A Study of Specific Absorption Rate in Coconut Exposed to RF Radiation

Ardhendu Kundu, Bhaskar Gupta, Sudhabindu Ray

Abstract – **Now-a-days researchers are very much concerned about the biological effects and potential hazards of Radio Frequency (RF) electromagnetic fields. They evaluate Specific Absorption Rate (SAR) at different human organs due to the radiation coming from cell phone antennas. SAR is a measure of the rate at which energy is absorbed by an object when exposed to an electromagnetic field. But, if the vision is slightly changed toward the effect of RF on agricultural field and plant kingdom, no such theoretical study has been done earlier. Few publications can be found on this topic which is limited to statistical observation. The purpose of this paper is to study the effect of RF radiation coming from base station antennas on coconuts. In this work, the radiation coming from the GSM-900 MHz, GSM1800 MHz and Wi-Fi 2400MHz base station to controlled and public zones have been taken into consideration as prescribed by ICNIRP and then taking the E-field well below the maximum allowable equivalent plane wave electric field, the SAR has been calculated for coconut using the CST MICROWAVE STUDIO numerical simulator based on Finite Integration Technique (FIT) method.**

Keywords – **CST Microwave Studio, Coconut, ICNIRP, Radio Frequency (RF), Specific Absorption Rate (SAR)**

I. Introduction

There has been increasing public concern about the adverse health effects of human exposure to the electromagnetic field radiated from the wireless communication devices and cell tower antennas [1-4]. According to the safety guidelines of International Commission on Non-Ionizing Radiation Protection [ICNIRP], Institute of Electrical and Electronics Engineers [IEEE] and Federal Communications Commission [FCC] standard, SAR is used as a metric of basic restriction for radio frequency (RF) exposure [5-7]. SAR is a measure of the rate at which energy is absorbed by the body when exposed to a RF electromagnetic field. It is defined as the power absorbed per unit mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged either over a small sample volume (typically point, 1 g or 10 g of tissue) or over the whole body. SAR measures exposure to fields from 100 KHz to 10 GHz. The value will depend heavily on the geometry of the part of the body that is exposed to the RF energy and on the exact location and geometry of the RF source. The basic restriction of Whole Body Averaged SAR (WBA-SAR) for human body is 0.4 W/kg for occupational/controlled exposure and 0.08 W/kg for public/uncontrolled exposure [5]. On the other hand, the plants/crops/fruits are equally or somewhat more exposed to the electromagnetic radiation from the wireless communication devices, base station antennas and repeaters. But, it is the hard truth that there is no guideline set by the electromagnetic radiation regulatory commissions for those speechless lives on the earth. Those plants, crops and fruits are exposed 24 hours a day without any radiation shield to those base station antennas.

In recent years, some researchers along with the peasants are claiming that the production of crops/fruits gets affected near the high radiation cell phone towers. But, there are no such scientific research document found except, few publications which are mostly limited to statistical observations [3], [8-11]. From that point of view, some effort has been given to throw light on this issue.

In this particular work, the work has been started with coconut (*Cocos nucifera*) as one of the major Indian fruits. At the initial stage the electrical and mechanical characterization of various layers of coconut has been done. Then using those parameters, the Maximum Local SAR, 1 g averaged SAR and 10 g averaged SAR have been calculated with plane wave exposure level well below the maximum allowable E-field strength prescribed in ICNIRP guideline for RF exposure. All the SAR evaluations have been performed using CST MWS software after modelling the coconut in the same platform using the IEEE C95.3 method available in CST MWS [12-15].

II. Computational Methods And Models

A. Computational Method

In this study of SAR calculation, the Transient analysis has been used in CST MWS simulation platform. Firstly the coconut has been represented as a simplified spherical shape with proper dimensions defined for each layer and then a better approximation to the exact shape obtained by elongating the poles of the sphere has been considered for better accuracy. The simplified spherical coconut and better approximated shape of coconut have been represented below respectively in Figs. 2(A) and 2(B). A plane wave with linear polarization has been used as the RF radiation source which passes through the coconut models in separate simulation environments. A 4-layered perfectly matched layer (PML) with 0.0001 reflection coefficient has been used as the absorbing boundary. The separation between the coconut and the boundary wall has been kept fixed at 3 cm by varying the

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mesh-lines per wavelength for different frequency of exposure.

B. Coconut Modelling

At the starting point of this work almost no information was in hand regarding the modelling and parameterization of real coconut (*Cocos nucifera*). So at the first phase, a typical medium size coconut with 720 g mass was taken from the market to measure the basic parameters like volume of the coconut, shape of the coconut, how many distinguishable layers are to be taken into consideration, thickness of each layer and inner-outer dimensions of each layer etc. After making a detailed observation of the geometrical shape and size of the coconut, 4 different layers got identified as outer most green skin (*Exocarp*), light weight pulpy region (Mesocarp) and hard shell (Endocarp) and the inner most coconut water content (Liquid Endosperm). All the above mentioned layers are pointed out in Fig. 1.

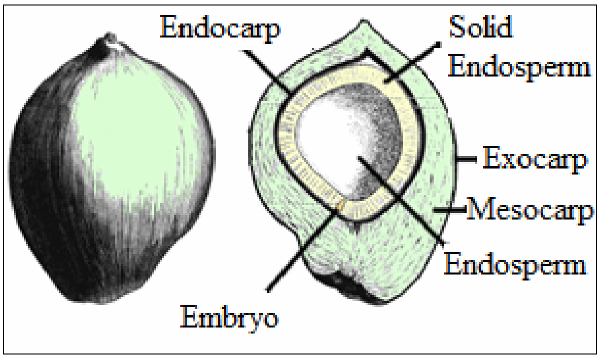
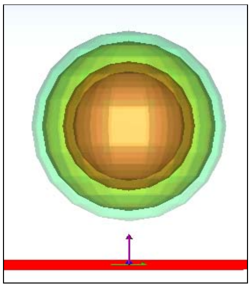
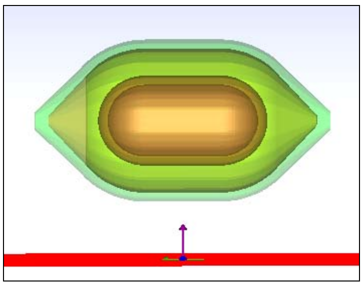


Fig. 1. Various layers of coconut

The coconut has been modelled in CST-MWS platform initially with a simplified spherical model (shown in Fig. 2(A)) with equivalent dimensions for each layer and then a more accurate model was also developed (shown in Fig. 2(B)) in the same platform for the better accuracy of the SAR calculation. The modelling specifications for simplified spherical model and more accurately shaped model of coconut have been tabulated in Tables 1 and 2 respectively.



