ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

BASE STATION ANTENNA'S ELECTROMAGNETIC FIELD DISTRIBUTION IN THE ROOM

M.Sc. THESIS

Şebnem ALTUNBAŞ

Department of Applied Informatics

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Thesis Advisor: Assoc. Prof. Dr. Vasil TABATADZE

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

BAZ İSTASYONU ANTENİNİN ODA İÇİNDEKİ ELEKTROMANYETİK ALAN DAĞILIMI

YÜKSEK LİSANS TEZİ

Şebnem ALTUNBAŞ
(708151033)

Bilişim Uygulamaları Anabilim Dalı

Bilişim Uygulamaları Programı

Tez Danışmanı: Doç. Dr. Vasil TABATADZE

ARALIK 2019

Şebnem Altunbas, a M.Sc. student of ITU Informatics Institute student ID 708151033, successfully defended the thesis entitled "BASE STATION ANTENNA'S ELECTROMAGNETIC FIELD DISTRIBUTION IN THE ROOM" which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 15 November 2019
Date of Defense : 11 December 2019

To my father,

FOREWORD

It was a long and hard journey to graduate and complete thesis for me. During my education, I had too many good times and bad times. After all, I could finally complete my thesis.
I would thank my advisor Assoc. Prof. Dr. Vasil Tabatadze for all his support, kindness and patience during the period.

December 2019 Şebnem ALTUNBAŞ

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ABBREVIATIONS

MAS	**:** Method of Auxiliary Sources
MHz	**:** Mega Hertz
f	**:** Frequency
m	**:** Meters
RAN	**:** Radio Access Network
2G	**:** Second Generation
3G	**:** Third Generation
4G	**:** Fourth Generation
5G	**:** Fifth Generation
RF	**:** Radio Frequency
CPU	**:** Central Processing Unit

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BASE STATION ANTENNA'S ELECTROMAGNETIC FIELD DISTRIBUTION IN THE ROOM

SUMMARY

The evolution in the telecommunications technology creates new discussion about human health and affect of other factros on the effect of radio network frequencies. By the appearance of new technologies in radio network, number connected users and as a result, number of base statitons increased with different type of base stations.

The crowded radio network elements induce discussion about effect of the radio network signals to human body in different cases. To enlight these kind of discussions, there are lots of researches are ongoing. To find close results to real cases, there are some assumptions needs to be done. During the thesis, boundary conditions and Method of Auxiliary Sources are used to obtain closest results to the real cases.

Method of auxiliary sources use mirror points close to the surface of the area to find the closest value of incident and reflected signals with the help of boundary condition satisfaction in scattering surfaces.

The aim of the thesis is to find the electromagnetic distribution of a signal radiated from a base station in a room. To handle the case, there are several use cases considered. Material of the room building and change on the frequency of the signal cases are handled separately. There are two type of rooms are considered and for each frequency, distribution on the room simulated.

An empty room and a base station outside the room are considered to find the distribution of electromagnetic signals inside the room. To be able to observe the comparison, two different building materials, one of them ferro-concrete and one of them dielectric building, are considered.

For the room built by each material, there are three different frequency considered as source frequency; 300 Mhz, 450 MHz and 900 MHz.

In the end, results are showed that room behaves like a resonator if built by a ferro-concrete material. If dielectric material is used on building of the room, signal could penerate trough the walls regardless which frequency is used.

BAZ İSTASYONU ANTENİNİN ODA İÇİNDEKİ ELEKTROMANYETİK ALAN DAĞILIMI

ÖZET

Yeni teknolojilerin ortaya çıkması ve varolan teknolojilerin hızlı gelişimi sonucu, mobil şebekeye bağlı kullanıcı sayısı her geçen gün artmaktadır. Bazı kaynaklara göre bu sayının önümüzdeki 10 yıl içerisinde toplam popülasyonun yaklaşık %60'ına ulaşması beklenmektedir. Mobil şebekeye bağlı kullanıcı ve ekipman sayısının artması sonucu olarak, oluşacak trafiği karşılayabilmek için yeni baz istasyonları ihtiyacı ortaya çıkmaktadır. Artışın büyüklüğü düşünüldüğünde, oluşacak trafik ile başa çıkabilmek için çeşitli baz istasyonları sayısında ciddi bir artışa ihtiyaç duyulacaktır.

Baz istasyonlarının ise insan sağlığı için etkileri henüz tam olarak bilinememektedir. Baz istasyonu sayısındaki artış beklentisi, radyo şebeke sinyallerinin insan sağlığı üzerindeki etkisine dair tartışmaları da arttırmaktadır. Bu tartışmaları aydınlatmak için bir çok araştırma yapılmaktadır.

Tezin amacı, baz istasyonlarından yayılan elekromanyetik alanın insan vücudu ve oda içerisindeki dağılımını analiz etmektir. Bu analizi yapabilmek için, bir oda ve binanın dışında bu odaya doğru servis veren bir baz istasyonu olduğu var sayılmıştır. Analizi derinleştirmek için, malzemelerden yapılmış olduğu varsayılan iki farklı oda ele alınmıştır.

Gerçek duruma en yakın sonuçlara erişebilmek için bazı varsayımlarda bulunulması ve elektromanyetik yöntemleri kullanmak gerekmektedir. Bu tezde, gerçek durumlara en yakın sonuçları elde edebilmek için sınır koşulları ve Method of Auxiliary Sources yöntemi kullanılmıştır.

Sınır koşulları, Maxwell denklemlerinden elde edilen, sınır durumlarında problemi çözmeyi sağlayarak, elektromanyetik sinyalin bir ortamdan diğerine doğru geçerken olan davranışını belirlemekte kullanılır. Sinyalin geçtiği ortamların iletkenliğine göre formüller farklı şekillerde ifade edilir.

Method of Auxiliary Sources yöntemi ise, elektromanyetik dağılımı daha az karmaşık bir yöntem ve daha az bilgisayar kaynağı kullanarak hesaplamayı hedefler. Saçılma yüzeyindeki sınır koşullarının sağlanmasından da faydalanarak, MAS yöntemi iletken yüzeyde elektrik alanın tanjant bileşenlerinin toplamının sıfıra eşit olması prensibini kullanır.

Method of Auxiliary Sources yöntemi, yüzeyde N tane ayrık saçılma noktası olduğunu varsayar. Her bir nokta için, sınır koşullarının sağlandığı varsayılır. Temel saçılma alanı özelliği kullanılarak, elektromanyetik alan hesaplanabilir ve saçılma noktaları yüzeyin içince taşınabilir hâle gelir.

