Dual-Frequency Strip-Sleeve Monopole for Laptop Computers

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***Abstract*— A novel dual-frequency strip-sleeve monopole antenna for use on a laptop computer is described. The antenna operates simultaneously in the 0.824–0.894 GHz and 1.85–1.99 GHz bands of the AMPS and the PCS systems with return-loss less than −9.5 dB. Effects of several antenna and computer parameters on the input impedance, radiation pattern, and directivity are given. The parameters considered include an angle between the keyboard and the screen, dielectric materials of the keyboard and the screen, number of parasitic antenna sleeves, and the dielectric covering the antenna.**

***Index Terms*—Monopole antennas, wireless LAN.**

I. Introduction

With the rapid progress in wireless communication technology and the ever increasing demand for it by professionals, laptop and other portable computers with wireless modems will very soon become *de rigueur*. Such computers operating in the single cellular telephone frequency band are already making an entrance to the marketplace. However, there is no published data on antenna design and performance for these devices. Furthermore, in situations where the laptop user travels from one cellular zone to another, the operation in a different frequency band is often required. For such use the laptop may have two separate antennas operating in the two frequency bands of interest or it may have a dual-frequency antenna operating in the two frequency bands. The second choice is more attractive since it effectively reduces the cost and complexity of installing and maintaining two separate antennas and their associated circuitry. The two frequency bands of interest in the North America are the 0.824–0.894 GHz for the advanced mobile phone systems (AMPS) band and the 1.85–1.99 GHz for the personal communication systems (PCS) band [1].

A wide-band dual meander-sleeve antenna that operated simultaneously in two different frequency bands was described by Ali *et al*. [2]. That antenna was designed to operate as a vehicular antenna. The operation in two frequency bands was achieved by adding two parasitic sleeves to a dual meander monopole. Based on the design principles in [2], in this paper, an analysis and design of a strip-sleeve monopole antenna for use on a laptop computer are given. The antenna is designed and analyzed using the finite-difference time-domain (FDTD) method [3]–[5]. Two placements of the antenna are evaluated, namely on the keyboard side (as used in commercial computers), and on the top of the screen.

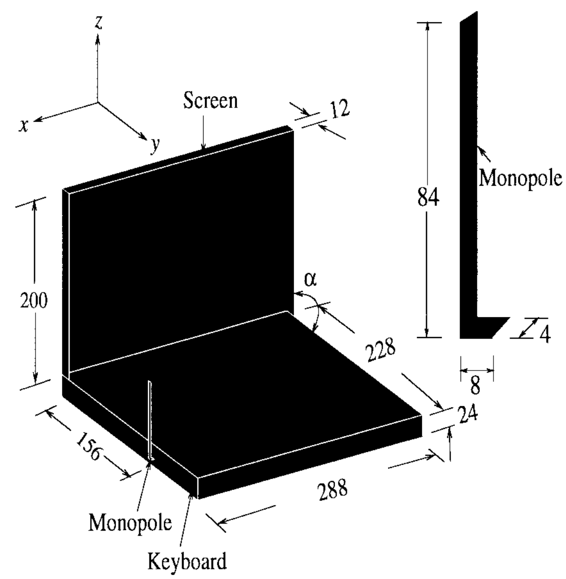

Fig. 1. Side-mounted strip monopole on a laptop computer; all dimensions in millimeters.

II. Antenna Modeling

The geometry of a typical laptop with a side-mounted strip monopole is shown in Fig. 1. The laptop model is highly simplified and consists of two metal boxes: a keyboard and a screen. The angle between the keyboard and the screen is α. The geometry of the new dual-frequency strip-sleeve monopole is shown in Fig. 2. The computer dimensions are the same as in Fig. 1. The parameters of the strip-sleeve monopole are antenna length L, sleeve length l, sleeve spacing S, base length b, and strip width w. The operation of this antenna in two frequency bands can be achieved by the proper design of the sleeves.

FDTD computations were performed with a program developed at the University of Victoria, BC, Canada [6]. The computational space was terminated with a perfectly matched layer (PML) (7, P, 0.01), i.e., perfectly matched layers with

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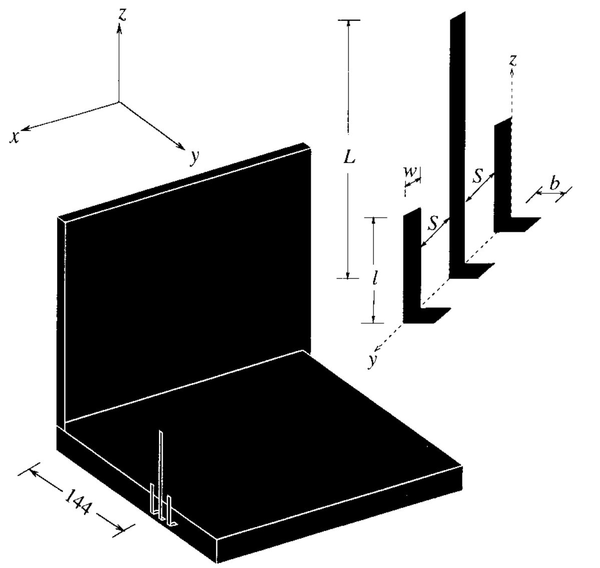

Fig. 2. Side-mounted strip-sleeve monopole on a laptop computer; all dimensions in millimeters.