(A)
Spherical model of coconut



(B)
More accurate model of coconut

Fig. 2. Coconut fruit modeled in CST-MWS platform

TABLE 1
MODELLING SPECIFICATIONS FOR SPHERICAL SHAPED COCONUT

Name of the layer	Outer radius of the layer [cm]	Inner radius of the layer [cm]	Thickness of the layer [cm]	Volume of the layer [cm^3]	Mass of the layer [g]
Green skin	5.75	5.125	0.625	223.07	237.34
Pulp	5.125	3.9	1.225	302.63	295.37
Shell	3.9	3.3	0.6	93.982	99.99
Water	3.3	0	3.3	144.44	146.32

TABLE 2
MODELLING SPECIFICATIONS FOR MORE ACCURATELY SHAPED COCONUT

Name of the layer	Sections required to construct the layer	Least thickness of the layer [cm]	Volume of the layer [cm^3]	Mass of the layer [g]
Green skin	Cone + sphere + cylinder + sphere + cone	0.625	189.894	202.047
Pulp	Cone + sphere + cylinder + sphere + cone	1.225	330.849	322.908
Shell	Sphere + cylinder + sphere	0.6	59.180	62.967
Coconut water	Sphere + cylinder + sphere	3.3	82.354	83.424

III. ELECTRICAL AND MECHANICAL PARAMETER MEASUREMENT OF COCONUT LAYERS

The electrical parameters for coconut green skin, pulp and shell have been measured at the Solid State Department (SSD) of Indian Association for Cultivation of Science [IACS], Kolkata (tabulated in Table 3). But, dielectric constant and loss tangent measurement provision for liquid coconut water was not there in SSD lab, IACS and after qualitative and quantitative analysis of mineral components in coconut water with respect to normal water and sea water [documented in CST-MWS material library], initially ε_r was considered to be 77 and conductivity to be 2.25 S/m. The practical measurement of ε_r and loss tangent was done later by using Agilent 85070E Dielectric Probe Kit at ETCE-Microwave Lab of Jadavpur University and the results matched perfectly with the approximated values. All the measured permittivity and loss tangent data are tabulated in Table 3. Table 4 represents the densities of different layers in a typical medium size green coconut.

TABLE 3
MEASURED VALUE OF PERMITTIVITY AND LOSS TANGENT OF VARIOUS LAYERS IN COCONUT

Name of the layer	Data taken at	GSM 900 MHz		GSM 1800 MHz		Wi-Fi 2400 MHz	
		ε_r	tan δ	ε_r	tan δ	ε_r	tan δ
Green skin	SSD, IACS	22.8	0.71	19.2	0.59	19.5	0.53
Pulp	Do	39.7	0.99	35.1	0.76	37.0	0.67
Shell	Do	83.6	0.68	91.4	0.55	120	0.68
Coconut water	JU	77.0	0.29	76.1	0.22	75.4	0.22

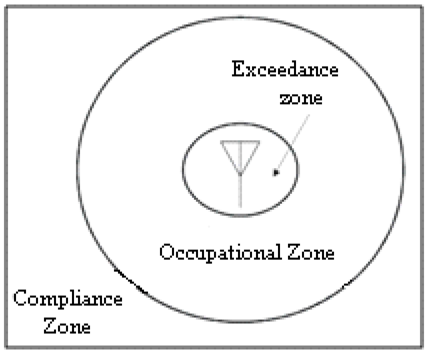


Fig. 3. Radiation Exposure zone around a Base Station

TABLE 4
MEASURED VALUE OF MATERIAL DENSITY OF VARIOUS LAYERS IN COCONUT

Name of the layer	Material density ρ [kg/m^3]
Green skin	1064
Pulp	976.5
Shell	1013.6
Water	1013

IV. COMPUTATIONAL RESULTS AND DISCUSSION

The main objective of this work is to evaluate the SAR of coconut (*Cocos nucifera*) exposed in accordance with the internationally accepted radiation exposure guideline. A coconut has been exposed to RF radiation due to base station antennas in GSM 900MHz, GSM 1800 MHz and Wi-Fi 2400MHz bands with E-field well below the maximum Electric field prescribed by International Commission on Non-Ionizing Radiation Protection [ICNIRP]. Before going in to the details of SAR calculation, it's better to discuss the ICNIRP guideline in brief.

ICNIRP guideline is one of the worldwide accepted radiation exposure standards and this particular exposure guideline was maintained in India (up to 31.08.12) along with many other countries. The safe limit of radio frequency radiation exposure as mentioned in ICNIRP guideline has been stated in Table 5. There are mainly three particular zones around a base station based on the radiated power density typically called 1.Excess exposure zone 2.Controlled/occupational exposure zone 3.Uncontrolled/Public exposure zone. The boundaries of these 3 different zones are pointed out in Fig. 3.

ICNIRP has given exposure guidelines for occupational exposure zone and public exposure zone but not for the excess exposure zone. Reference levels for occupational and public exposure to time-varying electric and magnetic fields (unperturbed r. m. s values) have been tabulated below in Table 5.