Bu sayede MAS yönetmi, tıpkı aynadaki sanal nokta gibi, auxiliary yüzey noktalarını varsayar. Sanal ve gerçek noktaların yüzeye olan uzaklığının birbirine yakın olması daha doğru sonuçlar elde etmeyi sağlar.

Tezin amacı, bir baz istayonundan yayılan sinyalin bir odadaki elektromanyetik dağılımını bulmaktır. Bu durumu çözümleyebilmek için, çeşitli durumlar ele alınmıştır. Odanın yapıldığı malzeme, odanın penceresinin boyutu ve sinyalin frekansındaki değişim ayrı ayrı olarak ele alınmıştır.

Boş bir oda ve odanın dışında bulunan bir baz istasyonu göz önüne alınarak farklı frekans değerlerinin yayılımı gözlenmiştir. Bu gözlemi yapabilmek için, aynı boyutlarda iki farklı malzemeden inşa edilmiş oda göz önüne alınarak, betonarme malzemeden inşa edilmiş ve yalıtkan bir maddeden inşa edildiği varsayılan odalardaki etkiler kıyaslanmıştır.

Bunun yanında insan vücudunu analiz etmek için de bazı varsayımlarda bulunulmuştur. Gerçek bir insan vücudu kemikler, kan, kas gibi birimlerle heterojen bir yapıdadır. Her bir vücut biriminin özgül soğurma hızı farklıdır. Hesaplamaları kolaylaştırmak adına, homojen yapıda bir insan vücudu kullanıldığı varsayılmıştır. Bu homojen yapının hangi birimden var olduğuna karar vermek için vücudun çeşitli birimlerinin özgül soğuma hızları araştırılmıştır. Kullanılan referans kaynaklar göstermiştir ki, kemik, kas ve kan dokuları ele alındığında, kas dokusunun özgül soğurma hızı ortalama bir değerdedir. Bu nedenle, tez çalışmasında kullanılan insan vücudunun tamamen kas dokusundan oluşan homojen bir yapıda olduğu varsayılmıştır. Bu sayede hesaplamalar ve varsayımlar kolaylaşmıştır.

Araştırma için oluşturulan tüm koşullar, fortran yazılımı kullanılarak simüle edilmiştir. Varsayımlar ve sabit değerler tutularak, değişen koşullar uygulanarak her bir durum için ilgili sonuçlar elde edilmiştir.

İlk durumda, yalıtkan bir malzeden yapıldığı varsayılan bir odaya 100 metre uzakta 10 metre yüksekte bulunan bir kaynağın 300MHz frekans değeri ile servis verdiği varsayılmıştır. Bu durumda kaynaktan gelen sinyalllerin odanın içerisinde yayılıp, kolayca geçip gidebildiği gözlenmiştir.

İkinci durumda ise, yine yalıtkan bir malzemeden yapıldığı varsayılan odaya, 100 metre uzakta ve 10 metre yüksekte bulunan kaynağın 450MHz frekans değeri ile servis verdiği durum incelenmiştir. Bu durumda da, kaynaktan gelen sinyallerin pencere çevresinde yoğunlaşmış olsa da odanın içerisinde yayılabildiği gözlenmiştir.

Üçüncü durumda, kaynağın konumunun siyalin yayılma yönüne etkisini gözlemek adına, aynı odaya aynı uzaklıktaki kaynağın yine 450MHz frekans değeri ile, bu kez farklı olarak 30 metre yükseklikteki bir konumdan servis verdiği varsayılmıştır. Kaynaktan gelen sinyallerin yine odanın içinde yayılabildiği gözlenirken, farklı olarak bir önceki durumda gözlenen dağılımın simetrik olma durumun bozulduğu gözlemlenmiştir.

Dördüncü durumda, yalıtkan malzemeden yapılan odaya, 100 metre uzaklıkta ve 10 metre yükseklikten 900MHz frekans ile bir 2G baz istasyonunun servis verdiği durum simüle edilmiştir. Sinyallerin yine odanın içerisinde, pencere önünde yoğun olmak üzere dağılabildiği gözlemlenirken, odanın arkasında kalan kısımda sinyal dağılımı açısından bir gölgeli kısım gözlenmiştir.

Yalıtkan oda için oluşturulan simülasyon ortamında son olarak, 900MHz ile servis veren kaynağın konumu tam ters bölgede olacak şekilde değiştirilmiştir. Bu durumda kaynağın odanın penceresi bulunmayan tarafından servis verdiği ele alınmıştır. Odanın içerisinde neredeyse homojen bir dağılım gözlenmiştir.

Simülasyon ortamı bu kez betonarme malzemeden yapılan bir odanın kullanıldığı durum varsayılarak değiştirilmiştir. Bu durum için, odanın içinde homojen yapıda bir insan vücudunun var olduğu da varsayılmıştır. Diğer tüm koşullar aynı tutulduğu durumda, 300MHz ile servis veren kaynağın sinyallerinin odanın içinde yayılıp duvarlardan geçip gidemediği gözlenmiştir. Dışarı yayılamayan sinyaller, insan vücudu üzerinde de yoğunlaşmıştır. İkinci bir durum olarak, pencere boyutunda küçültülmesi, oda içerisinde yoğunlaşan sinyalleri azaltmamıştr.

Betonarme oda için, tüm koşullar aynı tutularak kaynağın 450MHz frekans ile ya da 900MHz servis verdiği durumlar ele alındığında da, sinyallerin odanın içinde kalıp, duvarlardan geçerek yayılamadığı ve insan vücudu üzerinde yoğunlaştığı gözlemlenmiştir.

Sonuçların gösterdiği üzere, eğer odanın yapıldığı malzeme betonarme ise, oda bir rezonatör gibi davranarak sinyalin odanın duvarlarından geçip gitmesini engelleyip, elektromanyetik dalgaların odanın içinde yoğunlaşıp güçlenmesine neden olmuştur. Odanın yalıtkan malzemeden yapıldığı durumda ise, sinyaller duvardan geçip yayılmaya devam edebilmiştir.

Farklı frekans değerleri, farklı pencere boyutları ya da oda içerisinde bir insan bulunup bulunmamış olması sonuçları değiştirmemiştir. Gözlenen elektromanyetik dağılımda bazı farklılıklar olsa da, tüm farklı uygulamalar için benzer sonuçlar elde edilerek betonarme malzemeden yapılmış olan odanın rezonatör etkisi gözlenmiştir.

