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On the Effect of Metallic Earring on Antenna Performance and SAR at 2.4 & 5.8 GHz

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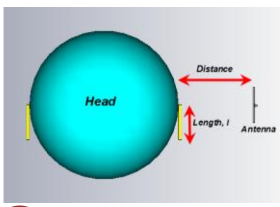
Graphical abstract



Abstract

This paper presents an investigation on the effect of metallic items on the antenna performance and SAR at 2.4 GHz and 5.8 GHz frequencies. The simulations are performed by means of CST Microwave Studio. The patch dipole antenna is used as the radiating source while the metallic items are modeled as $\lambda/4$ and $\lambda/2$ straight pin-type earrings respectively. The results show that the presence of the head shifted the antenna resonant frequencies and modify the antenna radiation pattern at both investigated frequencies. This study has also indicated that the additional metallic item in close proximity to the head has an additional effect on antenna resonance, albeit quite a small one. However, the straight-pin type earring has significantly increases the amount of energy absorbed in the human head at both frequencies tested.

Keywords: Antenna performance; human head; metallic items; specific absorption rate (SAR)

1.0 INTRODUCTION

The use of wireless devices has become more popular, yet the user has become more concerned on any possible health effects due to the electromagnetic field radiated by the antenna associated with the wireless devices. While using such wireless devices, the current and the electromagnetic fields are induced into the user's body and thus could result in tissue heating due to the dielectric losses [1]. In addition to that, there is general fashion amongst users wearing metallic objects such as spectacles and metallic jewellery on the head. The metallic items may be placed in relatively close proximity to the radiating sources. Therefore, the additional metallic items may have effects on the amount of the electromagnetic field radiated by the antenna. Numerous studies have examined the interaction between the electromagnetic fields radiated by the mobile handset with the presence of the human head [2,3], the additional conductors such as wire-framed spectacles, hands-free [4-6] and other types of metallic items such as ring, pierced metallic object [7-9].

However to date, the effects of metallic jewellery worn on the head have received limited attention in the literature. In addition, it should be noted that there is a general trend for higher frequency communication devices and the influence of jewellery may be more significant due to resonance effects.

In this paper, the effects of the head with and without the metallic earring on the antenna performance and SAR are presented. The results presented for two different frequencies of 2.4 GHz and 5.8 GHz.

SAR indicates the amount of RF energy absorbed by the body (per unit mass) when exposed to the electromagnetic field radiation. SAR is calculated by the equation (1):

$$SAR = \frac{\sigma |E^2|}{\rho} (W/kg) \quad (1)$$

|E| is the electric field magnitude (rms), σ is the conductivity (S/m) and ρ is the material mass density (kg/m^3).

2.0 SIMULATION SETUP AND METHODOLOGY

In this paper, a patch dipole antenna is employed as the radiating source, which operates at 2.4 GHz and 5.8 GHz frequencies. The antenna consists of 0.035 mm thickness of metallic layer (copper) on top of the FR4 substrate with dielectric constant ε_r= 4.7, loss tangent of 0.019 and thickness of 1.6 mm (see Figure 1).

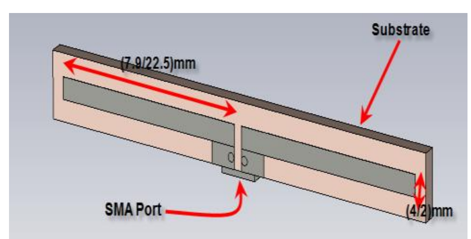


Figure 1 The antenna model used in this paper (5.8 GHz/2.4 GHz)

To begin, the antenna structure is simulated in free space condition using commercially available software package CST Microwave Studio. The antenna performances in free space are then compared with the two cases considered in this study, which are:

a) With the presence of the head
b) With the presence of the head and metallic items

2.1 The Head Modeling

The head is modeled as a homogeneous spherical head with the radius of 100 mm. The frequency dependent parameters (ε_r, σ) used in the human head are the same as the standard tissue equivalent liquids recommended by the IEEE and FCC [10] and listed in Table 1. In addition, the distance *d* between the head and the antenna is varied to 5, 10, 20, 50 and 100 mm (see Figure 2).