TABLE 5
ICNIRP RF EXPOSURE GUIDELINE FOR CONTROLLED AND PUBLIC EXPOSURE ZONES

Type of Exposure Zone around a base station	Frequency range [MHz]	Electric field Strength (V/m) [r. m. s]	Magnetic field Strength (A/m) [r. m. s]	Equivalent Plane Wave power Density S_{eq} (W/m²)
Controlled	900	90.00	0.24	22.50
	1800	127.30	0.34	45.00
	2400	137.00	0.36	50.00
General public	900	41.25	0.11	04.50
	1800	58.34	0.15	09.00
	2400	61.00	0.16	10.00

Except the above mentioned Reference levels, there are some other Basic restrictions [SAR, Induced current density etc.] imposed by ICNIRP which are imposed on human only. ICNIRP has also stated in addition to above given data,

1. *Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.*
2. *For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.*
3. *For peak values at frequencies between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.*
4. *For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68 / f^{1.05}$ min period (f in GHz).*

TABLE 6
SAR RESULTS FOR SPHERICAL COCONUT WITH E-FIELD WELL BELOW THE LIMITS PRESCRIBED BY ICNIRP

Serial no	Coconut model	Type of exposure	Peak E-field value of the plane wave [V/m]	Frequency of operation [GHz]	SAR Averaging mass [g]	Simulated max SAR [W/kg] (r. m. s)	Total SAR [W/kg] (r. m. s)
1.	Spherical	Controlled	90.00	0.9	Point	0.998	0.180
2.	"	"	"	"	1	0.461	"
3.	"	"	"	"	10	0.420	"
4.	"	"	127.30	1.8	Point	2.109	0.335
5.	"	"	"	"	1	1.039	"
6.	"	"	"	"	10	0.961	"
7.	"	"	137.00	2.4	Point	3.142	0.382
8.	"	"	"	"	1	1.537	"
9.	"	"	"	"	10	1.264	"
10.	"	Public	41.25	0.9	Point	0.209	0.037
11.	"	"	"	"	1	0.096	"
12.	"	"	"	"	10	0.088	"
13.	"	"	58.34	1.8	Point	0.443	0.070
14.	"	"	"	"	1	0.218	"
15.	"	"	"	"	10	0.201	"
16.	"	"	61.00	2.4	Point	0.623	0.075
17.	"	"	"	"	1	0.304	"
18.	"	"	"	"	10	0.250	"

Coming back to the main issue of SAR calculation of coconut (*Cocos nucifera*), first the SAR results for simplified spherical coconut (shown in Fig. 2(A)) with 750 g mass will be discussed and thereafter the SAR results for better modelled coconut (shown in Fig. 2(B)) with around 700 g mass (and comparable dimensions to that of spherical coconut model) will be compared with the preceding results.

A. SAR Results of Simplified Spherical Coconut with 750 g Mass with Plane Wave E-field well below the Maximum E-Field Prescribed by ICNIRP

SAR has been calculated in controlled as well as public exposure zone with E-field well below the maximum permissible limits given in ICNIRP guideline. Peak E-field values of the plane wave have been illustrated in Table 6. In this work, the numerical value of the peak E-field of the plane wave has been kept same as the numerical value of maximum r. m. s E-field prescribed in ICNIRP guideline. This implies that equivalent r. m. s field exposure is √2 times lower (for sinusoidal field variation) and is well below the ICNIRP limit in each case. In addition, ICNIRP prescribed peak E-field strengths are 10 times higher than r. m. s E-field strengths which also justifies authors' claim (Fig. 1, pp. 512, ICNIRP guideline) [5]. ICNIRP instructs to average the SAR over a time span of 6 minutes and in practical scenario, plane wave from the wireless base station antennas and repeaters gets radiated 24 hours/day and 365 days/year, so the calculated SAR values will not reduce by averaging over 6 minute time span. The averaging mass for calculating the SAR has been varied from point mass to 1 g mass and 10 g mass and all results have been documented. The documented SAR results are shown in Table 6 and graphs presented in Figs. 4 and 5.

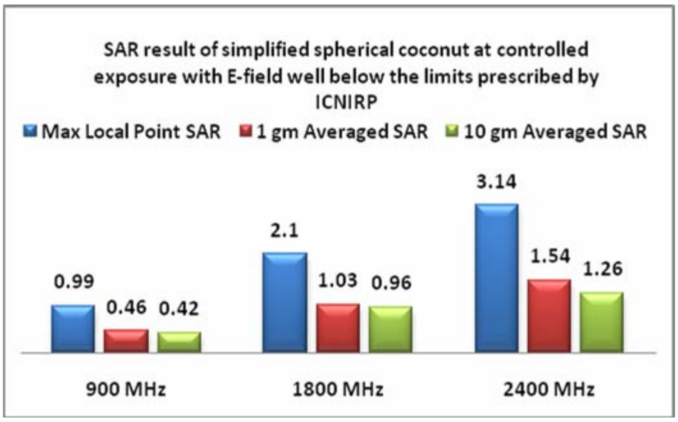


Fig. 4. Comparison of calculated SAR for simplified spherical coconut in controlled zone at three different frequency

Fig. 4 shows the comparison of SAR results of a spherical coconut present in a controlled exposure zone at three different frequency of operation. Those three frequencies of operations are GSM 900 MHz, GSM 1800 MHz and Wi-Fi 2400 MHz which are widely used in the era of wireless communication. The changes in SAR value have also been documented with changing the SAR averaging mass (i.e. point mass or 1 g or 10 g averaging mass) for SAR calculation. Now from the above given results in Table 6 and Fig. 4, it's very clear that the SAR values are quite remarkable at each and every frequency. Max local point SAR value goes to 3.14 W/Kg for a coconut in 2400 MHz and that goes to 2.1 W/Kg in GSM 1800 MHz, are they really ignorable! An important observation is that the SAR values increases at higher frequencies due to the higher allowed RF exposure levels prescribed in ICNIRP RF exposure guideline. Research must be carried out to see the local temperature rise of the tissues in various coconut layers due to the nodes and anti-nodes formation within the coconut. For example in GSM 1800 MHz, the free space wavelength is 16.67 cm whereas the wavelength in the coconut water is ($16.66/76^{½}$) cm ≈ 1.9 cm and there would be several nodes and anti-nodes within the water content of coconut fruit. That means, at some separate points of coconut water would have max E-field, Max H-field and Max Power, which may result in local temperature rise as well as there might be some ionic phenomenon within the xylem and phloem tissues of coconut fruit. Opinion should be taken from the botanical researchers to find out the real hazards in the growth of coconut fruit due to this much of energy absorption in the fruit.