1. INTRODUCTION

The evaluation of technology creates new concerns for human health affected by new technological developments. According to GSMA Mobile Economy Report (2019), it is expected to have about 5 billion connected users in 2025 (s. 4). Telecommunication related developments are concentric with daily human life. Number of both connected user equipment and base stations are increasing. Mobile phones and base stations are becoming a part of daily life.

During the thesis, effects of different frequency of signals on human body propagated by a base station are analyzed.

1.1. Purpose of the Thesis

The purpose of the thesis is investigating the effects electromagnetic signals of base stations to a human body in a room. The base station located in outside the room affects the human body inside a room. User in a room is served by a base station outside the room generally. Even there is not any source inside the room, the outside source coverage signals effect human body. During details of this thesis, electromagnetics effects on human body will be analyzed detailed.

The base station signals in a room affects human body in the room and creates magnetic waves inside the body. These signal levels changes based on technology. Hence, effect on human body changes based on technology.

During thesis, near field distribution inside the human body is calculated for different serving frequencies. To compare the affects; 3G, 4G and 5G frequencies are used on calculations and results are shared.

1.2. Literature Review

The connected devices keep people online any time. This connection is provided by the numerous sources inside and outside of the buildings. This coverage layer comes with some health questions for human body. Even there are lots of researches about harm of the base stations to human body, there is not any final decision for these discussions.

During the thesis, the electromagnetics effects of this coverage layer on human body analyzed by using the Method of Auxiliary Sources. Additionally, there is a comparison given between 3G, 4G and 5G signals in respect to electromagnetics affects on human body.

1.3. Hypothesis

Complicated electromagnetic problems cannot be solved easily without using some approaches. Since there are incident and reflected signals, by using regular methods, it is not easily possible to calculate the electromagnetics effects of a source for each point of an item.

To solve the boundary problems for electromagnetics problems with less complex and less CPU usage, there is a method called Method of Auxiliary Sources. (Tabatadze et al. 2014)

It is possible to observe the effects of different technologies on a human body in a room by using Method of Auxiliary Sources. By keeping all factors same, except the frequency of the signal propagated from base station, effect of different technology signals can be observed.

To solve boundary problems, Method of Auxiliary Sources considers discrete N points around the surface. For each point, boundary condition equations are resolved. Thus, when all results are sum, result of boundary conditions in total surface can be found.

The Method of Auxiliary Sources is available to apply 3D dimension. Similarly, to Method of Auxiliary Sources, there is Lattice approach to solve complex problems for 2D dimension.

Lattice method assumes that there is an array of same wire elements with same distance between them. In this method, array of wires can be considered as metal wires on a ferro concrete wall. Based on compare between the lambda value of signal and the distance between wires, penetration through the wall can be obtained. If lambda equals to distance between wires, signal can penetrate through the wall. If lambda greater than distance, signal cannot penetrate.

2. THEORATICAL DISCUSSIONS

The purpose of the thesis is to analyze the effects of a base station signals to a human body inside a closed empty room. To observe results for this situation, some electromagnetics methods are combined with assumptions. The main method used to observe results is the Method of Auxiliary Sources which gives real like results with minimized CPU usage while calculating results.

In the following sections, details of theorem and methods used during thesis will be declared detailed.

2.1 Electromagnetic Boundary Conditions

An electrical field can travel from a medium to another one. Based on medium's conductivity characteristic, electrical field may change its behavior across boundary.

Differential from of Maxwell's equations are used to formulize boundary conditions. It allows to define electric field behavior while travelling through a medium to another one based on their conductivity (K.S.Yee, 1966)

Traditional versions of Maxwell's equations are as below in equations 2.1-4 (Balanis, 2012, s.12),

$$\nabla * E = -M - j\omega\mu H \quad \textbf{(2.1)}$$

$$\nabla * H = J + j\omega\varepsilon E \quad \textbf{(2.2)}$$

$$\nabla * D = q_e \quad \textbf{(2.3)}$$

$$\nabla * B = q_m \quad \textbf{(2.4)}$$

These formulas are converted to differential forms based on conductivity of mediums.

For the case travelling, it is assumed that travelling through medium 1 to medium 2. If the medium 1 is a perfectly electic conductor, formulas can be updated as below in equations 2.5-8 (Gibson, 2015),

$$n\ x\ E_2 = 0 \quad \textbf{(2.5)}$$

$$n \, x \, H_2 = J_S \tag{2.6}$$

$$n * D_2 = q_{es} \tag{2.7}$$

$$n * B_2 = 0 \tag{2.8}$$

On the other hand, for the fields travelling from medium 1 to medium 2, if the medium 1 is a infinite magnetic conductor formulas can be used as below in equations 2.9-12 (Gibson, 2012, s.26).

$$-n \, x \, E_2 = M_s \tag{2.9}$$

$$n \, x \, H_2 = 0 \tag{2.10}$$

$$n * D_2 = 0 \tag{2.11}$$

$$n * B_2 = q_{ms} \tag{2.12}$$

2.2 Bessel's Function

To find the resonant frequencies for a circle, zeros of Bessel's function can be used.

2.3 Hankel's Function

A singularity appears in the Hankel function if there are any overlapped segments. To be able to calculate far field expression for A (ρ) and F (ρ), large argument approximation for the Hankel function can be used.

On the other hand, to be able to calculate overlapping segments, small argument approximation for the Hankel function can be used.

The general form of Hankel's function in equation 2.13 (Gibson, 2012, s.30),

$$H_0^{(2)}(k\rho) \approx 1 - j\frac{2}{\pi}\log(\frac{\gamma k\rho}{2}) \tag{2.13}$$

Where $\rho \to 0$.

2.4 Green's Function

Electrodynamic Green's function in two dimensions in equation 2.14 (Balanis, 2012, s.885),

$$G(\rho) = -\frac{j}{4} H_0^{(2)}(k\rho) \tag{2.14}$$

2.5 Hertz Dipole

Current and charge can be represented with one vector, called "Hertz Vector".

2.6 Application of Functions

Let's consider below table to find resonant frequencies by using zeros of Bessel's function represented in Table 2.1.

Table 2.1: Zeros of Bessel's function.

k	$J_0(x)$	$J_1(x)$	$J_2(x)$	$J_3(x)$	$J_4(x)$	$J_5(x)$
1	2.4048	3.8317	5.1356	6.3802	7.5883	8.7715
2	5.5201	7.0156	8.4172	9.7610	11.0647	12.3386
3	8.6537	10.1735	11.6198	13.0152	14.3725	15.7002
4	11.7915	13.3237	14.7960	16.2235	17.6160	18.9801
5	14.9309	16.4706	17.9598	19.4094	20.8269	22.2178

For example, in the case of k equals to 1, solution of $J_2(x)$ gives below result at resonant frequency in Figure 2.1.