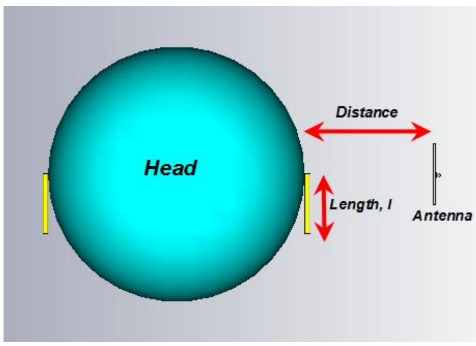


Figure 2 The simulation setup

Table 1 Dielectric properties of homogenous head model at 2.4 GHz and 5.8 GHz

Frequency (GHz)	ε_r	σ (S/m)
2.4	39.2	1.8
5.8	35.3	5.27

■3.0 RESULTS AND DISCUSSION

Results presented in this paper are the preliminary results based on simulations by means of CST Microwave Studio. The antenna performance in free space will be compared with the performance in the presence of the head with and without metallic earring. In addition, the amount of energy absorbed in the head will be presented in comparison with the case of wearing a metallic earring at both frequencies tested.

3.1 The Antenna Resonance

Figure 3 and Figure 4 show the variations on the antenna resonant frequency due to the presence of the head at 2.4 GHz and 5.8 GHz respectively. It can be clearly seen that the presence of the head has detuned the antenna resonant frequency at both frequencies. The EM coupling effect to the human head on the antenna characteristics may cause the antenna to appear as electrically longer or shorter than the actual length, thus shifting the antenna resonant frequency from the original resonance. However, the detuning effect may vary depending on the distance between the head and the antenna tested. The earring is however only show minor effect on the results.

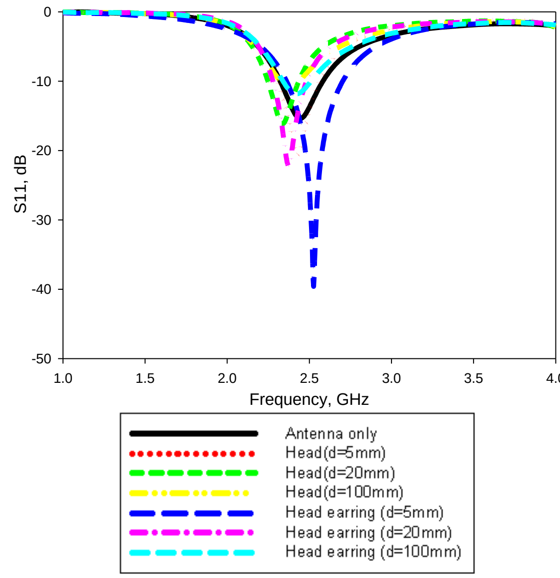


Figure 3 Simulated S_{11} at 2.4 GHz

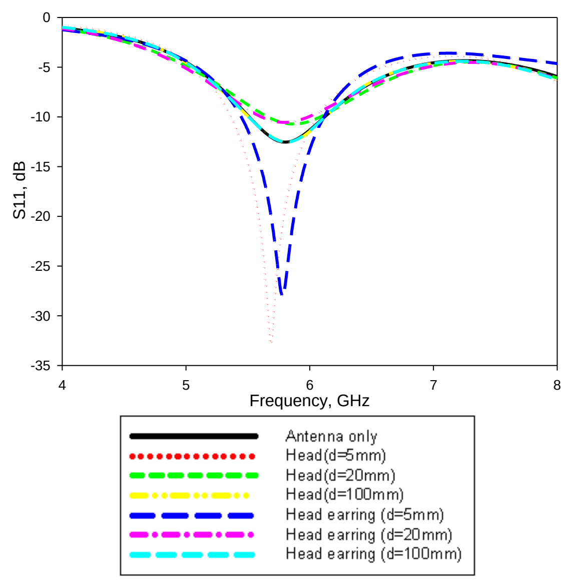
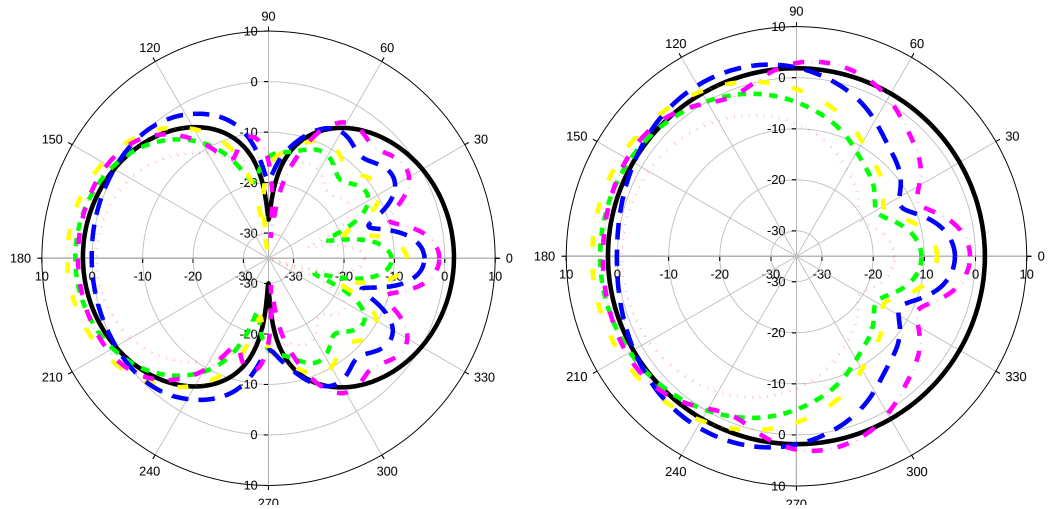


