staff. He is an NARTE-certified (USA) EMC engineer and a committee member of IEEE Singapore EMC chapter for years 2002–2003. Some areas of his interest are devoted to microstrip antennas, mobile antennas, numerical methods, computational electromagnetics, test chambers, military and commercial EMC, and EMI (electromagnetic interference)/radiation hazard/safety troubleshooting.

C. K. Lee was born in Malaysia. He received B.Sc. and Ph.D. degrees from the University of Kent at Canterbury, United Kingdom, in 1982 and 1987 respectively. He was a research fellow in the areas of microwave antenna majoring in frequency selective surface, at the above university between 1988 and 1990. He joined the Electro-Optic Group, Division of Radiophysics (Now renamed as Telecommunications and Industrial Physics), and Commonwealth Scientific Industrial Research Organisation (CSIRO) in Australia as a research scientist from Oct. 1990 to Jul. 1991 working on near field range. He is currently an associate professor in the school of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. His research interests include frequency selective surface, microstrip antenna and electromagnetic inverse scattering.