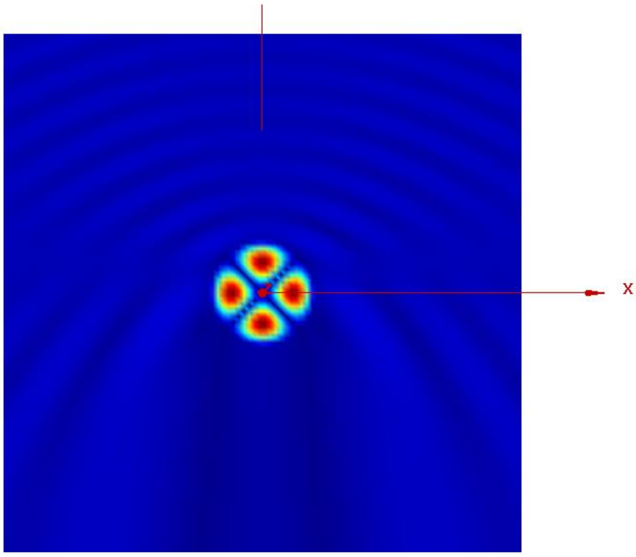

Figure 2.1: Zero based on Bessel's function when k=1.

If $J_3(x)$ is used in the case of k equals 1, below results appeared in Figure 2.2,

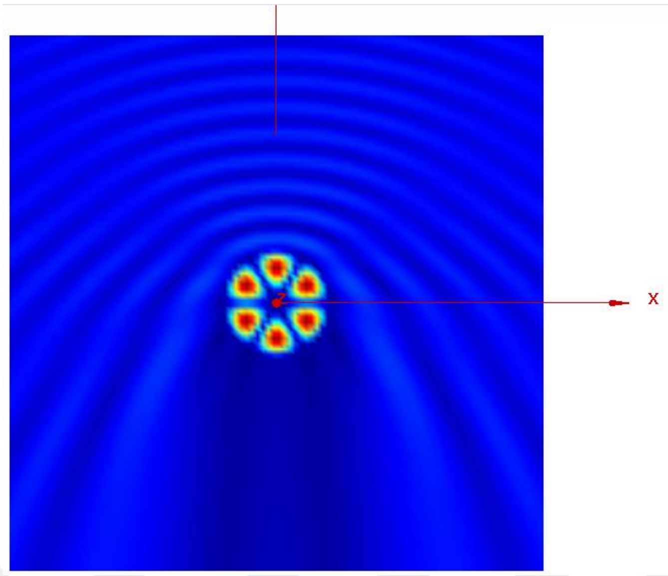

Figure 2.2: Zero based on Bessel's function when k=1 for third J.

If the number of k is increased, result will be changed. In below, k equals 2 and J_0 (x) is used in Figure 2.3.

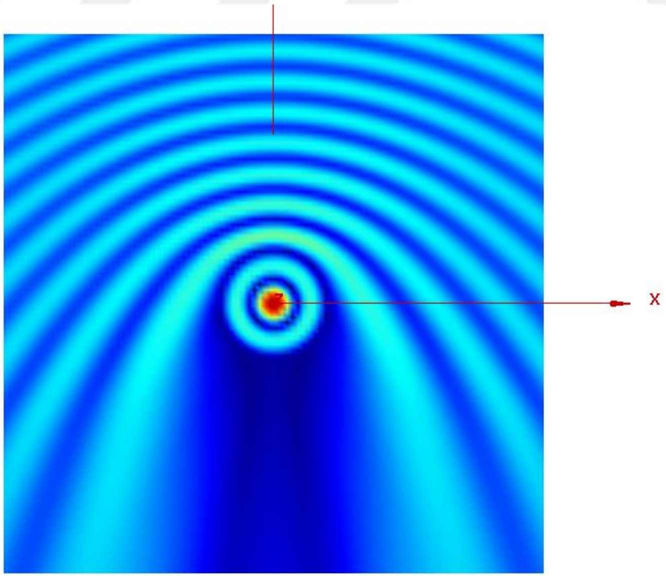

Figure 2.3: Zero based on Bessel's function when k=2.

2.7 Method of Auxiliary Sources

Method of Auxiliary Sources aims to find the field distribution in surface. To find the correct results, scattered fields and boundary condition satisfaction considered by the Method of Auxiliary Sources.

If the surface is assumed as a perfect conductor for a cylinder, then the tangential component of the total electric field should be zero based on boundary condition satisfaction. Thus, scattered field and incident field sum is zero as in equation 2.15.

$$E_z = E_z^i + E_z^s = 0 \tag{2.15}$$

On the light of this, to determine the scattered field, current distribution needs to be calculated. In this case, below integral equation observed in equation 2.16.

$$E_z^i(\rho) = \frac{k\eta}{4}\int CJ_z(\rho')H_0^{(2)}(k|\vec{\rho} - \vec{\rho}'|)dl' \tag{2.16}$$

To remove integral operation from the formula, it can be assumed that each point as a discrete current point. By applying Hankel's function, each discrete current point applies singularity. Additionally, MAS uses fundamental finite behavior of scattered field on the surface. Thus, it is possible to move field inside the scatter analytically. Hence, source points and collocation points are not coincided. Thus, formula become less complex with avoiding singularity as below to find scattered field in equation 2.17.

$$E_z^{sc}(\rho) = \frac{-k\eta}{4}\sum_{i=1}^{N} I_z^i(\rho^i)H_0^{(2)}(k|\vec{\rho} - \vec{\rho}^i|) \tag{2.17}$$

The next problem in this case is how to find the best point as an auxiliary surface. It is assumed that there are N discrete scattered points on the surface. For each scattered point, boundary conditions should be satisfied. Thus, there is a linear equation group is obtained. Discrete current points satisfy boundary conditions and provides singularity because of Hankel's function.

Method of Auxiliary sources use fundamental scattered field property instead of regularization to avoid singularity as other methods. EE field value is finite on the scatter surface even currents are excited and scattered field is analytical. Thus, the calculation becomes integrable singularity and it allows analytically continue field inside scatter. (Zaridze et al. 2002) Hence, moving scattering points inside the current surface and collocation does not coincide.

