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Novel micromachined patch antenna for mobile communication

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Abstract: The rapid development of wireless communications worldwide results in a huge demand for miniaturized antenna with excellent performance to send and receive wireless signals to and from communication devices. Microstrip patch antennas are used in a variety of applications for their salient features. By sandwiching a layer of Teflon between the silicon wafer and the ground plane, the novel micromachined shortened stacked patch antenna printed on high-index wafer has superior performance over those of traditional design, while its bandwidth has been increased by as much as 8.6%, and its length of patch has been miniaturized to only an eighth wavelength. The radiation patterns show that even if the antenna is on a ground plane of approximately the size of a handset phone circuit board, most of the radiation is directed away from the user's head, and the wide beamwidth can ensure wide angular coverage. The antenna micromachined in a silicon wafer can also be integrated with Si and GaAs IC without affecting any of the circuit requirements.

Key words: mobile communication; RF-MEMS; microstrip antenna; micromachining
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1　Introduction

The GSM wireless communication has witnessed an explosive growth in the last years. In 2002, there were more than 100 million mobile phone subscribers in China, and the figure is becoming greater at very fast speed. The wireless communication technology will be found in cell-phone, robot, information application (IA) products, Personal Digital Assistant (PDA), wireless intelligent sensor network, PC peripherals such as printers, keyboards, or mice, etc. The boom of the portable communication devices has fueled the demand for miniaturization and perfect performance of antennas, which fit for embedding or assembling.

Due to the salient features of microstrip patch antennas such as small size, lightweight, simplicity, low profile and low manufacturing cost, they are used in various devices and systems ranging from simple to sophisticated, as have been instanced by radar, telemetry, remote sensing, environmental monitoring, and so on. They provide

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some advantages over traditional external whip and helical antennas in terms of increased total efficiency, small size and without protruding problem. Such antennas for handset could decrease radiation towards the user and increase mechanical reliability. The main disadvantage is their narrow bandwidth, because the impedance bandwidth of traditional microstrip patch antenna is usually less than 2% (Lretn $\leqslant -10$ dB)[1].

To a great extent, the nature of microstrip antenna substrate can influence the performance of antenna. Substrate with high dielectric constant could make antenna miniaturized, however it will excite surface waves and even bring on low efficiency, narrow bandwidth and poor radiation pattern. On the contrary, miniaturization of antennas to some extent will be taken away by using low-index substrate, but efficiency enhanced and bandwidth expanded. Small antenna design is always a compromise among size, bandwidth and efficiency. In order to obtain antennas with small size, high efficiency and broad bandwidth simultaneously, a novel micromachined multilayer antenna is presented in this paper.

2 Broadband micromachined stacked antenna

2.1 Antenna structure

The antenna element consists of a rectangle patch, a shorting wall, a silicon wafer, a layer of Teflon, a ground plate and a microstrip vibrator. As shown in Fig. 1, the layer of Teflon is sandwiched between the wafer and the ground plane. There is a via slot through the wafer and the Teflon layer, and through it the shortened wall connects the patch and the ground plate. High dielectric constant of silicon ($\varepsilon_r = 11.7$) can miniaturize the antenna, and the patch printed and etched on wafer can be integrated with other circuit conveniently.

