

Simulation Researches on Feed Method of GSM Microstrip Antenna for Impedance Match

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Abstract—In present work, the feed method of GSM microstrip antenna for impedance match was studied. Firstly, Transmission Line Model (TLM) and impedance theory were introduced. Using three-dimensional electromagnetic simulation software ANSYS Ansoft HFSS, the effects of different feed points on the E-plane and H-plane pattern were studied for the GSM probe-fed microstrip antenna. Moreover, the variation tendency of the reflection coefficient of antenna with the frequency varying from 900 to 1000 MHz was discussed. The simulation results could not merely present directive significance to the suitable match between microstrip antenna and feed lines, but also contribute to the improvement of transmission efficiency and the acceleration of design cycle.

Keywords—microstrip antenna; input impedance; feed method

I. INTRODUCTION

As a major medium for information transmission, antennas were vital and indispensable parts in the field of wireless communication. Portable wireless communication devices, such as codeless telephone, personal communication service (PCS), cellular telephone, radio modem, *etc.*, usually were quite close to human body when working, and therefore some requirements were put forward on antenna, i.e., the imposed effects and the absorbed radiation should be minimized as much as possible, both of which could be satisfied to the fullest extent by the microstrip antenna, mainly owing to its good integration properties, specifically, the capability to be assembled internally. Microstrip antenna could be integrated to printed circuit board (PCB) or the case without any increase of device dimension, with the obtained built-in antenna being of high mechanical strength, good fracture resistance performance, little imposed impacts of human activities and no need to be pulled out when used. Moreover, the transresistance could be reduced to the greatest degree with the employment of high-level shielding technology. In the 21-st century, the worldwide rapid development of personal communications have largely motivated the boom of studies on microstrip antenna, in which analysis on the impedance characteristics remained as one of the key problems. For a specially-selected communication antenna, the perception of impedance characteristics within the working frequency band was

indispensable, by which the proper design of matching circuits or the favorable feed method could be obtained with the purpose to solve the matching problem between the antenna and feed line, and finally effective transmissions and emissions were achieved.

Due to its slight weight, small volume and flimsy section, microstrip patch antenna could be produced together with feed line and matching circuits simultaneously, which also could be integrated with the PCB in the communication system. The microstrip patch could be produced following designed process, with low cost and easy in mass production, making them widely adopted in GSM communication system. In present work, using the antenna simulation software, the effects of different feed points on the pattern and corresponding impedance characteristics of antenna were investigated for the probe-fed microstrip antenna, by which the matching feed and effective emission were achieved.

II. PRINCIPLE AND RADIATION FIELD OF MICROSTRIP ANTENNA

In spite of the short history, the microstrip antenna has attracted great attentions on account of its several advantages, and a lot of works have been carried out by researchers, by which various theories and analytic techniques on microstrip antenna were proposed. In general, three theoretical models were adopted, which would be elaborated as follows. In Transmission Line Model (TLM) theory, rectangular microstrip patch antenna was taken as a length of microstrip transmission lines, with both two ends loaded by the equivalent admittance of radiating slot. However, TLM theory was only applicable to thin rectangular patch antenna basically. As proposed by Prof. Luo, the lower space of thin microstrip antenna in Cavity Model (CM) theory could be regarded as a resonator cavity, which was composed of upper and bottom electric walls and peripheral magnetic wall. With the employment of CM theory, an in-depth perception on the performance characteristics of microstrip antenna could be obtained, and the input impedance of the antenna with the thickness ranging from $0.005\lambda_g \sim 0.02\lambda_g$ could be calculated. CM theory could be used in the discussion of patch antennas with different shapes; however, the model was restricted to the situation that far less antenna thickness compared with