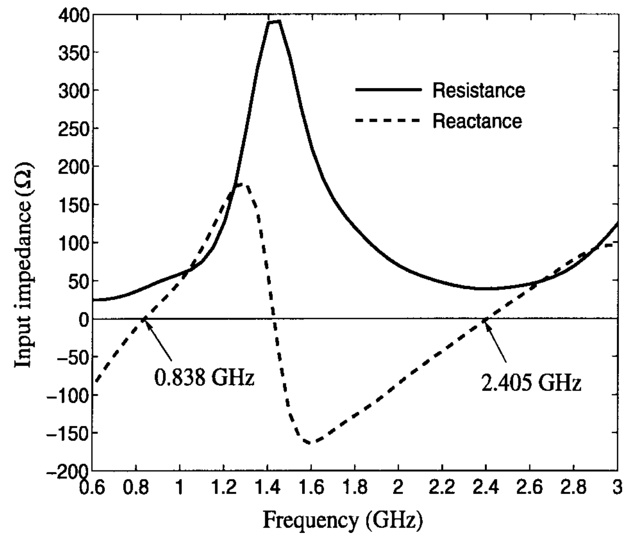

Fig. 3. The input impedance of a side-mounted strip monopole on a laptop computer. The geometry of the antenna is shown in Fig. 1.

seven layers, parabolic conductivity profile, and maximum reflection of −40 dB [7]. Since not all metal surfaces were conformal to the mesh an algorithm that significantly decreases the FDTD staircase error was used [8]. The excitation was with a frequency shifted Gaussian pulse, thus allowing for computations of the antenna characteristics in both bands in one computational run. The antenna gap was one cell wide.

Input impedance was computed using voltage across the gap and current computed from magnetic fields considering a loop centering the feed point. A correction factor was used to account for the $\frac{\Delta t}{2}$ of time shift between the voltage and the current. Spatial discretization of $\Delta x = \Delta y = \Delta z = 4$ mm was used and number of time steps ranged from 1600 to 2400. Typically the computational space consisted of 98 × 81 × 100 cells. Near to far-field transform in frequency domain was performed to compute radiation patterns [4]–[5].

III. Modeling Results

A. Side-Mounted Strip Monopole

The input impedance for the side-mounted strip monopole (Fig. 1) as a function of frequency is shown in Fig. 3. The first resonance at 0.838 GHz falls within the lower frequency band (0.824–0.894 GHz). The bandwidth for a 50-Ω coaxial line feed and a return-loss (RL)[1] upper limit of −9.5 dB satisfies the requirement for the lower frequency range (0.824–0.894 GHz). However, the antenna is not resonant within the upper frequency band (1.85–1.99 GHz).

B. Side-Mounted Strip-Sleeve Monopole

The strip-sleeve monopole (Fig. 2) is designed with the following objectives in mind: 1) that the antenna be resonant at around 0.85 and 1.9 GHz; 2) that the resistance for these resonances be close to 50 Ω; 3) that the bandwidth of the antenna with $RL \leq -9.5$ dB be adequate in both bands; and 4) that the radiation pattern of the antenna be similar to that of a conventional monopole. A number of simulations were performed to meet the above criteria. It was found that for both $\alpha = 90°$ and $\alpha = 110°$, the above requirements are satisfied for $L = 84$ mm, $l = 28$ mm, $b = 8$ mm, and $S = 8$ mm. The results were obtained by trial and error approach rather than optimization. However, because of the previously gained experience [2] the design cycle was short.

The computed input impedance and RL as functions of frequency for the laptop strip-sleeve monopole (Fig. 2) are shown for $\alpha = 90°$ in Fig. 4(a) and (b), respectively. The resonant frequencies as marked in Fig. 4(a), are 0.858 and 1.943 GHz. The resonant resistances at these two frequencies are close to 50 Ω. The RL frequency response shown in Fig. 4(b) demonstrates that the antenna can operate simultaneously in the AMPS (0.824–0.894 GHz) and the PCS (1.85–1.99 GHz) bands within $RL \leq -9.5$ dB.

The same data for $\alpha = 110°$ are shown in Fig. 5. The resonant frequencies of the antenna are 0.846 and 1.95 GHz. The change in the resonant frequency is <1.3% while α is increased from 90° to 110°. The RL versus frequency characteristic clearly shows that the antenna still has more than adequate bandwidth for simultaneous operation in the AMPS and the PCS bands.