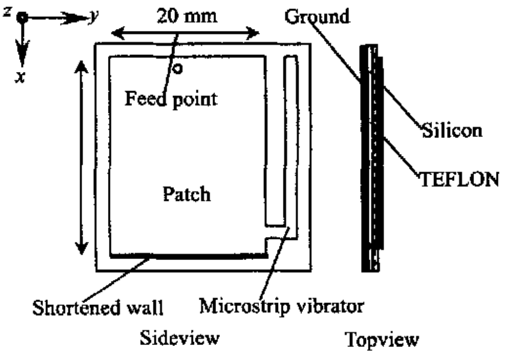


Fig. 1 Layout of novel broadband antenna

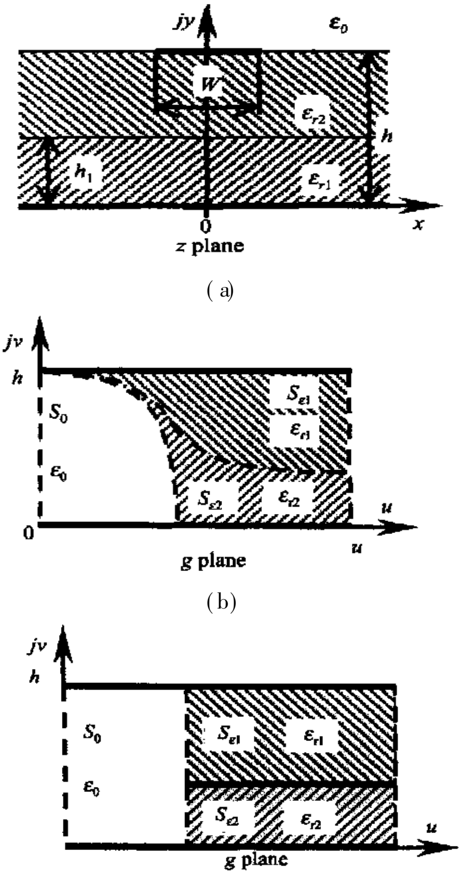
By sandwiching a Teflon-layer between the wafer and the ground, the excitation of unwanted surface waves is suppressed drastically when the antenna is working. The demand for central frequency of the novel antenna is $f_c = 1.9$ GHz.

2.2 Antenna design

2.2.1 Effective permittivity

There are many methods that investigate properties of monolayer microstrip in literature[2-3]. However in the fields of integrated circuits and microstrip antenna, there is a trend towards fabricating circuits made of more than one dielectric layer. Numerical methods of Green's function and conformal mapping method for calculation of multilayer microstrip properties have been described in detail in many publications[4,5]. But a common disadvantage of these methods is that they require long computation time or do not provide sufficiently accurate results.

A method based on conformal mapping method for the solution of multilayer microstrip has been put forth in[6-7]. The three-layer structure of the antenna (Fig. 2(a)) will be conformally mapped from the complex variable plane onto another plane with the results as shown in Fig. 2(b), and Fig. 2 (c) is the equivalent of Fig. 2(b). The individual interfaces between dielectric layers ε_{r1} and ε_{r2}, or ε_{r2} and ε_0, could be transformed. The degree of filling the cross section of a microstrip in a g-plane by individual dielectrics ε_1 and ε_1 is characterized by a filling factor q_1 or q_2, which is defined by the ratio of the area $S_{\varepsilon 1}$ ($S_{\varepsilon 2}$) taken up in the cross section by the respective dielectric and the whole area



(a)

(b)

(c)

Fig. 2 Conformal mapping of three-layer microstrip line

of the cross section in the g-plane[6]. Then with the aid of the conformal transformation, we can derive relationship between the filling factors q_1 and q_2. For wide mirostrip ($w/h \geqslant 1$), we have:

$$q_1 = \frac{S_{\varepsilon 1}}{S_c} = \frac{h_1}{2h}\left[1 + \frac{\pi}{4} - \frac{h}{w_{ef}}\ln\left(\frac{\pi}{h}\cdot w_{ef}\frac{\sin\left(\frac{\pi h_1}{2h}\right)}{\frac{\pi h_1}{2h}} + \cos\left(\frac{\pi h_1}{2h}\right)\right)\right], \qquad (1)$$

$$q_2 = \frac{S_{\varepsilon 2}}{S_c} = 1 - q_1 - \frac{1}{2}\cdot\frac{\ln\left(\frac{\pi w_{ef}}{h} - 1\right)}{\frac{w_{ef}}{h}}, \qquad (2)$$

where

$$w_{ef} = w + \frac{2h}{\pi}\ln\left[17.08\left(\frac{w}{2h} + 0.92\right)\right], \qquad (3)$$

for narrow microstrip ($w/h < 1$), we have

$$q_1 = \frac{\ln\left[\left(1 + \frac{h_1}{h}\right)/\left(1 - \frac{h_1}{h} + \frac{w}{4h}\right)\right]}{2\ln\left(\frac{8h}{w}\right)}$$
$$\left[1 + \frac{\pi}{4} - \frac{1}{2}\arccos\left(\frac{hw}{8hh_1}\sqrt{\left(1 + \frac{h_1}{h}\right)/\left(1 - \frac{h_1}{h} + \frac{w}{4h}\right.}\right]\right., \qquad (4)$$

$$q_2 = \frac{1}{2} + \frac{0.9}{\pi\ln\left(\frac{8h}{w}\right)} - q_1, \qquad (5)$$