Figure 4 Simulated S_{11} at 5.8 GHz

3.2 The Antenna Radiation Pattern

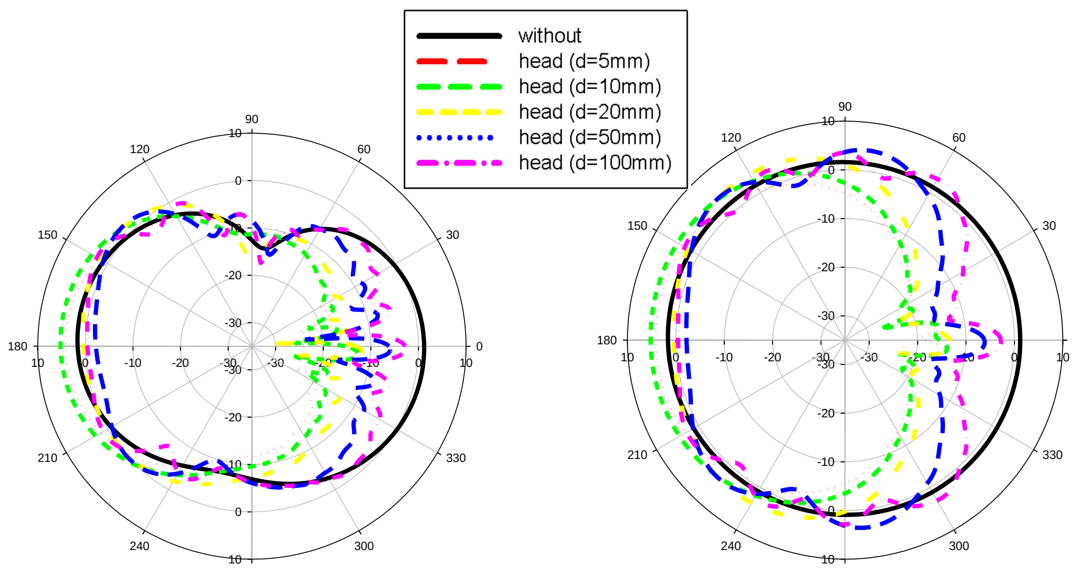
Figure 5 and Figure 6 show the far-field radiation pattern results at 2.4 and 5.8 GHz respectively. The head is placed at various distances from the antenna. Figure 5 and Figure 6 show that the tested antenna has an omni-directional radiation pattern in free space. In the presence of the head, the antenna radiation pattern has significantly changed in the direction of the head due to the blocking effect by the presence of the head and due to energy absorption inside the head. The head block the signal from passed through the head. In addition, it can be seen that the antenna radiation pattern is considerably modified when the head is at the closest distance from the antenna. The antenna radiation pattern is significantly improved as the *d* is increases.