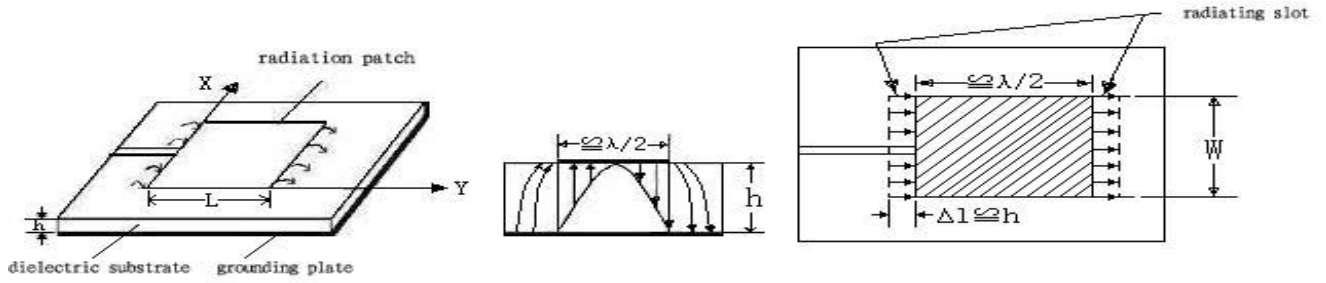


Fig. 1 The schematic diagrams for the structure of rectangular microstrip patch antenna and physical model of TLM theory.

the wavelength. IEM-Integral Equation Method (IEM) theory, also known as Full Wave theory, was a numerical solution problem based on the electromagnetic boundary conditions. In principle, IEM theory could be applicable to the microstrip antennas with different structures and thicknesses; nevertheless, it would suffer many limitations in practical, such as calculated models and time.

For the rectangular patch adopted in present work, TLM could be considered as the ground mode in CM theory. The calculated field distribution and related parameters approached the practical results at around the resonant frequency, which could meet the engineering accuracy on the whole. In TLM theory, the fundamental ideas were that the rectangular patch was considered as a section of low-resistance transmission lines and the two equivalent slots for two ends of patch were considered as the physical model displayed in Fig. 1.

As shown in Fig. 1, the dimension of rectangular microstrip patch was $L \times W$, with the thickness of substrate being h ; specifically, λ_0 , where λ_0 represented the wave length in free space. The patch mentioned above could be considered as a section of microstrip communication line, with the length and width being L and W , respectively. Open circuit appeared near the terminal end along L side, and therefore the voltage antinode formed. In general, L could be set as $L \approx \lambda_g/2$ approximately, while another antinode appeared at the other terminal end along L side. The radiation of antenna could be corresponding to a dual-slot radiation, and the equivalent magnetic current across the slot was uniform, by which the radiation field of antenna could be calculated

$$E_\theta = A \cos \phi \cos \left[\frac{K_0 L}{2} \sin \theta \cos \phi \right] \bullet F_1(\theta, \phi) \bullet F_2(\theta, \phi) \quad (1)$$

$$\text{in which } F_1(\theta, \phi) = \frac{\sin \left[\frac{K_0 W}{2} \sin \theta \sin \phi \right]}{\frac{K_0 W}{2} \sin \theta \sin \phi},$$

$$F_2(\theta, \phi) = \frac{\sin \left[\frac{K_0 h}{2} \sin \theta \cos \phi \right]}{\frac{K_0 h}{2} \sin \theta \cos \phi}, \quad A = j \frac{2VW}{\lambda_g r'} e^{-jk_0 r'}, \quad \text{and } r'$$

was the distance between a certain point in field and the central point of patch.

As mentioned before, $h \ll \lambda_g$, $F_2(\theta, \phi)$ were approximately to be 1 and Eq. (1) could be rewritten as

$$E_\phi = A \cos \theta \sin \phi \cos \left[\frac{K_0 L}{2} \sin \theta \cos \phi \right] \bullet F_1(\theta, \phi).$$

It could be deduced from above two equations that: (i) if $\phi = 0^\circ$, E_θ component existed, which could be considered as E plane, including the propagation direction of quasi-TEM wave and z axis; (ii) if $\phi = 0^\circ$, E_θ was zero and only E_ϕ component existed, which also known as H plane, being perpendicular to the direction of propagation.