Since singularity is prevented, solving below equation will give the scattered field in equation 2.18,

$$E_z^{sc}(\rho) = \frac{-k\eta}{4}\sum_{i=1}^{N} I_z^i(\rho^i) H_0^{(2)}\left(k\left|\vec{\rho} - \vec{\rho}^i\right|\right) \qquad \textbf{(2.18)}$$

Next step is to choose correctly auxiliary surface. Based on experience, it showed that any surface around real surface is not useful surface to use. In the case of elliptical scatter surface is used, if auxiliary sources fit to ellipse focus, the series will have good convergence. Otherwise, if auxiliary surface does not fit to elliptical shape, series will diverge.

To find correct auxiliary surface point, it can be considered as image point on the mirror case. If source and image point have similar distances to the surface, better results will be obtained. Thus, scattered field singularity provided by image point of the source.

To find the best auxiliary surface, surface should be found which circular scatter field singularities coincide to the surface.

For the sphere case, scattered field is represented by sum of the electric dipole fields, in below equations 2.19-21, Hertz Dipole.

$$\vec{E}^{(0)} = \nabla\nabla \cdot \vec{\Pi}^{(0)} + k^2\vec{\Pi}^{(0)} \qquad \textbf{(2.19)}$$

$$\vec{H}^{(0)} = -j\omega\varepsilon\nabla \times \vec{\Pi}^{(0)} \qquad \textbf{(2.20)}$$

$$\vec{\Pi}^{(0)} = 1\frac{1}{4\pi\varepsilon}\, p^{(1)}\frac{e^{ikR-i\omega t}}{R} \qquad \textbf{(2.21)}$$

If there is only one dipole, then $p^{(1)}$ is a constant vector and gives the polarization of the dipole. Hence, electric and magnetic fields of dipole can be represented as below formulas in equations 2.22 and 2.23;

$$E^{(0)} = \frac{1}{4\pi\varepsilon} e^{-i\omega t} * \frac{1}{R^3} \left[3R_0\left(R_0 * p^{(1)}\right) - p^{(1)}\right] - \frac{ik}{R^2}\left[3R_0\left(R_0 * p^{(1)}\right) - p^{(1)}\right] - \frac{k^2}{R}\left[R_0 * \left(R_0 * p^{(1)}\right)\right] \tag{2.22}$$

$$H^{(0)} = -\frac{i\omega}{4\pi} e^{-i\omega t} * \left(\frac{1}{R^2} - \frac{ik}{R}\right) p^{(1)} * R_0 \tag{2.23}$$

In above formulas, R_0 represents a unit vector directed from the dipole towards the observer.

For the sphere case, similar to the 2D case, auxiliary surface is shifted. In each auxiliary surface point, there are two perpendicular electric dipoles are located. For both perpendicular tangential vectors, boundary conditions are satisfied as in equation 2.24.

$$E^{sc}(r) = \sum_{i=1}^{N} X_{1i}(r^{\vec{\prime}}) * G^{E}_{Hertz,r1}\left(k * \left|\vec{r} - r^{\vec{\prime}}\right|\right) + \sum_{i=1}^{N} X_{2i}(r^{\vec{\prime}}) * G^{E}_{Hertz,r2}\left(k * \left|\vec{r} - r^{\vec{\prime}}\right|\right) \tag{2.24}$$

Based on diffraction, there are incident and out vectors of electric field as below equation 2.25 and 2.26,

$$\boldsymbol{E}_{in}(\boldsymbol{r}) = \sum_{i=1}^{N} X^{out}_{1i} G(k|\boldsymbol{r} - \boldsymbol{r}_{out}|) + \sum_{i=1}^{N} X^{out}_{2i} G(k|\boldsymbol{r} - \boldsymbol{r}_{out}|) \tag{2.25}$$

$$\boldsymbol{E}_{out}(\boldsymbol{r}) = \sum_{i=1}^{N} X^{in}_{1i} G(k|\boldsymbol{r} - \boldsymbol{r}_{in}|) + \sum_{i=1}^{N} X^{in}_{2i} G(k|\boldsymbol{r} - \boldsymbol{r}_{in}|) + E_{inc}(\boldsymbol{r}) \tag{2.26}$$

For the room acts like a resonator, there are two perpendicular dipoles appeared by usage of MAS. The field for the dipoles can be found by using below formulas in equations 2.27-32,

$$\vec{E}_{comb} = \vec{E}_{el} + \sqrt{\frac{\mu}{\varepsilon}} \vec{E}_{mag} \tag{2.27}$$

$$\vec{H}_{comb} = \vec{H}_{el} + \sqrt{\frac{\mu}{\varepsilon}} \vec{H}_{mag} \tag{2.28}$$

$$\vec{E}_{el} = \left(\frac{e^{ikR}}{4\pi\varepsilon}\right)\left\{\left(\frac{1}{R^3} - \frac{ik}{R^2}\right)\left[3\vec{R}_0 \cdot \left(\vec{R}_0 \cdot \vec{p}_{el}\right) - \vec{p}_{el}\right] - \left(\frac{k^2}{R}\right)\left(\vec{R}_0 \times \left(\vec{R}_0 \times \vec{p}_{el}\right)\right)\right\} \tag{2.29}$$

$$\vec{E}_{mag} = \sqrt{\frac{\mu}{\varepsilon}}\left(\frac{k^2 e^{ikR}}{4\pi}\right)\left(\frac{1}{R^2} - \frac{ik}{R}\right)\left(\vec{p}_{mag} \times \vec{R}_0\right) \tag{2.30}$$

$$\vec{H}_{el} = \left(\frac{i\omega e^{ikR}}{4\pi}\right)\left(\frac{1}{R^2} - \frac{ik}{R}\right)\left(\vec{R}_0 \times \vec{p}_{el}\right) \tag{2.31}$$

$$\vec{H}_{mag} = \left(\frac{e^{ikR}}{4\pi}\right)\left\{\left(\frac{1}{R^3} - \frac{ik}{R^2}\right)\left[3\vec{R}_0 \cdot \left(\vec{R}_0 \cdot \vec{p}_{mag}\right) - \vec{p}_{mag}\right] - \left(\frac{k^2}{R}\right)\left(\vec{R}_0 \times \left(\vec{R}_0 \times \vec{p}_{mag}\right)\right)\right\} \tag{2.32}$$

3. METHODOLOGY

In this chapter, details of thesis are explained. The main goal of the thesis is the find the near field distribution inside the body for the radio network frequencies. To calculate the distribution; radiation pattern of base station, energy absorbed by human body and the reflection from the walls need to be considered.

