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ANALYSIS OF MATERIALS EFFECTS ON RADIO FREQUENCY ELECTROMAGNETIC FIELDS IN HUMAN HEAD

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Abstract—In this paper, we propose to study the variability of specific absorption rate (SAR) of a human head due to different materials in the vicinity of the handset. We include the effects of the human hand, handset chassis and additional conductive material particularly hand-ring jewelry. A finite-difference time-Domain (FDTD) method was used to analyze different positions of the conductive ring materials within the hand model. Furthermore, the impact of this material on the performance of an antenna was considered in this study. We found that including a hand model leads to a significant reduction in SAR. The hand influences not only SAR distribution but also antenna performance. Moreover, adding conductive materials to the hand results in increases in the local SAR values of the head model. The results suggest that the hand model is important in SAR evaluation and that having an additional conductive material on the hand may vary the amount of electromagnetic (EM) energy absorption depending on the position of the material.

1. INTRODUCTION

Currently, the use of wireless devices, particularly mobile phones, has increased dramatically. The increasing use of these devices has also increased the amount of electromagnetic (EM) radiation to which human bodies are exposed and is accompanied by growing concern

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for possible health effects on humans. These effects are related to the amount of EM energy deposited in the tissue and are generally evaluated using SAR by averaging the value of the tissue mass. The American National Standards Institute (ANSI) has specified SAR safety limit of 1.6 W/kg over one gram of tissue, while the International Commission on Non-Ionizing Radiation Protection (ICNIRP) capped the limit at 2 W/kg over a tissue volume of ten grams in the shape of a cube [1, 2].

As reported by the World Health Organization (WHO), radiofrequency (RF) EM fields, such as those emitted by wireless communication devices, have become one of the top pollution sources, which may lead to potential health effects on humans. Based on the increased risk for glioma (a malignant type of brain cancer associated with cell phones), the WHO has classified RF EM fields as possibly carcinogenic to humans. Consequently, many research works were conducted regarding the interaction between EM energy and human head [3–5].

Many studies have evaluated the SAR in human body models [5–10]. Recently, compact antennas with a low SAR have become essential in the design of handsets. Some studies analyzed the reduction in SAR using a reflector between a radiator and a head [11–15]. Over time, different methods have been proposed to reduce the SAR in human tissue [8–14]. The authors have studied the effects of attaching additional materials to mobile phones, including the applications of conducting materials and insertion of ferrite sheets between an antenna and a human head. Currently, metamaterials, including electromagnetic band-gap (EBG) structures, have been proposed for handset antennas to reduce electromagnetic absorption in the human body [12, 14–17].

Because the EM field characteristics change as they propagate through different medias, the effects of conducting materials of different sizes and shapes close to the human body have been observed by the authors, and significant changes in the SAR were found in the human head [16–18]. In related topics, different methods have been proposed, including the application of different antennas and different metallic object positions. The FDTD method with scaled models of an adult head was used to consider the effects of metallic spectacles on adults and children with a mobile phone placed by the ears [18]. Metallic implants inside the human head have been found to increase the SAR in different human head models [18–21].

Recent studies show that the presence of a hand also changes the radiation performance of a mobile phone and, hence, changes the SAR in the human head [22–33]. In [34], the SAR values for two different human body postures were calculated and resulted in increasing values of the average peak SAR.

According to the literature, there are numerous factors that may affect the SAR induced in the human head, such as the antenna type, the antenna position relative to the human body, implants and others uncertainties. With the recent research findings that cell phone radiation may be linked to cancer, it is important to investigate and monitor any potential effects related to the amount of the EM energy deposited in the human tissue, in particular of materials and objects in the proximity area of the RF radiation. Hence in this paper, we emphasize that the SAR distributions and antenna performance in different situations with a variety of nearby materials.