Computed radiation patterns at 0.859 and 1.9 GHz for the antenna with the screen at 110° are shown in Fig. 6. Patterns are normalized to the directivity of the antenna at the two frequencies of interest which are 6.3 dBi at 0.859 GHz and 6.9 dBi at 1.9 GHz. When the E_θ, xy-plane patterns at 0.859 and 1.9 GHz are considered it can be observed that there exist dips along $\phi \approx 265°$ and $\phi \approx 240°$, respectively [Fig. 6(a)]. The E_ϕ pattern at 1.9 GHz [Fig. 6(b)] shows that this component is suppressed below approximately −10 dB. However, the same is not true for the pattern at 0.859 GHz, where this component varies between −6 to −22 dB. The complex radiation patterns

[1] Return-loss, $RL = 20\log_{10}\rho$ where ρ is the magnitude of the complex reflection coefficient. $RL = -9.5$ dB corresponds to VSWR $= 2.0$.

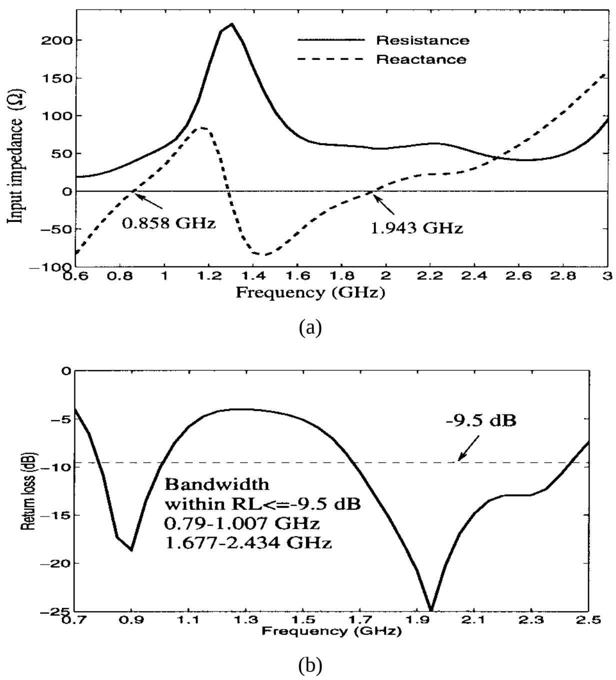

Fig. 4. (a) Input impedance and (b) RL of the side-mounted strip-sleeve monopole as a function of frequency. The angle (α) between the keyboard and the screen is 90°.

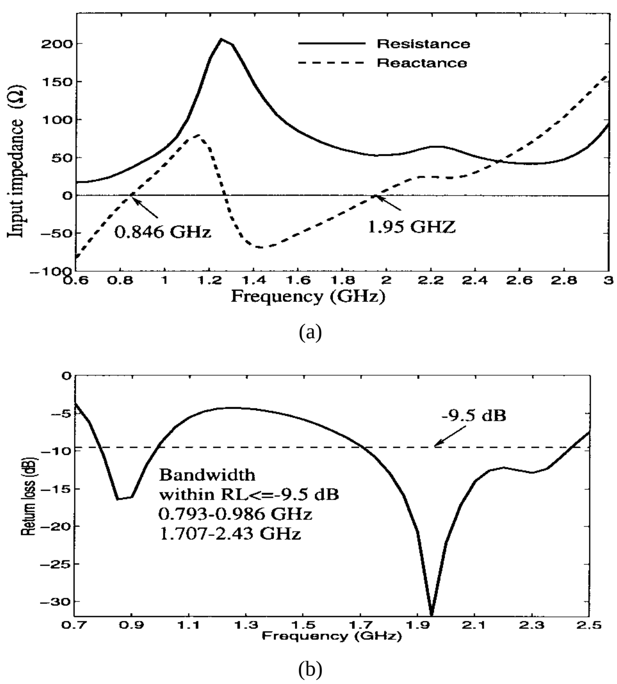

Fig. 5. (a) Input impedance and (b) RL of the side-mounted strip-sleeve monopole as a function of frequency. The angle (α) between the keyboard and the screen is 110°.

are a result of the corner reflector formed by the keyboard and the screen [9], and the keyboard acting as a part of the antenna. It is well known that the radiation pattern of an antenna mounted on a handset is different from the pattern of the same antenna on an infinite ground plane [10]. This is due to the current flow on the handset which makes the antenna subsystem look like an asymmetric dipole. The same situation applies to the laptop antenna. In addition, the metal screen and its orientation with respect to the keyboard, acting as a different angle corner reflector, also affect the pattern.

The elevation-plane patterns at 0.859 and 1.9 GHz [Fig. 6(c)] are computed in the planes of the beam maximum. At 0.859 GHz the direction of the beam maximum is given by $\phi = 145°$, $\theta = 55°$, while that at 1.9 GHz is given by $\phi = 130°$, $\theta = 65°$. The patterns are similar to the pattern of a half-wave z-directed dipole. However, while the main beam of the dipole is along $\theta = 90°$, that of the laptop is directed toward an elevation angle that is <90°. The reason is the same as described before. The E_ϕ elevation-plane pattern at 0.859 GHz is nearly uniform, while that at 1.9 GHz has dips along $\phi = 0$ and 180° [Fig. 6(d)].