3.1 Human Body Setup

First of all, to setup the thesis environment, it is assumed that there is a room with a window in a building and there is a base station outside the building. The electromagnetic signal effect on a human body inside the room is analyzed. Researches are showed that energy absorbed by the human body increased the temperature of the body. Thus, it is important to calculate specific absorption rates to see the effect through the human body. (Mushtaq and Kumar, 2013.) It is assumed that there is homogeneous human body model. To calculate the energy absorbed by the body, there is a homogenous mummy which is built completely by human's muscle tissue.

Specific absorption rate gives the energy absorbed by human body. Absorption value varies for different parts of body. Each part of body, bone, blood, muscle, has its own conductivity value. (Zuckerman et al. 1994) Based on conductivity of body layers, value of SAR changes proportionally. Different RF signal levels creates different SAR values on body layers, since different conductivity calculated based on frequencies (Haque et al. 2012).

Based on theoratical moment method calculations, Ranil et al. (2018) stated that "Specific absorption rate of human muscle tissue is about between 1.01 and 1.07 w/kg for 3G frequencies." (p. 2) Muscle tissue is selected since it has average permittivity and loss based on other layers of human body.

If dP_a belongs to power absorved to volume of the tissue, dm the mass of unit tissue, δ belongs to penetration depth and σ is the conductivity of tissue material with ρ local density value, SAR value can be calculated with below formulas for any kind of human body layer in equations 3.33-34 (Hsing-Yi and Hou-Hwa, 1994).

$$SAR = \frac{dP_a}{dm} = \frac{\sigma E^2}{\rho} (w/kg) \quad \textbf{(3.33)}$$

$$SAR = \frac{3\sigma\delta^2}{2\rho} (w/kg) \quad \textbf{(3.34)}$$

3.2 Room Setup

Additionally, to frequency propagate from the base station, reflection from the walls of the room has an important affect on the SAR value of homogeneous body model. It is assumed that room has been built with ferro-concrete material. Electromagnetic signal radiates from the base station enters the room from the window and because of the structure of build by ferro-concreate material, signal reflected from the walls. Thus, room behaves as a resonator because of signal came from base station. Also, room has an internal frequency based on its dimensions. Because of resonator behavior, room creates oscillation of the signal.

Walls of the room is built by ferro-concrete material. Metal vires inside material have an important role to calculate the electromagnetic field distribution inside the room and hence effect on the human body. To be able to penetrate over the wall, signal's wavelength should be equal or smaller than the distance between metal wires on ferro-concrete material.

Wavelength of the signal received from base station is calculated with wavelength formula with speed of light represented in equation 3.35.

$$\lambda = \frac{c}{f} \quad \textbf{(3.35)}$$

Iron wires inside the wall apply the Lattice theorem since distance between wires are same, as array of same wire elements. Distance between metal wires effect the penetration of signal through the wall. Bigger distance between metal wires allow bigger wave lengths. As an obvious example, if there is not any metal wire, that means distance between wires are infinite. In this case, any signal with any wave length can freely penetrate through the wall. If the wave length of signal equals to the distance between metal wires, signal can penetrate through the wall. If wave length is greater than the distance, signal can not penetrate. Human body acts like dielectric materials.

Thus, electromagnetic signals can penetrate trough the human body but with high frequencies, conductivity of body increase, and signal cannot penetrate. (Bernardi at el. 2000, p.4)

For different technologies, different frequencies are used on radio access network. Since walls of the room constant ferro-concrete material with constant wires, different technologies have different penetration behavior through the wall. As can be seen from the formula, frequency and wave length are inversely proportional. Therefore, wave length is smaller for the bigger frequencies.

3.3 Setup with 2G Frequencies

Mobile coverage around the living quarters are provided by the base stations in and out of the buildings. Radio frequency signals are transmitted from the base stations. 2G networks use about 800-900 MHz frequency band usually which provides a wide coverage on network. Base station is located outside the building and transmits through the window to the room which is built by concrete material. Homogeneous human body is located in the middle of room.

For the case considered during thesis, 2G network frequency is assumed as 900 MHz. Wave length of 2G network signals is about 0.33 meters, 30 centimeters which calculated in equation 3.36.

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{900 * 10^6} = 033\ meters \quad \textbf{(3.36)}$$

It is assumed that room is built by ferro-concrete material with 25 centimeters distance between each metal wire of material.

Based on lattice property, 2G signals can no penetrate through the walls and also, human body. That means, signal concentrates inside the room and in human body. 2G Electromagnetic signals concentrates on human body and increase the heat of the body. That increased heat shows the size of bad affect on human body.

3.4 Setup with 3G Frequencies

3G Radio network signals are released as third generation with fast internet connection capability. There are some different phases of 3G technology but generally 3G base stations radiates with 2100 MHz. All other elements of thesis test setup are kept same with other cases. There is room with a window and 3G base station radiates from outside the building through the window directed to inside the room. There is a homogeneous human body in the middle of the room which is specialized as mummy.

For the 3G network base stations, wave lenght is about 0,14 meters, 14 centimeters for 2100 MHz shown in equation 3.37.

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{2100 * 10^6} = 0.14\, meters \tag{3.37}$$

Because of 25 centimeters distance is assumed for the iron wires of ferro-concreate wall, 3G base station signals can penerate through the wall based on Lattice theorem.

Therefore, 3G network base station signals can penetrate through the wall and 3G signals concentrate on human body less.

3.5 Setup with 4G Frequencies

High speed connectivity is provided by 4G Radio network signals for mobile equipments. Generally, 4G technology base stations serve with 2600 MHz. Based on wave length formula, 4G base station signals have about 0,12 meters, 12 centimeters wave length calculated in equation 3.38.

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{2600 * 10^6} = 0.12\, meters \tag{3.38}$$

Test environment is designed with a base station outside the building which serve through the window of ferro-concrete building.

3.6 Setup with 5G Frequencies

Although it is not officially published and started to use, it is planned to use high frequency on 5G network base station signals. It is planned to release with about 3800 MHz. Accordingly, to the wavelength formula, 5G base station will serve with 0,08 meters, 8 centimeters wave length which is found with equation 3.39.

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{3800 * 10^6} = 0.08\, meters \quad \textbf{(3.39)}$$

In comparison with 2G network signals, wave lenght decreased to about ¼ of the value. For the same environment created for tests, 5G network signals can propagate easily through the wall and human body beside 2G network.

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4. NUMERICAL RESULTS

During the thesis, several use cases handled related with the building material of the room and human impact. There are two main consideration cases; one of them is a room built by ferro-concrete material with source outside the room and a room built by dielectric material and source outside the room. Geometry of room is represented in Figure 4.4.