Accordingly, the normalized pattern of E plane when $\phi = 0^\circ$ could be described as: $f_E(\theta) = \cos \left[k_0 \frac{L}{2} \sin \theta \right]$; while the normalized pattern of H plane when $\phi = 90^\circ$ could be

$$\text{described as } f_H(\theta) = \frac{\sin \theta \left[k_0 \frac{W}{2} \sin \theta \right] \cos \theta}{k_0 \frac{W}{2} \sin \theta}.$$

The corresponding radiation power could be expressed as:

$$P = \frac{1}{2} \oint_s E \times H^* \cdot \hat{r} ds \quad (2)$$

III. RESEARCHES ON FEED METHOD AND IMPEDANCE CHARACTERISTICS OF MICROSTRIP ANTENNA

As one kind of energy converters, transmitting antenna converted the high frequency current (HFC) into the radiation electromagnetic field energy, i.e., spatial electromagnetic wave, while receiving antenna performed are verse procedure. Either the connection between transmitter and antenna or the connection between antenna and receiver were implemented by feed lines, which implied that matching performance between antenna and feed lines would directly affect the effectiveness of transmitting and receiving of antenna. Only when matched with the input impedance of antenna acceptably, the feed lines worked in the traveling wave regime and yielded efficient transmission and emission of current. Consequently, studies on the feed method and impedance characteristics of antenna were necessary and significant.

The feed methods of microstrip patch antenna included two forms, side-fed and probe-fed, as displayed in Fig. 2, respectively.

When worked at a same frequency, the required area in side-fed antenna would be larger than that in probe-fed, since the characteristic of microstrip lines was similar to a RLC simple parallel resonance circuit when they worked at around the resonant frequency of dominant mode. With resonance oscillation occurred in the antenna, the input resistance could be calculated by:

$$R_{01} = \frac{120\lambda_0 h Q}{\epsilon_r W L} \cos^2\left(\frac{\pi y_0}{L}\right) = R_a \cos^2\left(\frac{\pi y_0}{L}\right) \quad (3)$$

where W and L were the width and length of the rectangular patch, respectively; and y_0 was the ordinate of the feedpoint.

As concluded from the Eq. (3), R_{01} reached the maximum R_a , usually at approximately $100 \sim 300\Omega$ when $y_0 = 0$ (side-fed method). With the aim of matching to a 50Ω feed system, the impedance matcher was introduced,

which led to an increase of antenna area as well. In present work, a coaxial probe-fed method was adopted, which gave rise to several advantages including: (i) the selected feed point could be at any interesting position for a suitable match; (ii) coaxial cable was located below the grounding plate for prevention from the influences on the antenna. Conclusively, the above-mentioned theoretical model of feeder could be expressed as the magnetic ring at the opening of coaxial line which linked the current cylinder with the grounding plate along z direction. To give a simplification processing, the magnetic current was neglected and the current sheet at the central axis of cylinder was used to represent the current column. A detailed introduction of method was presented in Ref. [2], in which the input impedance of microstrip antenna was calculated using TLE theory. For most of engineering applications, the calculations with TLE theory could produce appreciate results and applicable for any feed points, in which the mutual coupling between the radiating slots of antenna was taken into consideration, with the equivalent circuit exhibited in Fig. 3.