2. MODELS AND TECHNIQUES

2.1. Models

The elements of the numerical models in this paper were the head model, the hand model and a mobile phone model with a dual band PIFA antenna as a source, as illustrated in Figure 1. The frequency dependent parameters (the relative permittivity, ε_r and conductivity, σ) of the dielectric material was considered, and the values are based on human tissue measurement data, as described in [35–39]. The head model is based on the IEEE Specific Anthropomorphic Mannequin (SAM) model, which consists of a shell and brain simulating liquid. Regularization bodies such as IEEE and, IEC have established product compliance standards to assess exposure levels due to mobile phones and have specified the use of SAM phantoms in such assessments. In the majority studies, the SAR induced by a mobile phone is computed without a hand. In Ref. [25], the authors have shown that the inhomogeneous hand can be replaced with a homogeneous hand model to represent a human hand in real usage conditions, which is

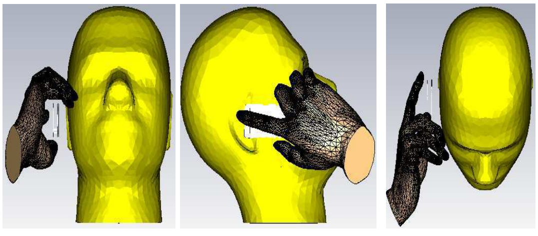

Figure 1. The configuration of the SAM head and hand model with the antenna at the cheek mode.

Table 1. Parameters of the numerical model.

	900 MHz		**1800 MHz**	
	ε_r	σ (S/m)	ε_r	σ (S/m)
Hand	36.2	0.79	32.6	1.26
SAM shell	3.5	0	3.5	0
SAM liquid	41.5	0.97	40.0	1.40
PEC	Perfect Electric Conductor			

implemented in this study. The dielectric properties of the tissues are chosen for the frequency bands used as described in Table 1. The dielectric compositions of the homogeneous hand used in the simulations are the average values between dry and wet hands.

An internal dual-band planar inverted F-antenna (PIFA) plate composed of perfect electric conductor (PEC) is placed at 20 mm from the head model at the cheek position. The conducted power in this study was normalized to 1 W and excited at the 900 and 1800 MHz frequency bands corresponding to the application of a GSM network. The conductive material investigated in this paper was 10 mm in diameter with a 2 mm thickness attached to the fingers (thumb, index, middle, ring and baby). For clarity, the conductive material in this paper is a ring composed of a PEC.

2.2. Techniques

The goal of this paper is to study the influence of different objects near the mobile antenna on the radio propagation. We considered several objects, including the human hand, the handset chassis and conductive materials. The effects on the SAR are studied through a determination of the EM fields in a specified tissue domain using a three dimensional FDTD technique, which is implemented in commercial software from computer simulation technology (CST MWS) and used as the main simulation instrument in this paper. With permutations of the perfect boundary approximation (PBA) and thin sheet technique (TST), significant developments in the geometry approximation with computation speed are achieved with highly accurate results. The non-uniform meshing scheme was adopted such that the majority of the computation was dedicated to regions along the inhomogeneous boundaries for fast and perfect analysis. The minimum and maximum resolutions chosen for the models were 0.1 mm and 0.25 mm in each dimension.

The local SAR at any point inside human tissue is defined as:

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

where E is the root mean square (rms) amplitude of the induced electric field (V/m), σ is the electrical conductivity of tissue (S/m) and ρ is the density of tissue (kg/m^3).

3. THE EFFECTS OF THE USER'S HAND AND THE HANDSET CHASSIS

In typical operating positions, most handsets are held by the user with their fingers on the side of the device. To examine the influences of the presence of a hand, the study was initially performed without a ring near the radiation source. Figure 2 shows the SAR distributions inside the human head model from the top view cutting plane at two different frequencies. As depicted in Figure 2, the intensity of the electric field is high in the tissue near the surface of the head close to the radiation source and attenuates as the electric field propagates through the tissue. The peak SAR was greater at lower frequency (900 MHz) and penetrated deeper into the human head compared to the higher frequency (1800 MHz). The value of the penetration depth of tissue decreases as the operational frequency increases.