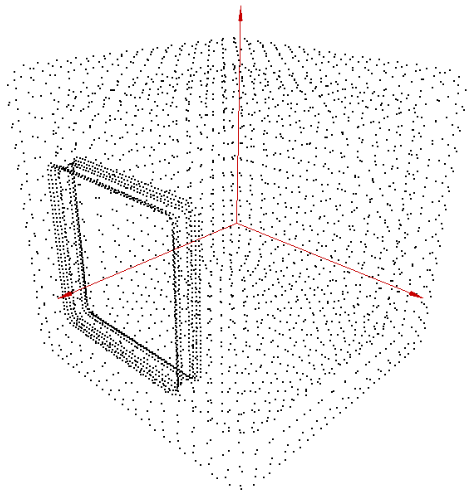

Figure 4.4: Geometry of the Room.

For the first case, a room built by a dielectric material is used. For this case, different sources with different frequencies are considered. Based on position and the height of the source, propagation of the plane signal has been changed (Petoev et al. 2013, s.3).

For the first case, it is assumed that there is a source serving with 300MHz frequency with 100 meters away source position and 10 meters height represented in Figure 4.5 and Figure 4.6.

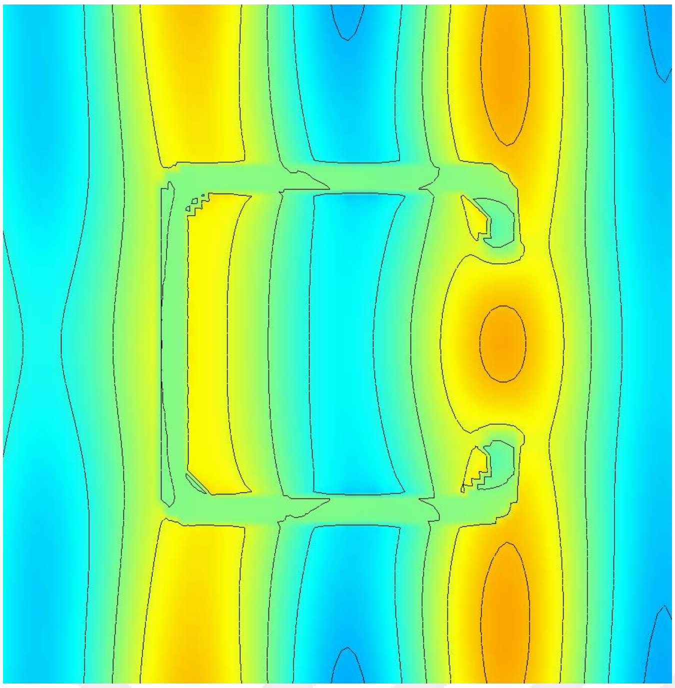

Figure 4.5: Animated version the of the results for f=300MHz.

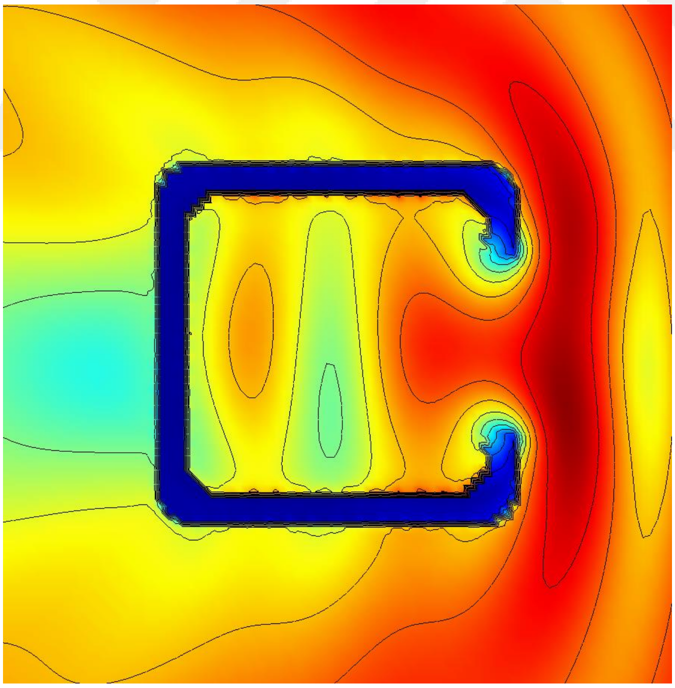

Figure 4.6: Static version of the results for f=300MHz.

Second case considers a source which is serving with 450MHz frequency in 100 meters way source position and 10 meters height shown in Figure 4.7 and 4.8.

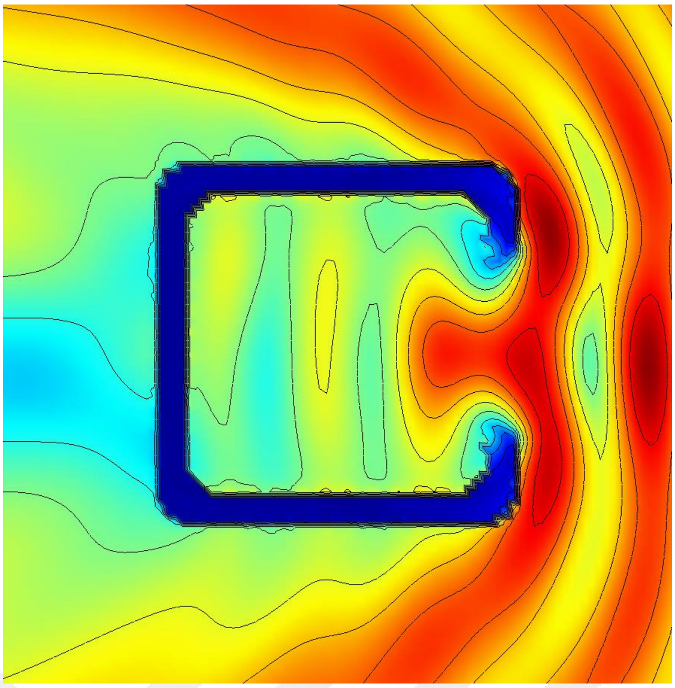

Figure 4.7: Static version of the results for f=450MHz.