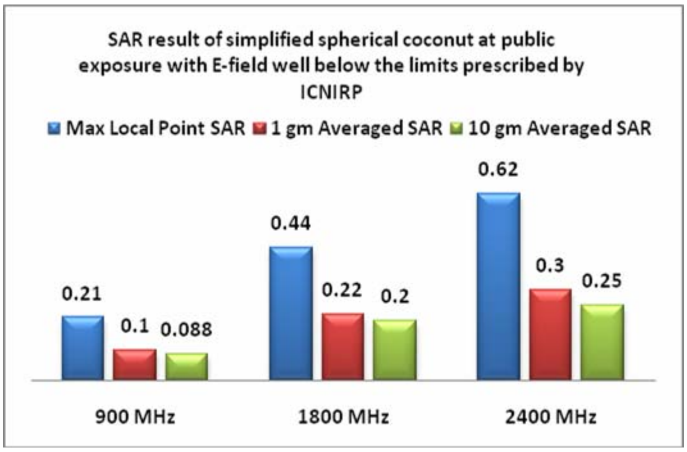


Fig. 5. Comparison of calculated SAR for simplified spherical coconut in public zone at three different frequency

The comparison of SAR results of a coconut present in a public exposure zone at three different frequencies of operation has been shown in Fig. 5. Those three frequencies of operations are as stated before i.e. GSM 900 MHz, GSM 1800 MHz and Wi-Fi 2400 MHz. The changes in SAR value has also been documented with changing the averaging mass (i.e. point mass or 1 g or 10 g averaging mass) for SAR calculation. Max local point SAR (ML SAR) value goes up to 0.62 W/Kg for a coconut in 2400 MHz and that comes down to 0.44 W/Kg in GSM 1800 MHz. The above SAR values appear to be low but that does not imply that it can be neglected because the local rise in temperature (as discussed earlier) in various tissues of coconut needs to be taken care of and the adverse effects in the properties of the biological tissue parameters needs to be evaluated with utmost care and one important fact to be mentioned is that the radiation is always there without any discontinuity. So the recommendation from the botanical scientists should be taken into consideration and the ICNIRP regulation should be revised so that the hazards from RF radiation get minimized to the coconut plants.

B. SAR Results for More Accurate Shaped Coconut with 700 g Mass with Plane Wave E-field well below the Maximum E Field Prescribed by ICNIRP

There are some drawbacks in the previous simplified spherical model of coconut (shown in Fig. 2(A)). The reasons are discussed here. Firstly, due to the assumption of simplified spherical model of coconut, the mass of coconut was increased than the actual mass of the coconut with similar realistic shape and dimensions, which factor gave a reduction in the SAR result in the previous case. Secondly, the exact shape of the coconut is somewhat different than to be spherical and due to that different shape of coconut, the resonance frequency of the coconut structure, the direction of RF exposure, direction of E-field and H-field, changes in the position of nodes and anti-nodes (as discussed in case of simplified spherical coconut SAR results) will play a role to modify the calculated SAR results.

Due to the above mentioned reasons, it was deemed necessary to develop a more accurate model of coconut (shown in Fig. 2(B)) and then re-evaluation of the SAR results in the same environment. So, the above given modified coconut modelling has been done using CST-MWS and all the SAR results got re-evaluated. After developing the exact structure of coconut with the same equivalent dimensions, the mass got reduced by 10%.

After re-evaluating the all the SAR results, the calculated results have been tabulated in Table 7. It is to be noticed that there is an increment in the SAR results for the new accurately modelled shape of coconut.

Fig. 6 describes the changes in SAR result in controlled exposure zone, just after changing the spherical coconut model into more accurately shaped coconut model and keeping all other parameters same. It can be noticed clearly that the Max local point SAR got increased a lot with around 70% increment for two GSM frequency bands and 20% increment at 2400 MHz. The 1 g averaged SAR got increased by around 30%, 65% and 40% for 900 MHz, 1800 MHz and 2400MHz respectively. The 10 g averaged SAR also got an increment of 20% at each frequency of interest. These increments in the SAR value is due to some of the above mentioned factors like reduction in overall mass, change in the resonant structure of the coconut, E and H field direction becoming orientation dependent and the changes in the position of nodes and anti-nodes within the coconut. There would be somewhat higher value of SAR when the real twig will be taken into consideration that connects the coconut fruit to the coconut tree and due the higher values of SAR at that twig point; some small coconuts may fall down from the tree earlier at an immature stage.

Similarly, Fig. 7 shows the changes in SAR result in public exposure zone, just after changing the spherical coconut model into the better model and keeping all other parameters same. It can be noticed clearly that the Max local point SAR got increased a lot with around 75% increment for two GSM frequency bands and 15% increment at 2400 MHz. The 1 g averaged SAR got increased by around 30%, 65% and 50% for 900 MHz, 1800 MHz and 2400MHz respectively. Finally, the 10 g averaged SAR also got an increment of around 20% at each frequency of interest. So all the time higher value of SAR comes in to the picture due to the complexity brought into the exact shaped coconut than the earlier simplified structure.