Furthermore, Figure 7 and Figure 8 show the far-field radiation pattern results at 2.4 and 5.8 GHz respectively in the presence of the head with and without the metallic earring. The plot is taken at d = 5 mm and d = 20 mm whilst the earring length is $\lambda/2$. For the distances greater than 5 mm, the effects of the earring are more likely to the effect at d = 20 mm as shown in the Figure 7 and Figure 8. At the d = 5 mm, the metallic earring causes the radiation pattern of the antenna to be less penetrates through the head (caused the v-shape at the earring direction). Both figures clearly showed that the metallic earring only cause minor change on the pattern owing to the presence of the head. These results seem to suggest that metallic objects will be less likely to perturb the antenna radiation performance at both frequencies tested.



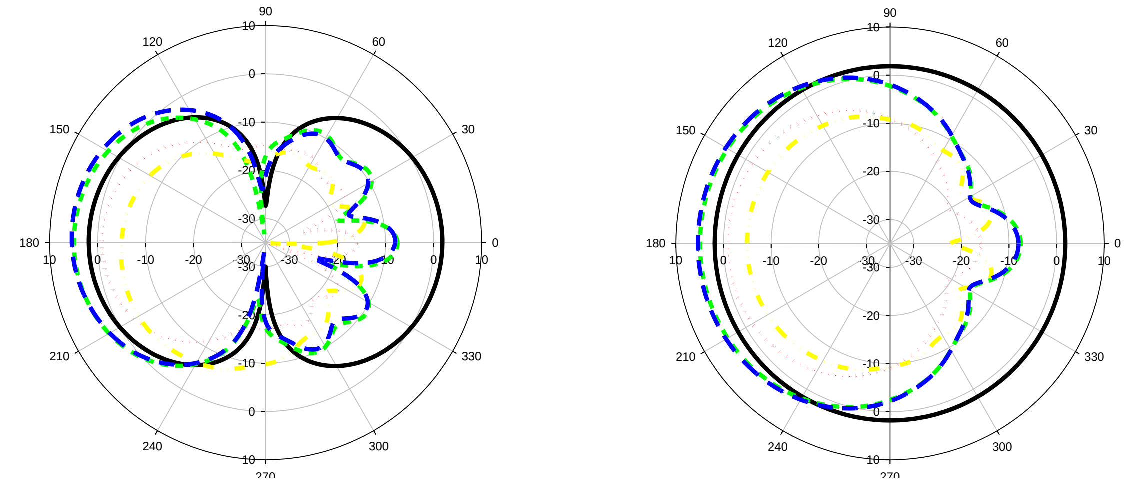
(a) (b)

Figure 5 Antenna radiation pattern simulated at 2.4 GHz with and without the head (a) E-plane, (b) H-plane



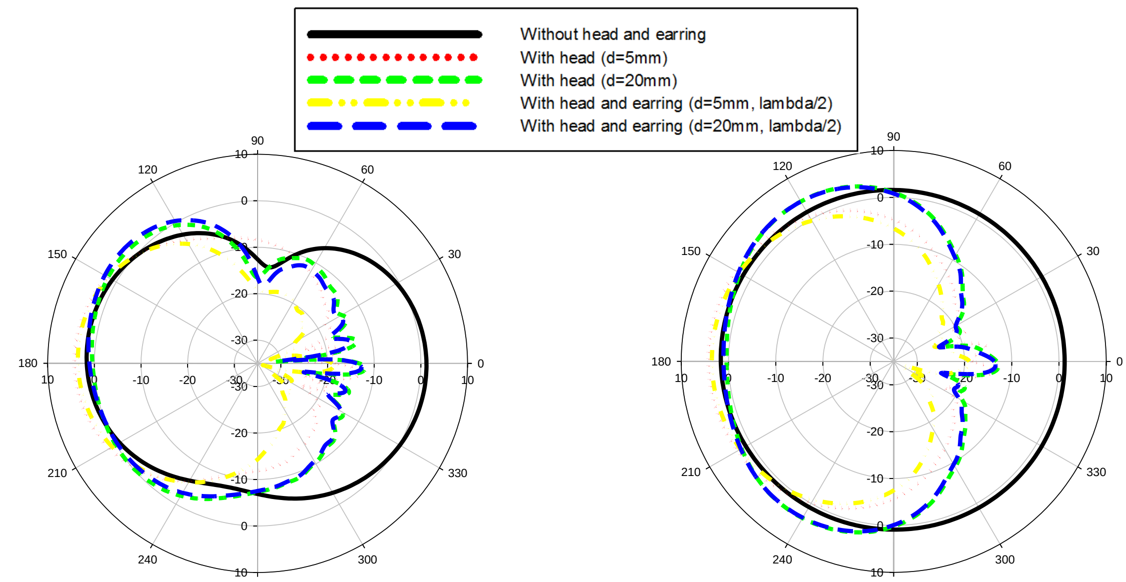
(a) (b)