Radiation patterns are also computed for an upright screen position ($\alpha = 90°$). Comparing the patterns at 1.9 GHz for $\alpha = 110°$ with those for $\alpha = 90°$ (not shown) a number of differences is observed: 1) the E_θ, xy-plane pattern for $\alpha = 110°$ is more uniform than its counterpart for $\alpha = 90°$; also, there is a -16 dB dip along $\phi \approx 147°$ for $\alpha = 90°$, while there is a -7 dB dip along $\phi \approx 157°$ for $\alpha = 90°$; 2) the E_θ elevation-plane pattern is relatively broader for $\alpha = 110°$ as compared to the same for $\alpha = 90°$. This makes the directivity of the former smaller than the latter—6.3 dBi as compared to 8.5 dBi.

C. Top-Mounted Strip-Sleeve Monopole

A top-mounted strip-sleeve monopole is shown in Fig. 7. The dimensions of the computer are the same as in Fig. 1. The antenna is approximately in the middle of the top surface of the screen, with the screen in an upright position ($\alpha = 90°$). The details of the antenna geometry are shown as an inset in Fig. 7. Computed RL as a function of frequency for this antenna is shown in Fig. 8, as the curve labeled Antenna A represents the RL characteristic for the antenna of Fig. 7. As evident, the antenna satisfies the bandwidth requirement. Computed patterns at 0.859 and 1.9 GHz are shown in Fig. 9. The E_θ, xy-plane patterns [Fig. 9(a)] at both frequencies are nearly omnidirectional, as the effect of the corner reflector is eliminated. The omnidirectionality of the pattern is more pronounced at 1.9 GHz. The directions of maximum radiation are along $\phi = 0$ and $180°$. The directivity of the antenna is 2.1 and 2.6 dBi at 0.859 and 1.9 GHz, respectively. The E_ϕ, xy-plane patterns [Fig. 9(b)] at both frequencies resemble the pattern of a long dipole (approximately 1.6λ). The E_θ elevation-plane patterns [Fig. 9(c)] resemble the pattern of a resonant half-wave dipole. The E_ϕ elevation-plane patterns [Fig. 9(d)] show that the cross polarization in the plane is below -10 dB.

The characteristics of the same antenna but mounted at the side (Fig. 10) are also examined. In Fig. 10 the antenna is in the $y = 4$ mm plane while the depth of the screen is 12 mm. Computed RL as a function of frequency is shown in Fig. 8 as the curve labeled Antenna B. It is apparent, that the antenna satisfies the bandwidth requirement as well. Computed radiation patterns are shown in Fig. 11. Patterns are normalized to the directivity of the antenna at the two frequencies of interest, namely 2.3 and 4.1 dBi at 0.859 and