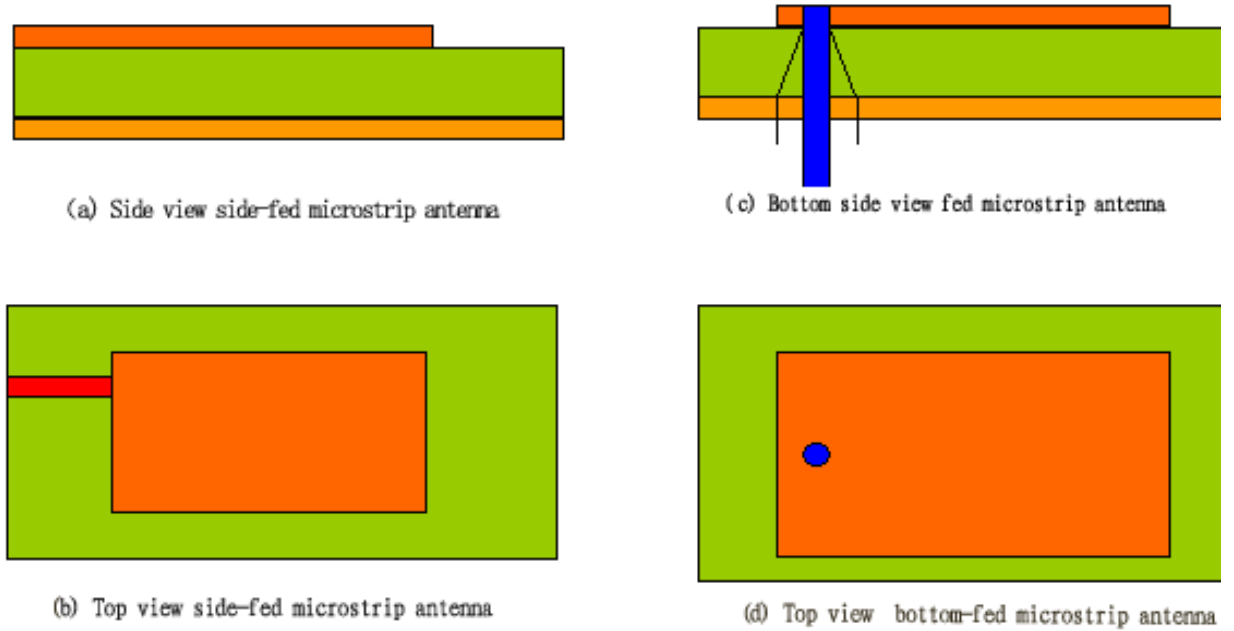
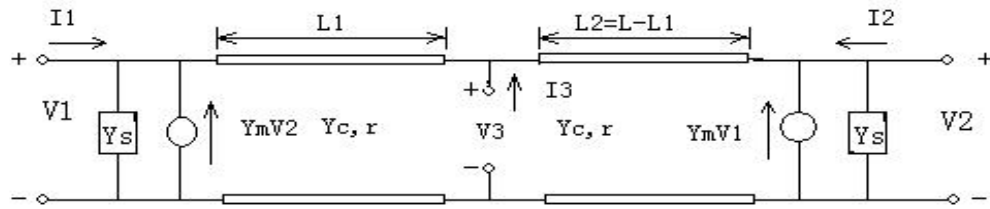


Fig. 2 The schematic diagrams for the side-fed and probe-fed microstrip antennas. (a) side view of side-fed microstrip antenna; (b) top view of side-fed microstrip antenna; (c) side view of probe-fed microstrip antenna and (d) top view of probe-fed microstrip antenna.



where Y_s denoted the self-admittance of the radiating slot, Y_m denoted the self-admittance of the radiating slot which counted the mutual coupling of radiating slot, Y_c denoted the characteristic admittance of microstrip line formed by the patch, and $\gamma = \alpha + j\beta$ was the complex propagation constant of this line.

Fig.3 Equivalent circuit in TLE theory

As displayed in Fig. 3, the admittance matrix of three-port network could be described as:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_s + Y_c \coth(\gamma L_1) & -Y_m & Y_c \csc h(\gamma L_1) \\ -Y_m & Y_s + Y_c \coth(\gamma L_1) & -Y_m \\ Y_c \csc h(\gamma L_1) & Y_c \csc h(\gamma L_1) & Y_s + Y_c \coth(\gamma L_1) \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (4)$$

With the regard to the system fed by radiation side, i.e., $I_2 = I_3 = 0$, $L_3 = 0$, and then

$$Y_{in} = \frac{I_1}{V_1} = Y_s + Y_c \coth(\gamma L) - \frac{[Y_m + Y_c \csc h(\gamma L)]^2}{Y_s + Y_c \coth(\gamma L)}$$

$$Y_{in} = \frac{I_1}{V_1} = \frac{Y_c^2 + Y_s^2 - Y_m^2 + 2Y_c Y_s \coth(\gamma L) - 2Y_c Y_m \csc h(\gamma L)}{Y_s + Y_c \coth(\gamma L)}$$

For the system fed by any feed points, the ports were adopted as the feed point, and then

$$Y_{in} = \frac{I_1}{V_1} = Y_s + Y_c \coth(\gamma L) - \frac{[Y_m + Y_c \csc h(\gamma L)]^2}{Y_s + Y_c \coth(\gamma L)}$$

$$Y_{in} = \frac{I_1}{V_1} = \frac{Y_c^2 + Y_s^2 - Y_m^2 + 2Y_c Y_s \coth(\gamma L) - 2Y_c Y_m \csc h(\gamma L)}{Y_s + Y_c \coth(\gamma L)}$$