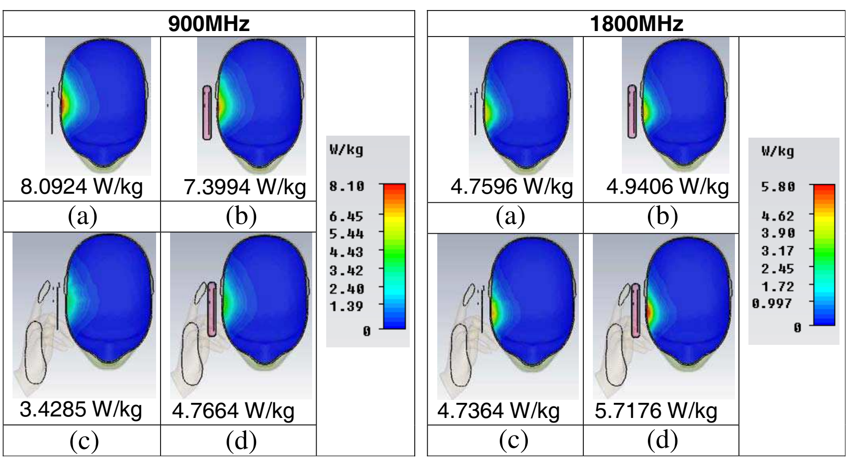

Figure 2. Peak SAR induced at the cheek position for 900 and 1800 MHz, (a) PIFA with head, (b) PIFA with chassis and head, (c) PIFA with head and hand, (d) PIFA with chassis, head and hand.

Figure 2 also shows that, for the PIFA antenna radiating at 900 MHz, the peak SAR 1 g values for the case without a hand and with hand model are 8.0924 W/kg and 3.5595 W/kg, respectively while the SAR 10 g value are 5.6278 W/kg and 2.5245 W/kg, respectively. The difference of the peak SAR 1 g without and with the hand model is a remarkable reduction of 56%, whereas, in [25] it was almost a 50% reduction. As indicated in [37], the peak SAR 1 g in the presence of a head and hand is 2.856 W/kg. This value was found to be lower than the result attained in this study. Regarding the SAR differences, it is interesting to consider the configuration of the hand and head model geometry as well as the type, position, and size of the mobile phone antenna. Moreover, it has been reported in [25] that the human hand significantly alters the near-field of the mobile phone; it may therefore also affect the absorption pattern and the peak SAR in the head. In addition, the effect of the index finger position has been an important factor that is not addressed in detail in this paper. Because the index finger may be close to the antenna, a slight shift can lead to a strong variation of the SAR. The hand model geometry and the exact position of the phone inside the hand must be very precisely defined in order to obtain highly reproducible results in SAR assessment. For the purpose of validation, the calculated SAR without the hand model is compared with the result in [5], which is 9.14 W/kg using the same approach with dual band PIFA and a homogenous head model. The slight difference may be due to different antenna geometry and conductivity. Because communication devices operate with a duty factor of 1/8, all comparisons results were scaled to 1 W.

To determine antenna performance, the PIFA is simulated for return loss (S_{11}) calculation under free space conditions, followed by inclusion of the head, hand and chassis, as shown in Figure 3. The presence of these objects detunes the antenna by shifting the frequency up to 200 MHz. The return loss is significantly affected by the presence of the hand, which reduces the magnitude by 17 dB with respect to free space conditions. Thus, it is important to take this effect into consideration when designing the antenna of the handset.

The impact of the models on TRP will be addressed in this paper as related to the SAR. TRP provides a good assessment of the antenna performance from the system point of view. Figure 4 shows the TRP number for all cases. Noticeably, the TRP of the PIFA at both excited frequencies were decreased quickly by approximately 4 dB when the hand model was included. At 1800 MHz, the plastic chassis led to an unremarkable change in the TRP, with a difference of less than 0.5 dB. Overall, the PIFA without a hand showed the highest TRP and conversely resulted in higher values of the SAR, which implies that

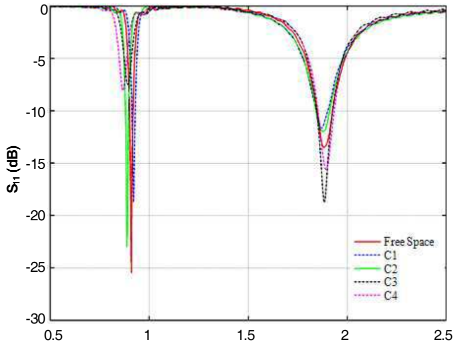

Figure 3. Variation of the return loss with different cases as in Fig. 2, (a) $= C1$, (b) $= C2$, (c) $= C3$, and (d) $= C4$.