TABLE 7
SAR RESULTS FOR ACCURATELY SHAPED COCONUT WITH E-FIELD WELL BELOW THE LIMITS PRESCRIBED BY ICNIRP

Serial no	Coconut model	Type of exposure	Peak E-field value of the plane wave [V/m]	Frequency of operation [GHz]	SAR averaging mass [g]	Simulated max SAR [W/kg] (r. m. s)	Total SAR [W/kg] (r. m. s)
1.	Exact	Controlled	90.00	0.9	Point	1.824	0.239
2.	"	"	"	"	1	0.637	"
3.	"	"	"	"	10	0.513	"
4.	"	"	127.30	1.8	Point	3.658	0.377
5.	"	"	"	"	1	1.717	"
6.	"	"	"	"	10	1.225	"
7.	"	"	137.00	2.4	Point	3.615	0.407
8.	"	"	"	"	1	2.277	"
9.	"	"	"	"	10	1.527	"
10.	"	Public	41.25	0.9	Point	0.372	0.050
11.	"	"	"	"	1	0.133	"
12.	"	"	"	"	10	0.107	"
13.	"	"	58.34	1.8	Point	0.768	0.079
14.	"	"	"	"	1	0.360	"
15.	"	"	"	"	10	0.257	"
16.	"	"	61.00	2.4	Point	0.716	0.080
17.	"	"	"	"	1	0.451	"
18.	"	"	"	"	10	0.302	"

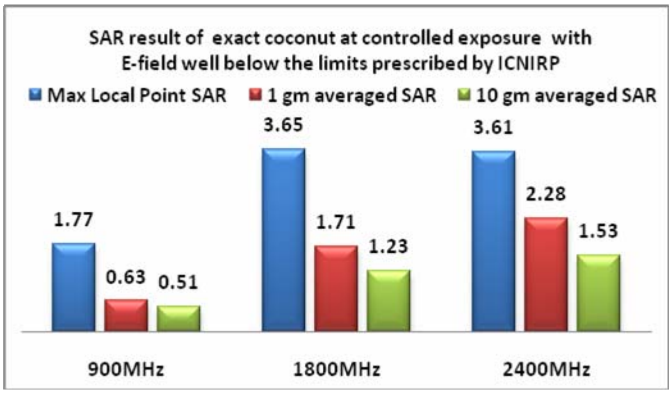


Fig. 6. Comparison of calculated SAR for exact coconut in controlled zone at three different frequency

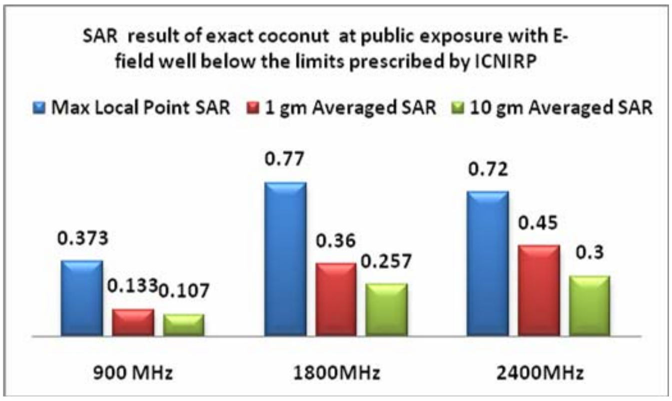


Fig. 7. Comparison of calculated SAR for better coconut model in public zone at three different frequency

C. Study of the Variation in Max-3D SAR Position of More Accurately Shaped Coconut and the Variation in SAR Results at the Surface of Each Layer w. r. t Change in the SAR Averaging Mass

At the time of simulation of each SAR result with a particular coconut structure, one interesting observation is the location of the Max-3D SAR gets shifted with the change in the SAR averaging mass at the same frequency of operation. Another important fact is the energy absorption rate i.e. the SAR / Power Loss Density is totally different in the different layers of coconut. For establishing the fact, the direction of plane wave exposure has been illustrated in Fig. 8 for the more accurately shaped coconut exposed to RF in controlled zone at 900 MHz with 90 V/m peak electric field which is below the maximum allowable E-field as per ICNIRP guideline. After the completion of simulation, the Power loss density monitor views at the surface of each layer have been shown in Fig. 9. The SAR monitor views averaged over point mass have also been presented in Fig. 10.

Fig. 8 shows the coconut gets exposed to a plane wave propagating in X direction whereas the E-field (90 V/m peak) and H-field are in Z and Y direction respectively. All the SAR results for exact coconut model have been evaluated with the above mentioned orientation of coconut and the direction of plane wave propagation. There could be another case of RF exposure where plane wave could propagate in Z direction while E-field and H-field could take any of the remaining directions and the resultant SAR could be different due to the rotation dependent view of the better modelled coconut structure. That case has not been considered here.

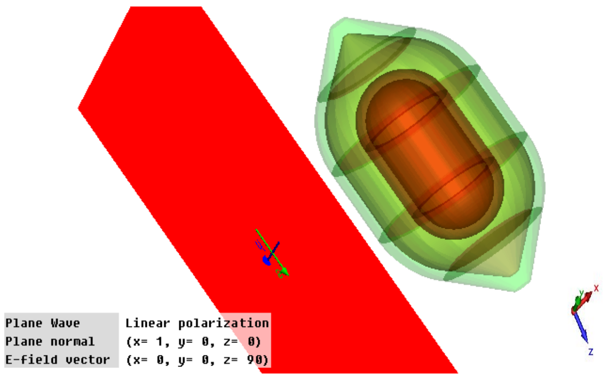
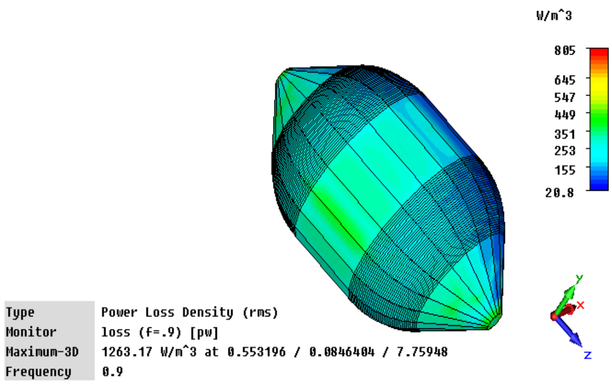
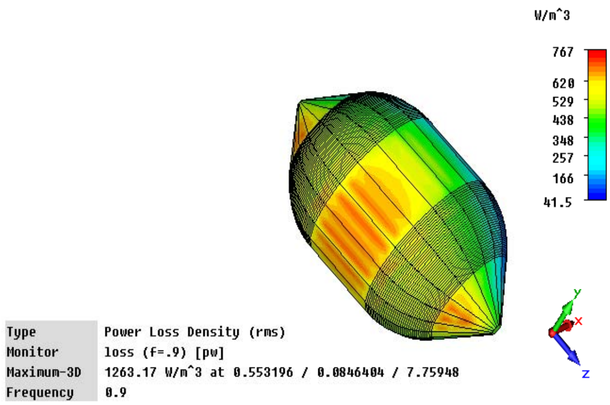