Figure 6 Antenna radiation pattern simulated at 5.8 GHz with and without the head(a) E-plane, (b) H-plane



(a) (b)

Figure 7 Antenna radiation pattern simulated at 2.4 GHz with and without the head and metallic earring (a) E-plane, (b) H-plane



(a) (b)

Figure 8 Antenna radiation pattern simulated at 5.8 GHz with and without the head and metallic earring (a) E-plane, (b) H-plane

3.3 The Specific Absorption Rate (SAR)

Figure 9 shows the Peak SAR values inside the head with and without the presence of the straight-pin type earring at both frequencies tested. Table 2 and Table 3 summarize the average 10 g SAR inside the head with and without the earring. The length of the earring is varied to $\lambda/4$ and $\lambda/2$ of the respective frequencies considered in this paper.

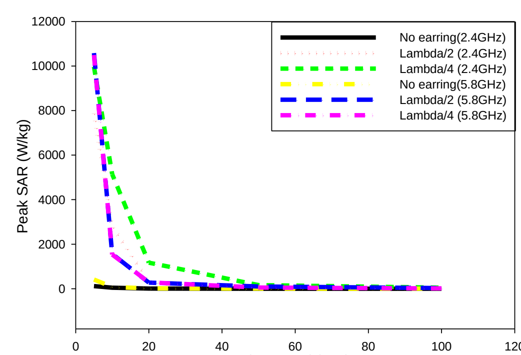


Figure 9 Peak SAR in the head with/without earring at 2.4 and 5.8 GHz

(a)

Table 2 Average 10 g SAR with and without earring at 2.4 GHz

	SAR (10g) W/kg				
Distance, *d* (mm)	**5**	**10**	**20**	**50**	**100**
Head only	19.26	10.60	2.58	0.37	0.10
Head + earring λ/2	27.52	14.91	3.19	0.43	0.16
Head + earring λ/4	27.55	15.22	3.68	0.52	0.17

Table 3 Average 10 g SAR with and without earring at 5.8 GHz

	SAR (10g) W/kg				
Distance, *d* (mm)	**5**	**10**	**20**	**50**	**100**
Head only	17.18	5.10	1.63	0.39	0.10
Head + earring λ/2	25.60	6.38	1.87	0.52	0.14
Head + earring λ/4	24.63	5.86	1.72	0.45	0.12

From Figure 9, it can be observed that the earring has significantly increases the Peak SAR values in the head by more than 5 times at 5.8 GHz while the Peak SAR has increased by more than 50% at 2.4 GHz when compared with the case of the head by itself. When the electromagnetic field impinges on metallic object, the field is scattered and the metallic objects may redistribute the incident RF energy around them, leading to stronger energy absorption inside the human tissues. In addition to that, metallic items with resonance length are also expected to cause high enhancement of the field thus increases the SAR.

From Table 2 and 3, the averaged 10 g SAR values inside the head is increased by the straight-pin type earring, albeit quite a small one if compared to the Peak SAR values. The averaged 10 g SAR is expected to be less affected as at these two higher frequencies (2.4 and 5.8 GHz), the field penetrates less than at lower frequency bands. Nevertheless, the amount of energy absorbed inside the head is noticeably decreased when the distance between the head and the antenna is increased, either with or without the metallic item.

Figure 10 illustrates the SAR distribution inside the head at 2.4 GHz. This could provide some overview of the SAR distributions owing to the presence of metallic jewellery on each case investigated. Figure 10 presents the SAR distribution for two different distances *d* between the antenna and the head model which are at *d* = 5 mm and *d* = 10 mm respectively.