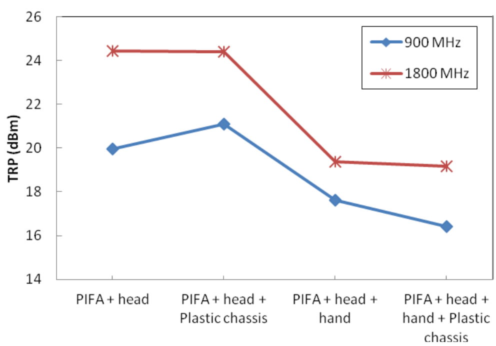

Figure 4. Effect of different models on radiation performance at 900 and 1800 MHZ.

the hand plays a significant role in determining the handset antenna performance.

4. DEPENDENCE ON METALLIC RING POSITIONS

4.1. Evaluation of the Peak SAR Magnitude and Position

Before deriving the hand-ring effects on the SAR, the study first evaluated PEC ring placed at a fixed distance at five different positions, as shown in Figure 5. Although this ring placement is not realistic, this study supports the intended investigations of the effects of hand ring jewelry on the SAR in the next section. When an electromagnetic wave traveling through free space encounters a different medium, the wave

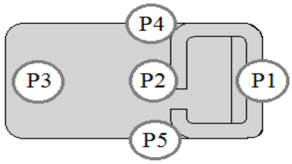

Figure 5. PIFA indicating different ring positions.

is reflected, transmitted and/or absorbed. This mechanism results in different SAR distributions on the surface of the head phantom, as shown in Figure 6. Furthermore, the locations where the maximum SAR occurred were also determined.

4.2. Evaluations of Hand Ring Jewelry on the SAR and Antenna Performance

Regarding the variations of the SAR distribution in Figure 6, the interactions of the EM fields and human head were further assessed with the hand included to study the effects of hand ring jewelry. A PEC ring was placed on each finger one at a time at typical positions whereas jewelry is worn. Tables 2 and 3 contain the peak SAR 1 g, the total SAR and the tissue power simulated at an output power of 1 W for 900 and 1800 MHz respectively. The dosimetry and safety limits for RF exposure are based on the averaged SAR values for 1 g of tissue. In addition, the variations in the peak SAR for 1 g of tissue were calculated and are presented in Figure 7 to determine which ring position has a greater impact on the SAR in the human head. The aim of this section is to focus on the greatest and least significant effects of hand ring jewelry.

The results show that the attachment of a metallic ring on the hand affects not only the peak and total SAR in the head but also the tissue power. As expected, when the total SAR is decreased, the energy absorption was also reduced. Because the available power, conductivity and permittivity are fixed, these results show the decreased level of power absorption as a consequence of the presence of the hand. At a close proximity, most of the power emitted by the antenna is absorbed by the hand and radiated away.

In Figure 7, we find that a hand ring attachment leads to the greatest effects for 900 MHz and causes the peak SAR to increase up to 14.4% with a ring on the index finger. Moreover, the power absorbed also shows a maximum at this rings position with 0.275 W. Concentrating on the higher frequency band, a ring on the ring finger provides the highest peak SAR increase of 9.8%, while the ring on