Fig. 8. The better modeled coconut gets exposed in a plane wave at 900 MHz with 90 V/m peak E-field in controlled exposure zone

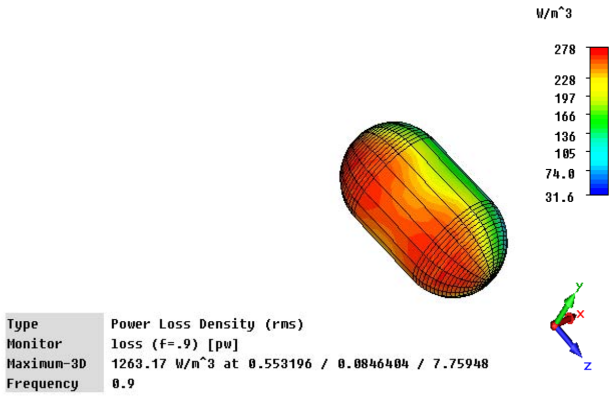
Figs. 9(A), (B), (C) and (D) demonstrate the Power Loss Density at the surface of green skin, pulp, shell and coconut water respectively. The Power loss density monitor views describe the power absorption at the surface of all four layers among them pulp is having higher Power absorption rate than the other three layers.



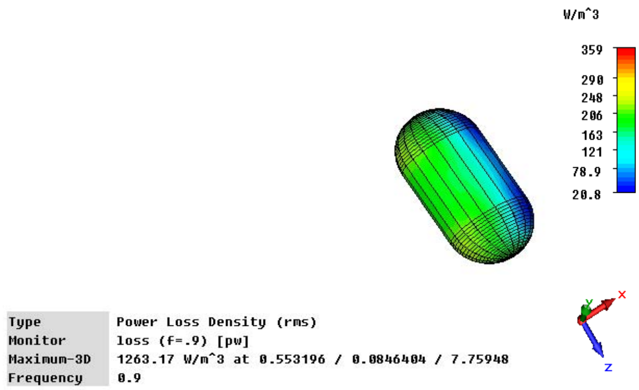
(A): Power loss density (W/m³) at the surface of green skin



(B): Power loss density (W/m³) at the surface of pulp



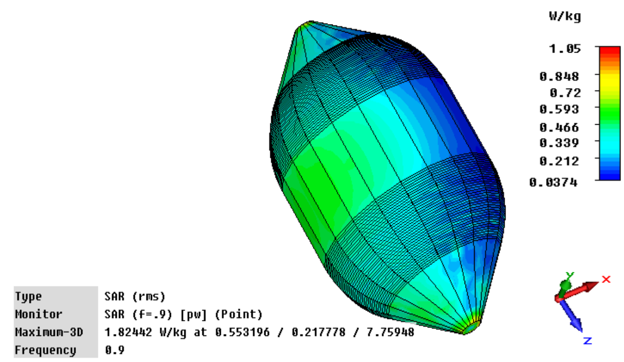
(C): Power loss density (W/m³) at the surface of shell



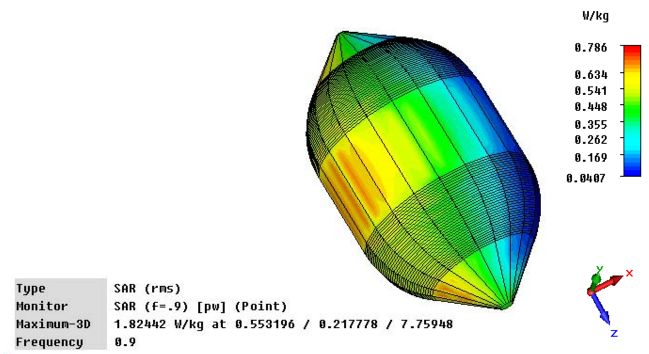
(D): Power loss density (W/m³) at the surface of coconut water

Fig. 9. The power loss density (W/m³) at the surfaces of green skin, pulp, shell and coconut water content respectively

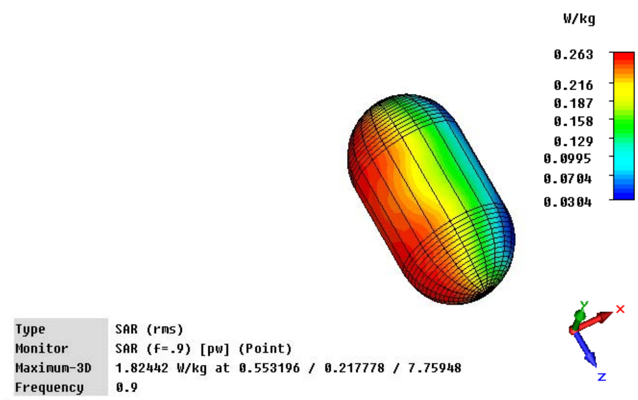
Figs. 10 (A), (B), (C) and (D) demonstrate the Local Point SAR at the surface of green skin, pulp, shell and coconut water respectively. From the Max local point SAR result at the surface of green skin and pulp, it is clear that max energy gets absorbed at the poles of the more accurately modelled coconut. But average energy absorption rate is maximum at the pulp layer and minimum at the shell and coconut water.