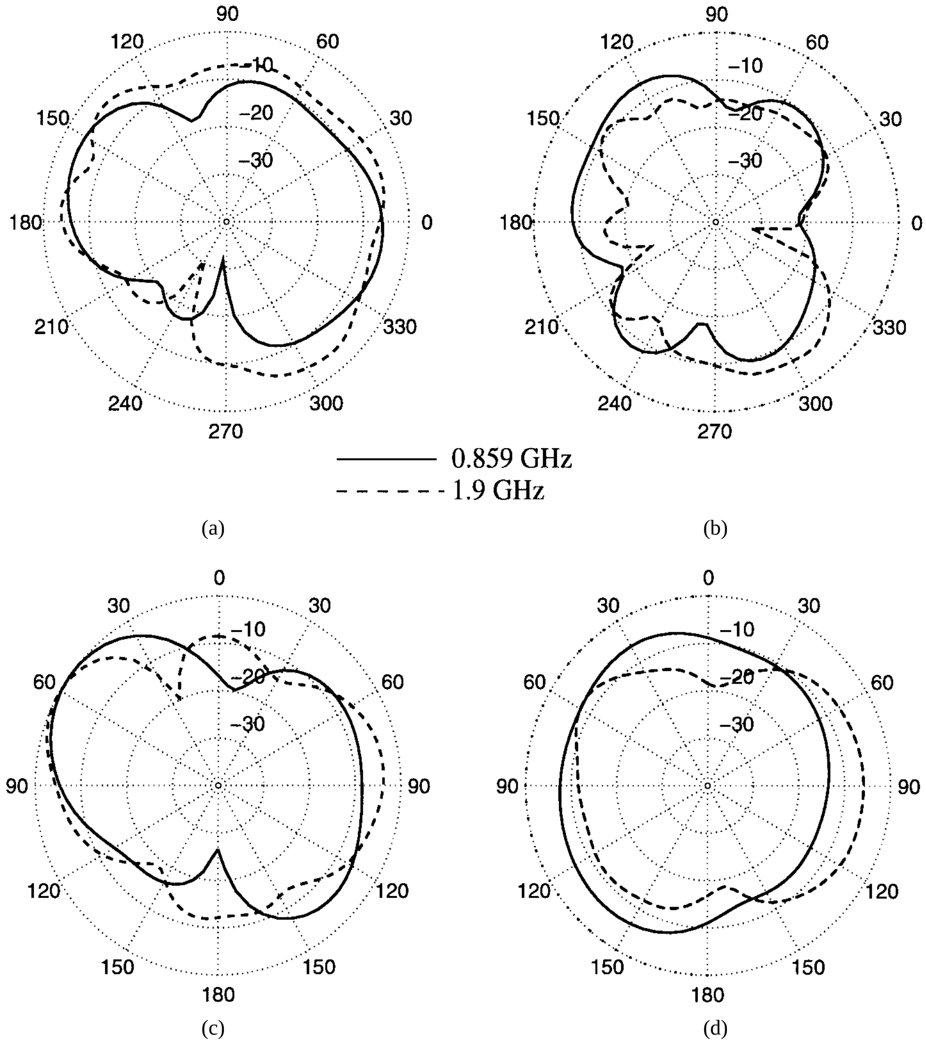

Fig. 6. Radiation pattern of the side-mounted strip-sleeve monopole. The angle (α) between the keyboard and the screen is 110°. (a) E_θ horizontal-plane (xy-plane) pattern. (b) E_ϕ horizontal-plane (xy-plane) pattern. (c) E_θ elevation-plane pattern. (d) E_ϕ elevation-plane pattern.

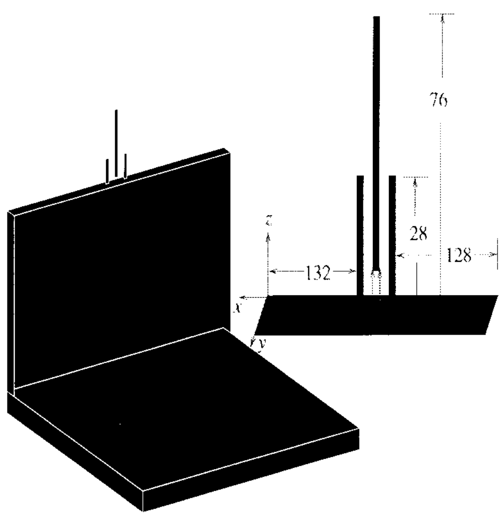

Fig. 7. Top-mounted strip-sleeve monopole on a laptop computer.

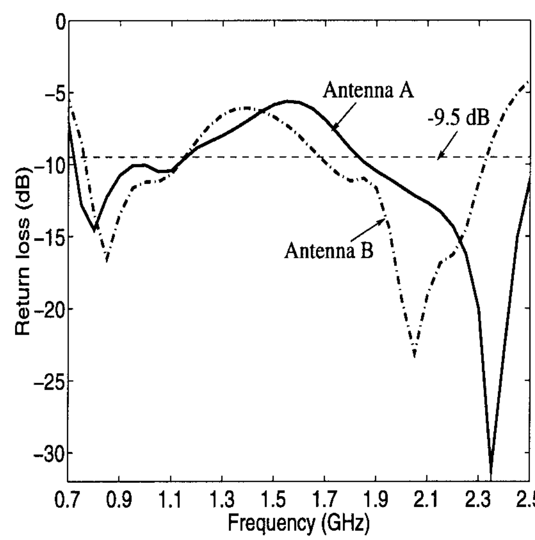

Fig. 8. RL versus frequency of top-mounted strip-sleeve monopoles. Antenna A and B represent the configurations of Figs. 7 and 10, respectively. The angle (α) between the keyboard and the screen is 90°.

1.9 GHz, respectively. The E_θ, xy-plane patterns at both frequencies are nearly omnidirectional. The main difference between the patterns of Figs. 9(a) and 11(a) is that the latter ones do not have preferred directions of radiation.

The E_ϕ, xy-plane patterns at both frequencies resemble the pattern of a long dipole (approximately 1.6λ) with a partial