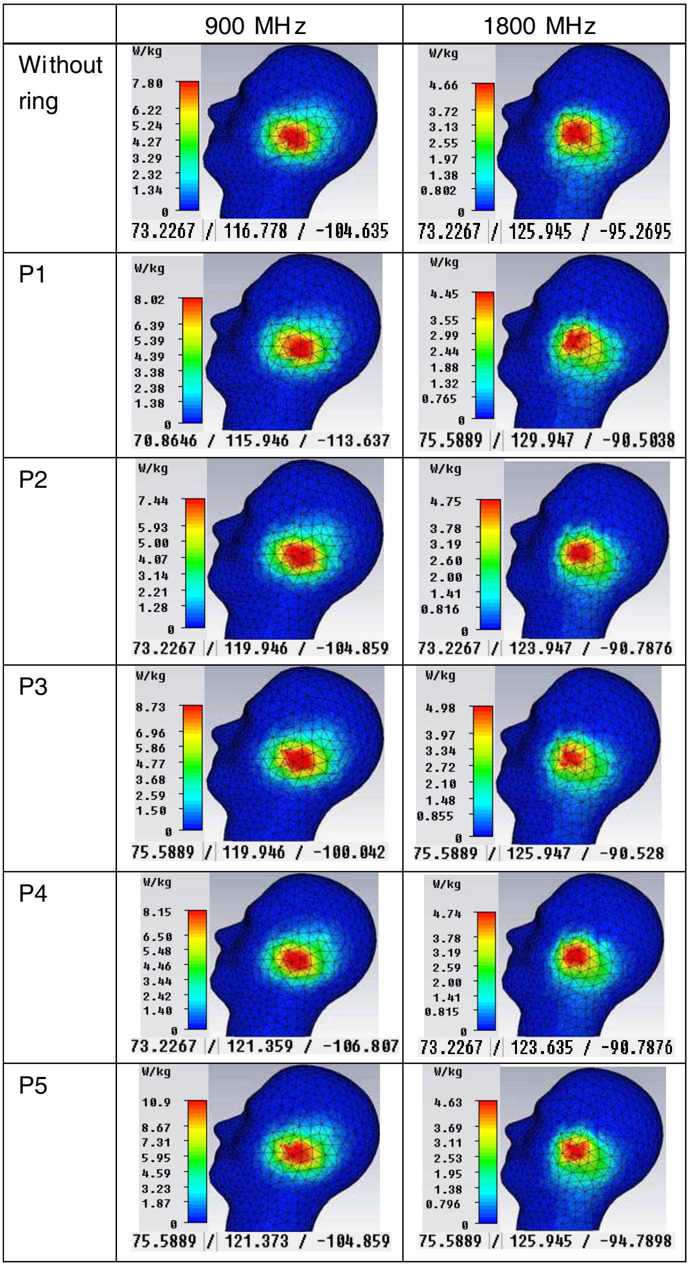

Figure 6. Comparisons of peak SAR distributions without and with ring attachments at five different positions.

Table 2. Local SAR values on the head surface with a hand ring attachment at 900 MHz.

Ring of different fingers	Peak SAR 1 g (W/kg)	Total SAR (W/kg)	Tissue power (W)
Without ring	3.5595	0.04718	0.24776
Thumb	4.0243	0.05055	0.26587
Index	4.0748	0.05242	0.27570
Middle	3.9989	0.05036	0.26443
Ring	3.9989	0.05071	0.26668
Baby	3.9790	0.05113	0.26889

Table 3. Local SAR values on the surface of the head with a hand ring attachment at 1800 MHz.

Ring of different fingers	Peak SAR 1 g (W/kg)	Total SAR (W/kg)	Tissue power (W)
Without ring	4.7842	0.04360	0.22893
Thumb	4.9889	0.04682	0.24624
Index	5.1485	0.05082	0.26722
Middle	5.0466	0.04681	0.24576
Ring	5.2527	0.04914	0.25840
Baby	4.7812	0.04859	0.25552

the baby finger shows a very small effect, with a change less than 1%. Compared with international standards safety limits, the SAR/1 g tissue exceeds the limit. However, communication devices operate with a duty factor of 1/8 and not a continuous wave; thus the results can be scaled by 1/8th to create a time averaged SAR value. When scaled by the duty factor, all values are less than the specified limit of 1.6 W/kg.

In addition to the alteration of the SAR and absorption power, the introduction of a hand ring could affect antenna performance. Figures 8 and 9 indicate the return loss and radiation pattern for both frequencies. The resonant frequencies of the lower and higher bands in the vicinity of the head and hand (without a ring) are 892.5 MHz

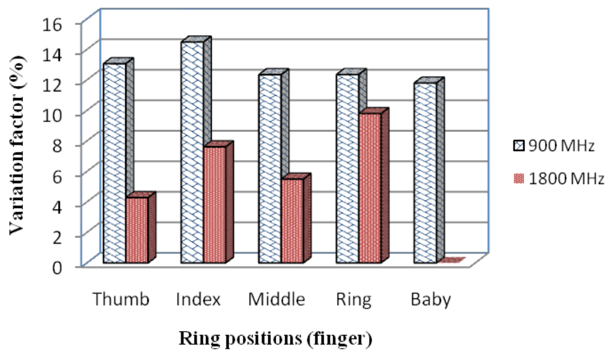

Figure 7. The effects of hand ring jewelry on peak SAR.