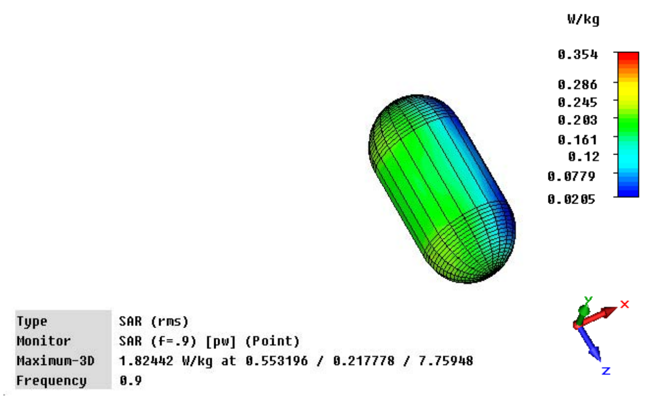
(A): Local Point SAR (W/Kg) at the surface of green skin



(B): Local Point SAR (W/Kg) at the surface of pulp



(C): Local Point SAR (W/Kg) at the surface of shell



(D): Local Point SAR (W/Kg) at the surface of coconut water

Fig. 10. The Local Point SAR (W/Kg) at the surfaces of green skin, pulp, shell and coconut water content respectively

Tables 8 and 9 describe the shift in coordinates of Max-3D SAR position of the more accurate model of coconut due to the variation in SAR averaging mass with different controlled exposures at two different frequencies of our interest (i.e. GSM 900 MHz and GSM 1800 MHz).

IV. Conclusion

In the computational result, it is clear that the SAR result got increased by a remarkable percentage due to the change from spherical shape to more accurate shape of coconut. The reasons are discussed below. The mass of the more accurate structure of coconut is lower which contributes to increase in the SAR values. The exact shape of the coconut is somewhat different than spherical and due to that different shape of coconut, the change in the resonance structure of the coconut, the direction of RF exposure, direction of E-field and H-field, changes in the position of nodes and anti-nodes (as discussed in case of simplified spherical coconut SAR results) will play a role to modify the calculated SAR results. The more accurately shaped coconut contains some part similar to cone structure as pointed out in Fig. 11 and due to that reason, the power got accumulated there and the SAR was increased by a remarkable amount. Even, the region and value of Max local point SAR, 1 g averaged SAR and 10 g averaged SAR got changed with the different frequency of operation. The change in the value of SAR at different frequency is purely due to the different exposure levels prescribed at different frequencies along with many other factors at different frequencies. But, position changing of SAR at different frequencies is due to the change in the wavelength, position of nodes-antinodes and resonant structure of the coconut etc.

Fig. 11. Cone-like poles of coconut

It is interesting to point out from Table 8 that the Max-3D SAR position changes (and SAR value reduces) with the increase in SAR averaging mass. The Max-3D SAR position in 10 g averaging method is far away from the corresponding position of point mass averaging method. This implies the 10 g averaging method hides the true position of Max-3D SAR and still ICNIRP has given guideline based on 10 g averaging method for SAR calculation. The above mentioned facts are suggesting giving more importance to Max Local Point SAR as the basis of SAR evaluation method. In reality, tissue and cell size and mass are much smaller than 1g/10g and that also suggesting evaluating Max Local Point SAR with more importance.

TABLE 8
STUDY ON THE SHIFT OF THE COORDINATES OF MAX-3D SAR RESULT OF THE BETTER MODEL OF COCONUT DUE TO THE VARIATION IN SAR AVERAGING MASS WITH EXPOSURE [90 V/M PEAK E-FIELD] AT 900 MHZ IN CONTROLLED EXPOSURE

I	II	III	IV	V	VI	VII	VIII
Serial No.	Frequency (GHz)	SAR averaging mass (g)	Max-3D SAR of total coconut for that averaging mass (W/kg)	Location of Max-3D SAR X/Y/Z (cm) with coconut structure centred at 0/0/0 (cm)	Layer of coconut	Max (r. m. s) SAR at the surface of same layer (W/Kg)	Remarks
							1. [V , III] It is very important observation that the position of Max-3D SAR changes with change in averaging mass. 2. [VII] SAR at the surfaces of diff. layers is totally different.
1.	0.9	Point	1.82442	(0.55)/(0.21)/(7.75)	green skin	1.050	
2.	0.9	Point	"	"	Pulp	0.786	
3.	0.9	Point	"	"	Shell	0.263	
4.	0.9	Point	"	"	Water	0.354	
5.	0.9	1	0.636765	(-1.37)/(-0.08)/(5.6)	green skin	0.621	
6.	0.9	1	"	"	Pulp	0.612	
7.	0.9	1	"	"	Shell	0.277	
8.	0.9	1	"	"	Water	-	
9.	0.9	10	0.513155	(-3.3)/(2.09)/(0.04)	green skin	0.513	
10.	0.9	10	"	"	Pulp	0.513	
11.	0.9	10	"	"	Shell	0.331	
12.	0.9	10	"	"	Water	0.247	

TABLE 9
STUDY ON THE SHIFT OF THE COORDINATES OF MAX-3D SAR RESULT OF THE BETTER MODEL OF COCONUT DUE TO THE VARIATION IN SAR AVERAGING MASS WITH EXPOSURE [127 V/M PEAK E-FIELD] AT 1800 MHZ IN CONTROLLED EXPOSURE