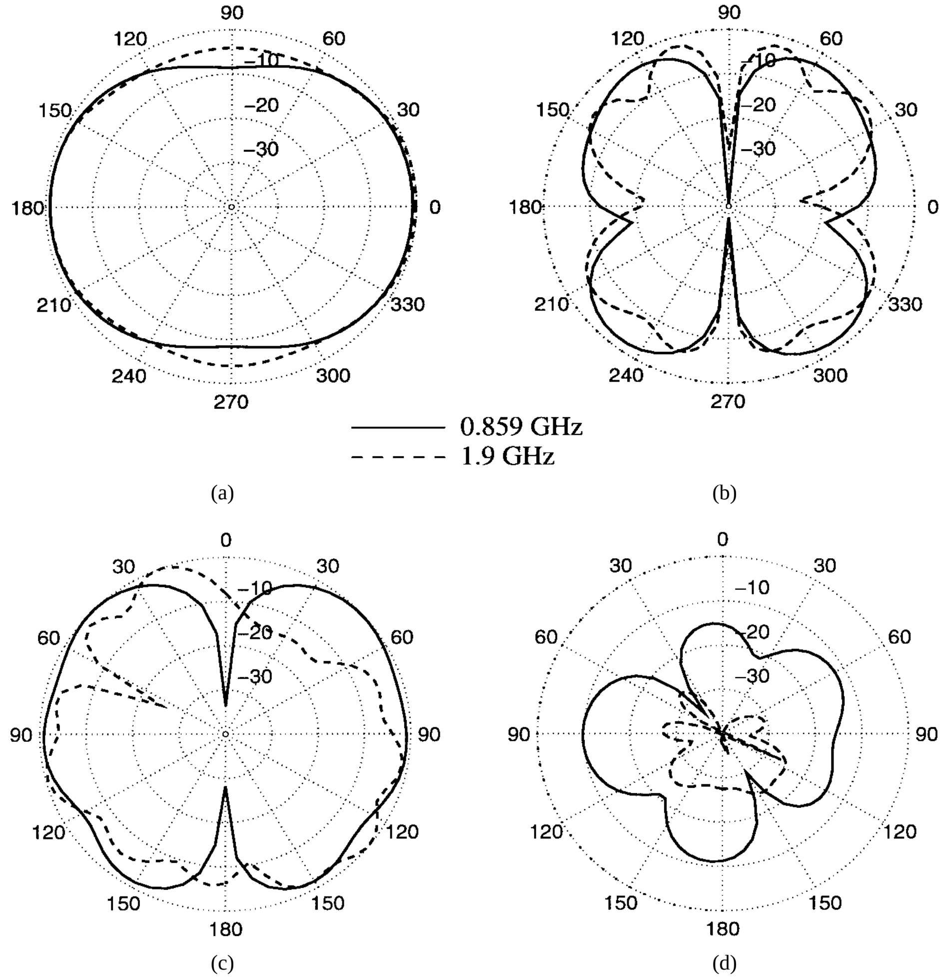

Fig. 9. Radiation pattern of the top-mounted strip-sleeve monopole of Fig. 7. The angle (α) between the keyboard and the screen is 90°. (a) E_θ horizontal-plane (xy-plane) pattern. (b) E_ϕ horizontal-plane (xy-plane) pattern. (c) E_θ elevation-plane pattern. (d) E_ϕ elevation-plane pattern.

screening along $\phi = 180°$. The E_θ elevation-plane patterns shown in Fig. 11(c) are similar to the pattern of a resonant half-wave dipole. According to the E_ϕ elevation-plane pattern shown in Fig. 11(d), the cross polarization is greater than that in Fig. 9(d).

D. Effect of Dielectric Layers

Real laptop computers are usually coated with dielectrics and may contain other dielectric materials and metal objects. To observe the effect of dielectric materials on antenna performance, a 4-mm-thick layer with $\epsilon_r = 1.5$ and an 8-mm-thick layer with $\epsilon_r = 4.0$ were simulated for the keyboard and the screen, respectively, in the configuration shown in Fig. 2 with $\alpha = 110°$. The resonant frequencies were 0.835 and 1.925 GHz, as compared to 0.846 and 1.95 GHz for the same configuration without dielectric layers (Fig. 5). The reduction in the resonant frequencies was <1.3%. The bandwidths of the antenna were satisfactory and the radiation patterns were only minimally affected.

E. Modified Strip-Sleeve Monopole

The dimensions of the antenna of Fig. 2 are 12 × 28 × 84 mm[3]. If one of the parasitic antenna sleeves can be eliminated a 42.8% reduction in the antenna volume can be achieved. Such an antenna consisting of only one parasitic sleeve was, therefore, analyzed. For the screen in an upright position, input impedance and RL are shown in Fig. 12. The bandwidths are

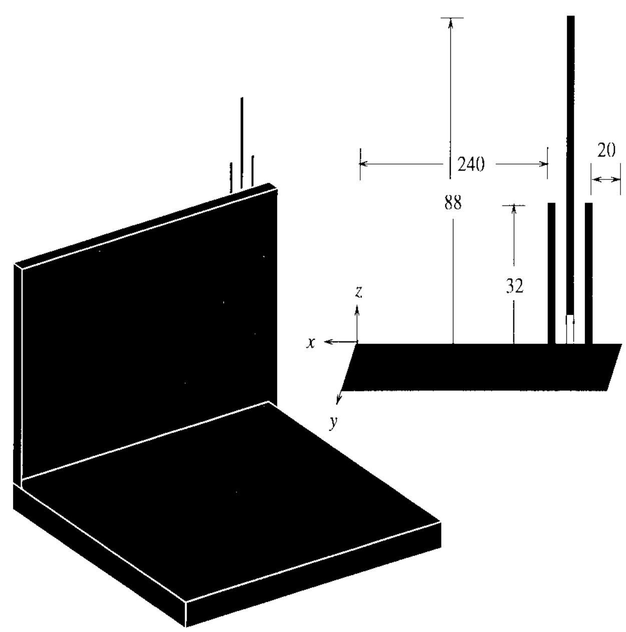

Fig. 10. A top-mounted strip-sleeve monopole.