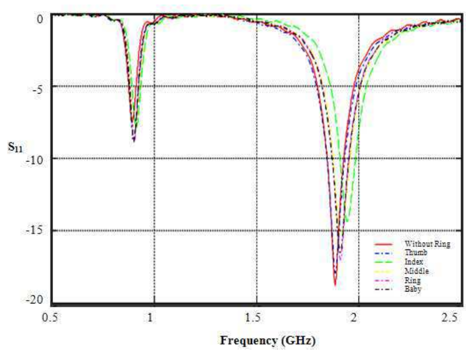

Figure 8. Variation of return loss with and without hand ring jewelry.

and 1885 MHz, respectively. Correlated to the highest peak SAR, the resonant frequency of the antenna with an index finger ring is 912.5 MHz, which is shifted by 20 MHz from the reference frequency (without a ring). At the higher band, when the ring is placed on the index finger, the resonant frequency becomes 1942 MHZ and causes the maximum degradation in the return loss magnitude of approximately 5 dB. Figure 8 also clearly shows that the resonant frequencies are almost unaffected at lower bands frequencies

Figure 9 shows the effect of a hand ring on the antenna pattern in the θ-plane for $\Phi = 0°$ and the Φ-plane for $\theta = 90°$. It is evident that the presence of the ring has a negligible impact on the radiation pattern. The differences computed for both frequency bands are less than only 2 dB in all cases.

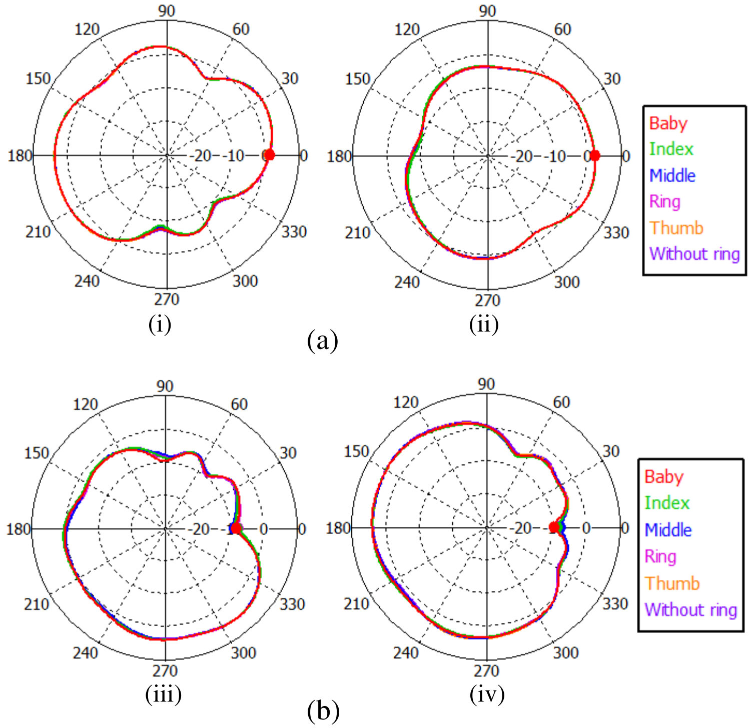

Figure 9. Radiation patterns of PIFA due to hand ring jewellery (i) xz-plane (top view of the head), (ii) xy-plane (front view of the head). (a) 900 MHz. (b) 1800 MHz.

5. CONCLUSION

This paper has analyzed the variability of the SAR values in the human head and handset antenna performance. Neglecting the influence of the hand resulted in an overestimation of the SAR in the head and affected the antenna performance of the handset. The impact of holding the mobile phone in a hand reduced the average peak SAR in the head and thus reduced the power absorbed by the head. The introduction of a ring worn on the human hand caused the SAR distribution to increase depending on the position of the ring. Therefore, by means of real life conditions, SAR assessments with a ring attached to the hand provide meaningful valuation because wearing jewelry on the hand is common among mobile phone users. Furthermore, future studies should also extend this research to the effects of the handset chassis materials and shapes on SAR reduction because the present results show some valuable indications

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