When fed by probe, the inductance of lead wire should be added to the input impedance, which could be calculated approximately by the probe reactance of the dielectric-filled parallel-plate waveguide. Assumed that the thickness of probe was d_0 , and then

$$X_L = \frac{377h}{\lambda_0} \ln \frac{\lambda_0}{\pi d_0 \sqrt{\epsilon_r}} \quad (5)$$

where $Z_c = \frac{\eta_0}{\sqrt{\epsilon_e}} \frac{h}{W_e}$; $\beta = \frac{2\pi}{\lambda_g} = k_0 \sqrt{\epsilon_e}$, $\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_e}}$, $\alpha = 0.5\beta \tan \delta_e$, $\eta_0 = 120\pi$, representing the wave impedance in free space; $k_0 = 2\pi / \lambda_0$, representing the wave number in free space; $\epsilon_e = \frac{1}{2}[\epsilon_r + 1 + (\epsilon_r - 1)(1 + \frac{10h}{W})^{-1/2}]$, representing the corresponding dielectric constant; $\tan \delta_e$ was the equivalent tangent value of losses; W_e was the equivalent width, i.e., $W_e = W + \Delta l$, W was the actual width and Δl could be calculated by Hamosita's empirical formula:

$$\frac{\Delta l}{h} = 0.412 \frac{(\epsilon_e + 0.3)(W/h + 0.264)}{(\epsilon_e - 0.258)(W/h + 0.8)} \quad (6)$$

The relationship between the calculation of parameters in admittance matrix and the above-described radiation field of antenna was depicted minutely in Ref. [4].

IV. ANALYSES ON THE FUNDAMENTAL CHARACTERISTICS OF PROBE-FED MICROSTRIP ANTENNA WITH ANSOFT HFSS

Taken a fan-beam base station antenna for example, the effects of the variation of feed point on the input impedance and pattern of antenna were studied using three-dimensional electromagnetic simulation software ANSYS Ansoft HFSS, by which the feed point would be selected properly to produce a satisfactory match between microstrip antenna and feed lines.

The related parameters in the system were listed as follows. The dimension of antenna was 46 mm * 50 mm * 2.5 mm, and the substrate was composed of PTEE glass fiber, with the dielectric constant ϵ_r being 2.55 and conductivity σ_c being 10^4 s/mm. The antenna worked in the TM_{01} mode, and the field exhibited an even distribution along X direction and a varied distribution along Y direction meanwhile. Along the Y direction, the feed point was shifted at about 5, 15, 20 and 25 mm, and the corresponding tendency of input impedance and pattern of antenna would be discussed deeply in the following.

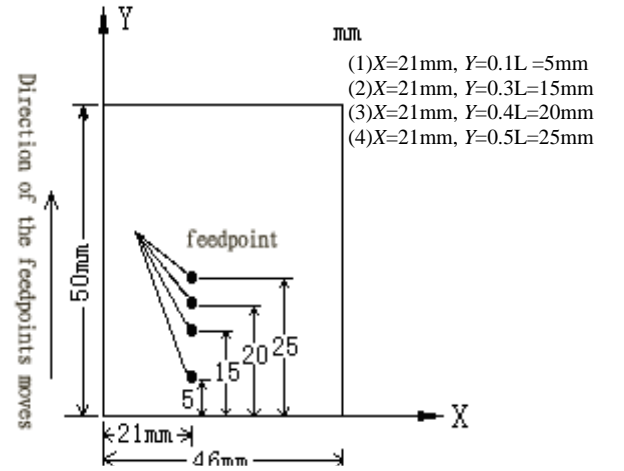


Fig. 4 The schematic diagram of the feed-point position.