Owing to the predominant character of the lines dividing the individual dielectric area in Fig. 2(b), it is possible to substitute the cross section of lines in the g-plane by an approximately equivalent structure in Fig. 2(c). Consequently the effective permittivity is given as

$$\varepsilon_{efr} = 1 - q_1 - q_2 + \varepsilon_{r1}\varepsilon_{r2}\frac{(q_1 + q_2)^2}{\varepsilon_{r1} q_2 + \varepsilon_{r1} q_1}, \qquad (6)$$

The antenna substrate is made from a wafer of 0.5 mm high, a cavity 0.25 mm high was created, so $h = 0.5$ mm, $h_1 = 0.25$ mm, $\varepsilon_{r1} = 1$, $\varepsilon_{r2} = 11.7$. According to above precondition, it is easy to obtain $\varepsilon_{efr} = 3.95$. We can determine the width of the patch[8]

$$w = \frac{V_c}{2fr}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2}, \qquad (7)$$

where

$$V_c = 3 \times 10^8 (m/s), \qquad (8)$$

$f_r = 1.9 \times 10^9$, $\varepsilon_r = 11.9$

so we can obtain $w = 20$ cm.

2.2.2 Length and characteristic resistance

The shortened rectangular microstrip antenna is a quarter wavelength antenna, so it's length is given by[6]

$$L = \frac{V_c}{4f_r\sqrt{\varepsilon_e}} - \Delta l, \qquad (9)$$

where

$$\Delta l = 0.412h\frac{(\varepsilon_e + 0.3)(w/h + 0.264)}{(\varepsilon_e - 0.258)(w/h + 0.8)}, \qquad (10)$$

Δl is the open-end effect extension length to the antenna.

Because the electromagnetic coupling effect between the additive microstrip vibrator and the drive patch could extend the antenna bandwidth somewhat, if we let the drive patch and the additive microstrip vibrator resonant at lower and upper side of central frequency 1 900 MHz, then the antenna bandwidth could be extended. Hence, the length of the antenna obtained from Eq. (9) is about 20 mm, we let

$$L = 21\ \text{mm}, \qquad ((11)$$

The characteristic resistance of the antenna is

$$Z_c = Z_0/\sqrt{\varepsilon_{fr}}, \qquad (12)$$

where Z_0 is the resistance of an air suspended microstrip with the same dimensions as the antenna, since $w/h > 1$, from[8] we can have

$$Z_0 = \frac{120\pi}{w/h + 2.42 - 0.44\,h/w + (1 - h/w)^6}, \qquad (13)$$

Substitute the values of w, h and ε_{fr} into Eq. (11) and (12), then we have $Z_0 = 48.9\ \Omega$.

3 Measurement and analysis

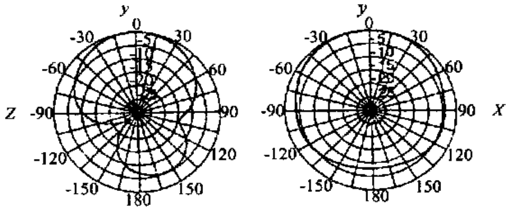
3.1 Measurement

The measurements carried out on an Agilent 8720C vector network analyzer show that there are two resonant frequencies, one is 1.86 GHz, and the other is 1.98. The lower and upper ends of 10 dB bandwidth(Lrtn ⩽ − 10 dB) is 1.809 GHz and 1.97 GHz, respectively, so the band width is approximate to 8.6% (Fig. 3). The drift between the design and measured frequencies is less than 3%. The measured impedance at the resonant frequency is 47.8+ 0.26 j. Discrepancies between the design and measured parameters are given in Tab. 1.