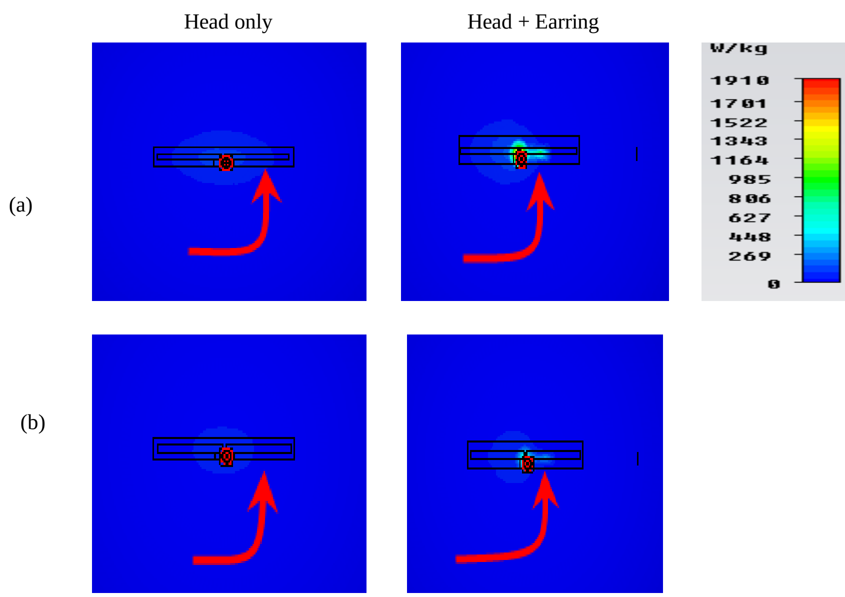


Figure 10 The SAR distribution in the head at 2.4 GHz. (a) At *d* = 5 mm. (b) At *d* = 10 mm

Figure 10 clearly showed that when a metallic objects like an earring lies close to the radiating source; it affects the radiated field and the SAR distribution. The maximum SAR generally appears in the area where the earring is in the closest distance from the head. In other words, the earring also could cause the EM field to be focusing on the smaller region close to the place where the earring is attached compared to the case of without the earring. In addition, the figure also illustrated that the SAR in the head is decreased when the distance between the antenna and the head is increased.

■4.0 CONCLUSION AND FUTURE WORKS

The results presented in this paper are solely based on computer simulation using the commercially available software CST Microwave Studio. It is currently difficult to validate the simulation results with the direct measurement of SAR due to the lack of currently available equipment and the inherent difficulty of producing such an item. In the current paper, a patch dipole antenna has been used as the radiating source. It is well-known that the human head have influences on the antenna performance. This study has indicated that the additional metallic jewellery worn on the human head has an additional effect.

In this study, a homogeneous spherical head model filled with ε_r = 39.2 and σ = 1.8 for 2.4 GHz whereas ε_r = 35.3 and σ = 5.27 for 5.8 GHz has been modeled and placed at various distances from the antenna. The metallic jewellery was modeled as straight-pin type earrings made of copper and the length was chosen to be $\lambda/4$ and $\lambda/2$ for both frequencies tested respectively. The results show that the antenna resonant frequency and radiation pattern were notably detuned due to the presence of the human head. However, the metallic items shows small effect on the antenna radiation performance (d = 5 mm) but significantly affects the amount of energy absorbed inside the human head. The magnitude of absorption may be affected by the proximity of the metallic earring to the antenna and the position and geometry of the head model. Results have shown that the SAR inside the head significantly increased due to the presence of the straight-pin type earring compared to the case of without the earring. Peak SAR values in the head increased by more than 5 times at 5.8 GHz while the Peak SAR is increased by more than 50% at 2.4 GHz when compared with the case of the head by itself.

Nevertheless, the SAR values are varying depending on the operating frequency and the distance between the antenna and the head model. The metallic jewellery may significantly enhance the amount of energy absorbed in the head when the head is placed in close proximity to the antenna. There is no serious effect can be seen when the distance between the head and the antenna is increased, while no noticeable enhancement was seen deeper in the head due to the earrings at both frequencies tested. Hence, at higher frequencies the field penetrates less than at lower frequency bands.

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