As illustrated in Figs. 5-8, the E-plane and H-plane patterns with the selection of different feed points were displayed in (a) and (b), respectively; and the variations of reflection coefficient of antenna with the change of frequency at different feed points, with the frequency varying from 900 to 1000 MHz were given in (c). As a single-port network, the reflection coefficient of antenna presented a one-to-one correspondence relationship with the input impedance:

$$\bar{Z} = \frac{1 + S_{11}}{1 - S_{11}}$$

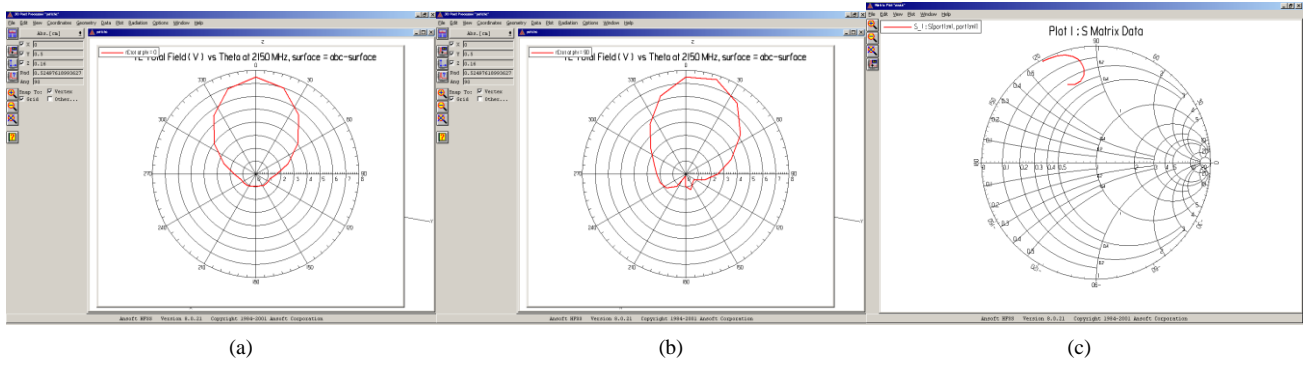


Fig. 5 The variations of pattern and reflection coefficient S_{11} when $Y=0.1L=5\text{mm}$.

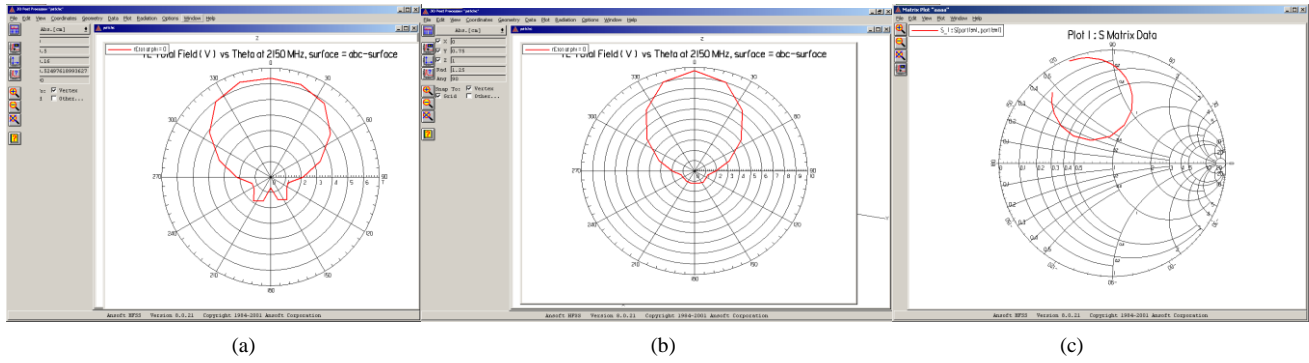


Fig. 6 The variations of pattern and reflection coefficient S_{11} when $Y=0.3L=15\text{mm}$.