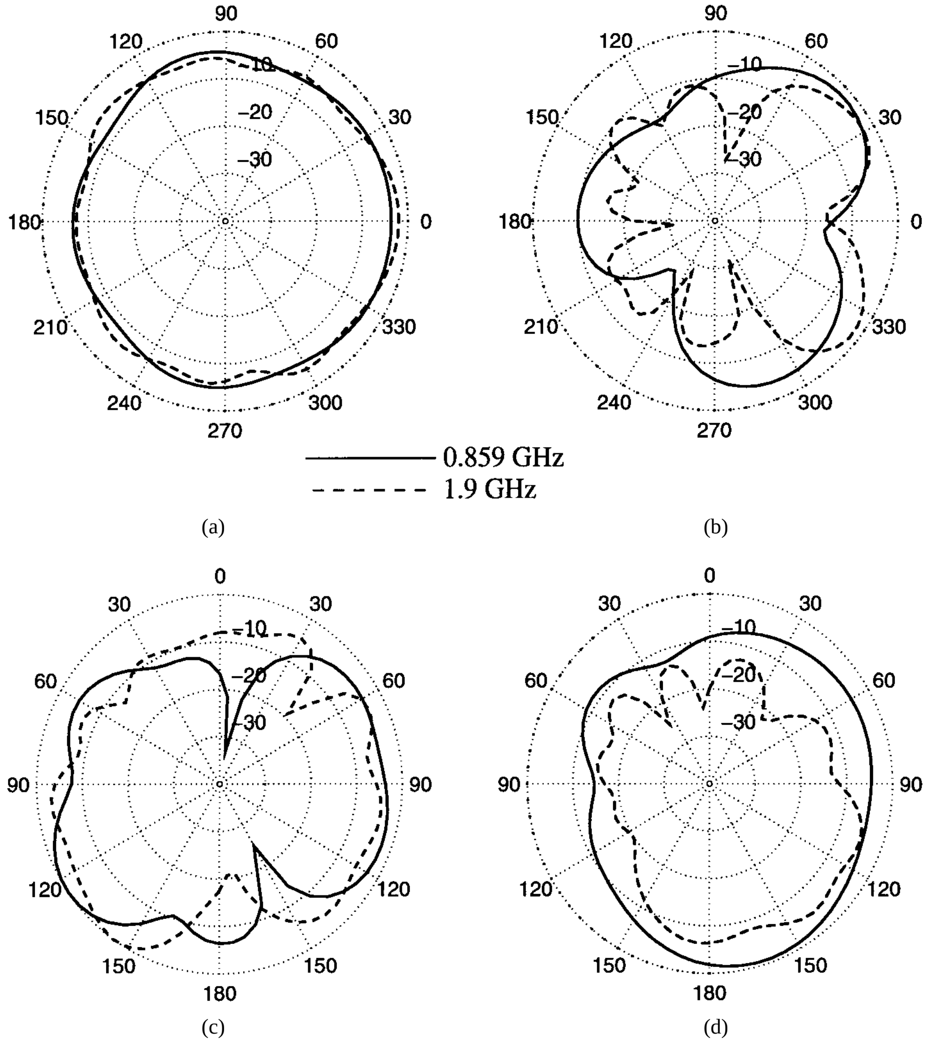

Fig. 11. Radiation pattern of the top-mounted strip-sleeve monopole of Fig. 10. The angle (α) between the keyboard and the screen is 90°. (a) E_θ horizontal-plane (xy-plane) pattern. (b) E_ϕ horizontal-plane (xy-plane) pattern. (c) E_θ elevation-plane pattern. (d) E_ϕ elevation-plane pattern.

TABLE I
EFFECT OF A DIELECTRIC RADOME; $b = 8$ mm, $s = 8$ mm FIXED

Radome	Antenna dimensions (mm)	Resonant freq. (GHz)			Resonant res. (Ω)			Bandwidths (%)
		fr1	fr2	fr3	R1	R2	R3	
Yes ($\epsilon_r = 1.5$)	L=76, l=24	0.84	1.25	1.80	31.4	187	42.7	22.3 and 26.2
No	L=84, l=28	0.85	1.28	1.94	39.2	218	56.2	24.3 and 38.7

still satisfactory. Comparing the results in Fig. 12 with those in Fig. 4, it can be noted that: 1) the impedance curves in Fig. 12 show an additional resonance and 3) the bandwidths of the antenna are narrower than before. The radiation patterns for the modified antenna are similar to the patterns in Fig. 6.