I	II	III	IV	V	VI	VII	VIII
Serial No.	Frequency (GHz)	SAR averaging mass (g)	Max-3D SAR of total coconut for that averaging mass (W/kg)	Location of Max-3D SAR X/Y/Z (cm) with coconut structure centred at 0/0/0 (cm)	Layer of coconut	Max (r. m. s) SAR at the surface of same layer (W/kg)	Remarks
							1. [V , III] It is very important observation that the position of Max-3D SAR changes with change in averaging mass. 2. [VII] SAR at the surfaces of diff. layers is totally different.
1.	1.8	Point	3.658	(-0.77)/(-0.05)/(7.56)	green skin	2.27	
2.	1.8	Point	"	"	Pulp	1.82	
3.	1.8	Point	"	"	Shell	0.30	
4.	1.8	Point	"	"	Water	0.17	
5.	1.8	1	1.717	(-0.45)/(0.05)/(6.63)	green skin	1.64	
6.	1.8	1	"	"	Pulp	1.64	
7.	1.8	1	"	"	Shell	0.29	
8.	1.8	1	"	"	Water	0.16	
9.	1.8	10	1.225	(-1.28)/(-0.05)/(6.49)	green skin	1.21	
10.	1.8	10	"	"	Pulp	1.21	
11.	1.8	10	"	"	Shell	0.40	
12.	1.8	10	"	"	Water	0.22	

In practical scenario, there is a twig in between the coconut and tree; and as the SAR value is highest at the pole so there is a possibility of Local temperature rise and damage in the tissues of surroundings resulting in earlier fall of coconut at an immature stage.

In the computational result what we see is that the SAR value is very high in case of controlled exposure for any type of coconut model. The telecom company can restrict public to enter into the Controlled exposure zone but they don't consider that there are a number of coconut plants just in front of the main beam of the sector antenna. So the coconut gets affected due to radiation in controlled zone without any shielding. That was the case for Controlled exposure but, even it can't be concluded that those coconut trees which are at public exposure zone are totally safe because the local temperature rise in tissues of each layer of coconut is not known due this much energy absorption either in controlled or in public exposure zone. The changes in biological nature of coconut cells and tissues of each layer are not correlated with the energy absorption rate/ SAR till now. So, the coconut tree and fruits are safe or not with this much of energy absorption that should concluded by the Botanical researchers. For, the advancement of the research, this SAR result files can be handed over to the Botanical research institutes and after the completion of their research regarding the correlation of SAR and effects in biological nature of coconut cells and tissues, a meaningful conclusion can be drawn. Then a report can be sent to ICNIRP about the effect on coconut due to RF exposure to take the necessary steps from their part. It is quite important to point out that ICNIRP RF exposure guidelines was maintained in India for a long time up to 31st August 2012, but recently Indian government has lowered the RF exposure level to 1/10th of ICNIRP limits w. e. f 1st September 2012 (as done by many other countries much earlier than India). This also supports the fact that ICNIRP RF exposure level is not that safe.

At the time of dielectric constant measurement, coconut was kept in a closed plastic bag after taking out the water from it and carried over to IACS for the measurement. There was a delay of 24 hours between the extraction of coconut water and cutting the samples from each layer of coconut. It might have affected the parameter measurement to some extent of inaccuracy. All the time the numerical value peak E field exposure has been kept at the numerical value of maximum r. m. s E field prescribed in RF exposure limiting guideline given by ICNIRP which justifies the work has been done well below the limits prescribed in ICNIRP. The evaluated SAR values will not fall down due to the SAR averaging over 6 minute time span as the radiated plane wave is present all the time without any discontinuity from the telecom towers.

Further research can be carried over with some other fruits and vegetables as per ICNIRP guideline and it would be better if real time telecom and wireless base station antenna radiated cumulative power can be used as the RF exposure source to simulate the SAR results of this type fruits and plants.

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REFERENCES

[1] M. A. A. Karunarathna, I. J. Dayawansa; "Energy absorption by the human body from RF and microwave emissions in Sri Lanka", *Sri Lankan Journal of Physics*, vol. 7, pp. 35-47, 2006.

[2] L. K. Ragha, M. S. Bhatia; "Numerical Evaluation of SAR for Compliance Testing of Personal Wireless Devices",*International Journal of Recent Trends in Engineering*, vol. 2, no. 6, November 2009.

[3] G. Kumar, "*Report on Cell Tower Radiation*" submitted to secretary, DOT, Delhi; December 2010.

[4] S Sivani*, D Sudarsanam; "Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review", *Biology and Medicine*, vol. 4, no. 4, pp. 202–216, 2012.

[5] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)," *Health Phys*., vol. 74, pp. 494-522, 1998.

[6] IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields 3 kHz to 300 GHz, IEEE Std. C95.1, Institute of Electrical and Electronics Engineers, New York, NY, 1999.

[7] Evaluating Compliance with FCC Guidelines for human exposure to Radio Frequency Electromagnetic Fields, *FCC OET Bulletin.65*, Washington D.C., August 1997.

[8] V. Balodis, G. Brumelis, K. Kalviskis, O. Nikodemus, D. Tjarve, V. Znotina, "Does the Skrunda Radio Location Station diminish the radial growth of pine trees?", *Science of The Total Environment,* vol. 180, no. 1, pp. 57-64, 2 February 1996.

[9] I. Magone; "The effect of electromagnetic radiation from the Skrunda Radio Location Station on Spirodela polyrhiza (L.) Schleiden cultures", *Science of The Total Environment*, vol. 180, no. 1, pp. 75-80, 2 February 1996.

[10] A. Balmori, "Electromagnetic pollution from phone masts. Effects on wildlife", *Pathophysiology*, vol. 16, pp. 191–199, 2009

[11] S Sivani, D Sudarsanam; "Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review", *Biology and Medicine*, vol. 4, no. 4, pp. 202–216, 2012.

[12] *CST user's manual, HP Design and analysis*; CST MICROWAVE STUDIO ® 4—*Getting started*.

[13] *CST user's manual*, CST MICROWAVE STUDIO ® 5—*Advanced Topics*.

[14] *CST user's manual*, CST MICROWAVE STUDIO ® *Tutorials*.

[15] *CST STUDIO SUITETm2006 User's Manual*; http://www.cst.com