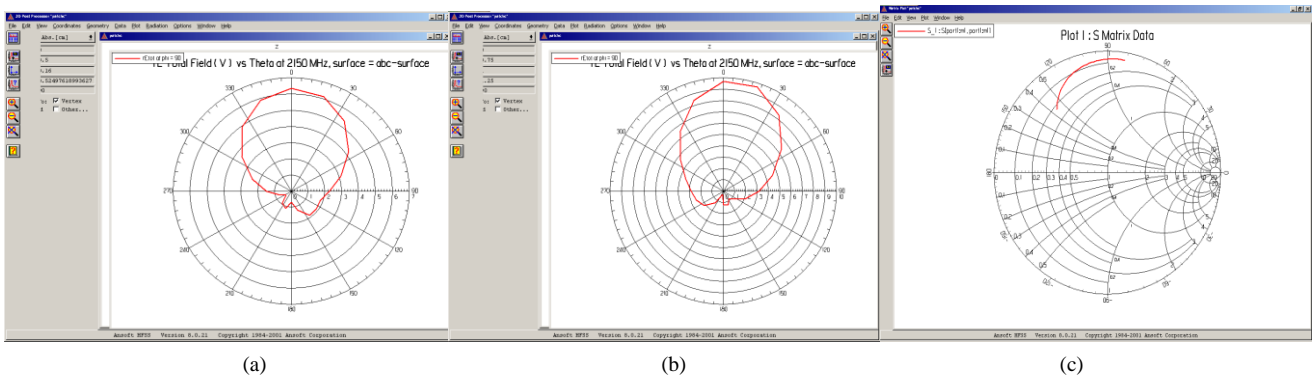


Fig. 7 The variations of pattern and reflection coefficient S_{11} when $Y=0.4L=20\text{mm}$.

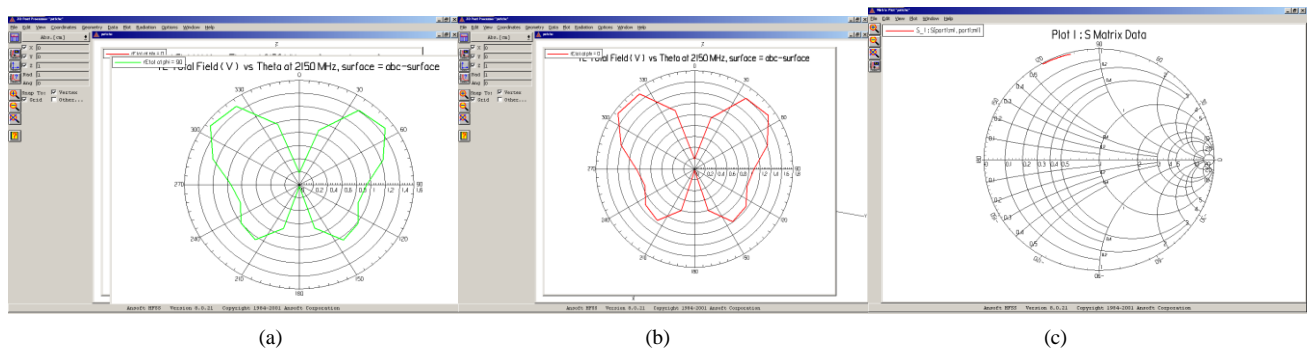


Fig. 8 The variations of pattern and reflection coefficient S_{11} when $Y=0.5L=25\text{mm}$.

V. CONCLUSIONS

From the simulation results in Figs. 5-8, some main conclusions could be drawn and listed as follows:

(i) As shown in (c) of Figs. 5-8, the input impedance of antenna presented a variation to a large degree with the shift of feed point along Y direction. The reflection coefficient in Fig. 7 (c) almost approached the circle of pure reactance, resulting in a severe mismatch. It could be found in Fig. 6 (c) that frequency range located in the circle of equal standing wave was the biggest, which implied that an excellent match state was obtained and therefore provided theoretical basis for the suitable selection of feed point.

(ii) The pattern of antenna mainly depended on the dominant mode field, which remained almost invariable with the change of feed-point position, as shown in the (a) and (b) of Figs. 5-7. Nevertheless, the feed point could not be selected at around $Y = 0.5 L$, since the related reflection coefficient would be at the unit circle, i.e., $|s_{11}| \approx 1$, implying a serious mismatch. Meanwhile, the pattern displayed an awful distortion, which could not meet the requirements in normal communications.

In summary, using Ansoft HFSS simulation software, the pattern and reflection characteristics of GSM microstrip antenna with the selection of different feed points were investigated, and the degree of impedance match in a specified range of working frequency was studied, which would provide directive significance to the achievement of the match between GSM microstrip antenna and feed lines, the improvement of transmission efficiency and reduction of the design circle of antenna.

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