F. Effect of a Dielectric Radome

In a practical laptop, the antenna may be covered with a dielectric radome. The effect on the antenna performance of a 4-mm-thick radome having $\epsilon_r = 1.5$ was evaluated for the configuration shown in Fig. 2 for $\alpha = 90°$. The results are presented in Table I. Clearly, the radome decreased the resonant frequencies, resistances, and bandwidths in the lower and upper frequency bands. Nevertheless, the bandwidths in both bands were satisfactory for the intended operation. The radiation patterns of the antenna were similar to those shown in Fig. 6.

IV. DISCUSSION AND CONCLUSIONS

A dual-frequency strip-sleeve monopole antenna mounted on a laptop computer was analyzed using the FDTD method. Since a conventional monopole antenna was not suitable for dual-frequency operation, the strip-sleeve monopole was introduced. The new antenna was designed to operate in the

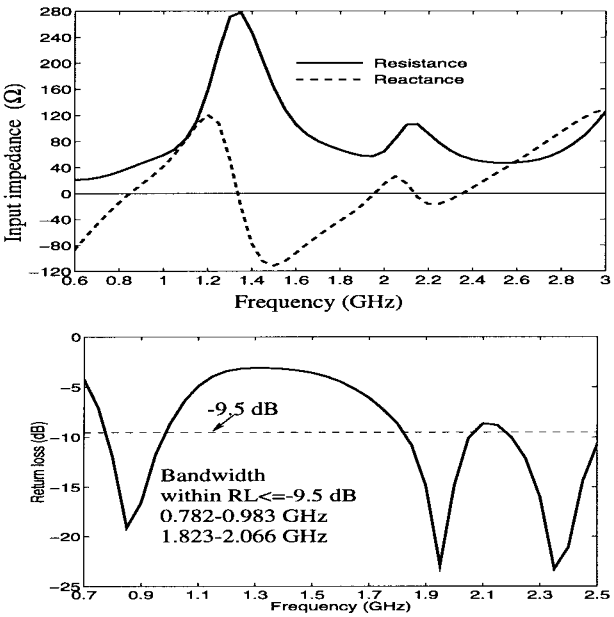

Fig. 12. Input impedance and RL of the side-mounted modified strip-sleeve monopole as a function of frequency. The angle (α) between the keyboard and the screen is 90°.

0.824–0.894 and 1.85–1.99 GHz frequency bands within $RL \leq -9.5$ dB. The characteristics of the antenna subsystem were then investigated by varying a number of parameters, e.g., the antenna geometry, the angle between the keyboard and the screen, the position of the antenna with respect to the laptop, the presence of dielectric materials, and the modification of the antenna by eliminating one of the parasitic antenna sleeves.

It was observed that by adjusting the sleeve length and the sleeve spacing the resonant frequencies and corresponding resistances can be changed. Thus, the dual-frequency operation of the antenna is not restricted to the 0.824–0.894 and 1.85–1.99 GHz bands only and operation in another pair of frequency bands can also be achieved by properly designing the sleeves.

When the antenna is mounted on the side of the keyboard, as in some commercial single band computers with wireless modems, the resulting radiation pattern is not omnidirectional. The nonomnidirectional pattern is likely not to be of significance in practical communication environments [11], [12]. The antenna mounted on the top middle of the screen results in an omnidirectional pattern with the main beam directed along the horizon. The antenna positioned on the top right-hand edge of the screen also has an omnidirectional pattern. However, the main beam for this case is not directed in the horizontal direction.

Eliminating one of the parasitic sleeves changes the input impedance and the RL. However, the bandwidths of the antenna remain satisfactory and the effect on the pattern of the antenna is negligible. A dielectric radome of the antenna (4-mm thickness $\epsilon_r = 1.5$) reduces the resonant resistance of the antenna and its bandwidth. Nevertheless, the bandwidths of the antenna is more than adequate for the required dual-frequency operation. The effect of the radome on the radiation patterns of the antenna is negligible.

In summary, a novel dual-frequency strip-sleeve monopole antenna has been designed and analyzed for use on a laptop computer. The antenna can operate simultaneously in the 0.824–0.894 GHz and 1.85–1.99 GHz bands with the input impedance close to 50 Ω and return loss less than −9.5 dB (VSWR ≤ 2.0). This antenna can be side or top mounted on the computer. The top-mounted antenna provides more omnidirectional radiation pattern than the side-mounted antenna. The angle of the screen with the keyboard, dielectric material on the computer (screen, keyboard), and antenna radome alter the antenna characteristics only very moderately. Overall. thin antenna configuration provides for wider than required frequency ranges with VSWR < 2 in both designated bands and, thus, is not sensitive to reasonably small changes in the geometry of the computer and changes in the antenna position with respect to its basic location. However, there is a significant difference in the antenna performance when its basic location is changed from the side of the keyboard to the top of the screen.

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M. A. Stuchly (M'71–SM'76–F'91), photograph and biography not available at the time of publication.

S. S. Stuchly (M'70–SM'72–F'91), photograph and biography not available at the time of publication.