Tab. 1 The discrepancies between the design and measured parameters

Parameter	Design	Measured	Discrepancies
Central frequency of 10dB bandwidth (GHz)	1.9	1.890	< 1%
Characteristic impedance(Ω)	48.9	47.8+ 0.26 j	2.31%

The antenna was also measured at the resonant frequency using antenna measurement set-up. The radiation patterns are shown in Fig. 4, and the gain is 5.87 dB.



(a) yz - plane (b) xy - plane

Fig. 4 Measured cuts of radiation patterns of the antenna

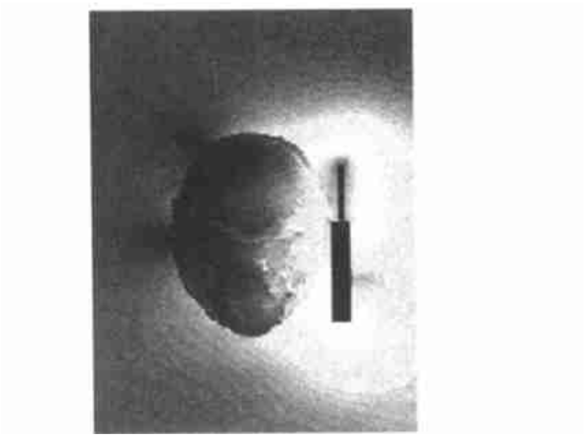


Fig. 5 Electromagnetic radiation from the whip antenna of handset to human head

3.2 Analysis

The measured impedance bandwidth of the shortened micromachined patch antenna approximate to 8.6%, that is 3~ 4 times of that of conventional microstrip antennas due to an electromagnetic coupling effect between the drive patch and the additive microstrip vibrator.

In the *yz* plane of the radiation pattern, the 3 dB beamwidth is 93°, and in the *xy* plane 135°. The results show that even if the antenna is on a ground plane approximately the size of a handset phone circuit board, most of the radiation is directed away from the user's head. For lower electromagnetic radiation to human head, the novel broadband micromachined antenna is more propitious than whip and helix antennas for mobile phone users[9]. On the other hand, *xy* plane beamwidth is wide enough; it can ensure wide angular coverage. Obviously, the radiation pattern of the antenna is suitable for handset and cordless telephone.

3.3 Experiments on Motorola G18 evaluation board

We have connected this novel micromachined antenna to Motorola G18 Evaluation Board. it can send short messages normally to GSM mobile phone, and can receive short messages too. Consequently, the antenna meets the requirement for portable communication applications.

4 Conclusion

This paper has put forth the broadband micromachined shortened stacked antenna using teflon-silicon substrate. In order to meet antenna properties (bandwidth, beamwidth, gain and radiation efficiency), this paper offers an easy method to miniaturize size, broaden bandwidth and increase efficiency by a sandwiched Teflon layer and an additive microstrip vibrator.

The broadband micromachined stacked antenna with shortened wall is only about an eighth wavelength long, pretty smaller than a conventional half wavelength patch antenna. The measured impedance bandwidth of the antenna is up to 8.6%, the radiation pattern is suitable for cellular handset and cordless telephone antenna applications. The merit of the micromachined patch antenna show that antennas manufactured using micromachining techniques fit portable communication devices.

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用于移动通信中的新型微机械贴片天线

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摘要: 近年来无线通信在全球范围内得到了迅猛的发展, 对收发无线信号的天线尺寸的小型化和性能要求也在日益增加。微带贴片天线以其卓越的性能, 得到了广泛应用。传统的半波天线尺寸较大, 在小型通信设备中使用会出现许多问题。本文提出了一种在高介电常数上用微机械工艺制作的短接层叠式贴片天线, 该天线在硅片和接地板间夹一层 Teflon(聚四氟乙烯), 这样天线的性能得到了提升, 相对带宽增加到 8.6%, 而几何尺寸仅为波长的 1/8。天线的测试方向图表明, 天线靠近手机电路板时, 大部分的电磁辐射会远离使用者的头部, 且波束宽度可保证足够大的覆盖范围。此天线是在硅片上进行微机械加工的, 可与硅和 GaAs 集成电路集成在一起, 而不会影响电路本身。此天线可适用于移动通信设备。

关 键 词: 移动通信; RF-MEMS; 微带天线; 微机械
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