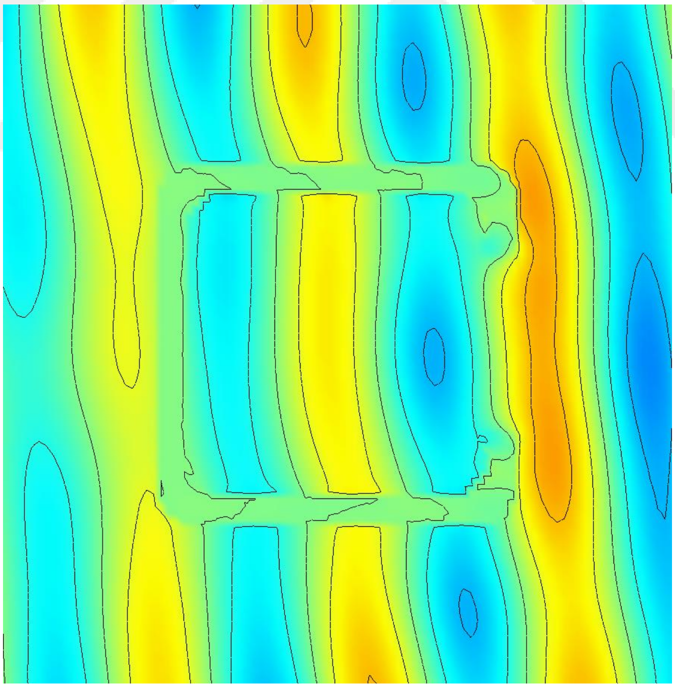

Figure 4.8: Animated version the of the results for f=450MHz.

Another version of second case considers a source which is serving with 450MHz frequency in 100 meters way source position and 30 meters height to see the affect height of the source simulated in Figure 4.9 and 4.10.

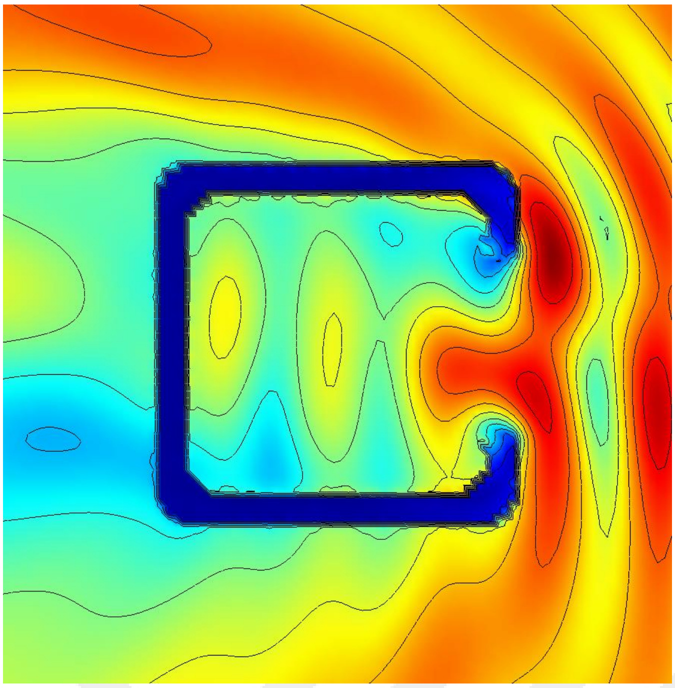

Figure 4.9: Static version of the results for f=450MHz with 30m height.

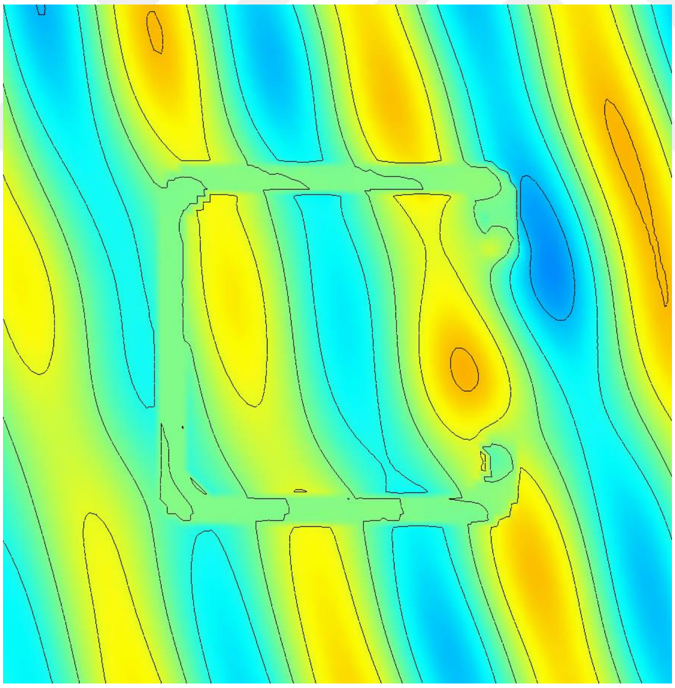

Figure 4.10: Animated version of the results for f=450MHz with 30m height.

On the third case, as a source of frequency, a 2G base station is used which is served with 900MHz frequency in 100 meters away and 10 meters height shown in Figure 4.11 and 4.12.

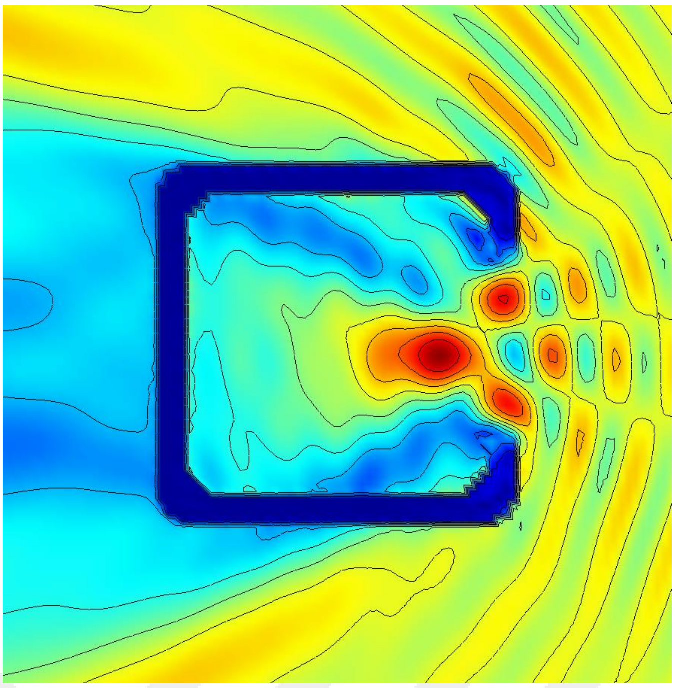

Figure 4.11: Static version of the results for f=900MHz.

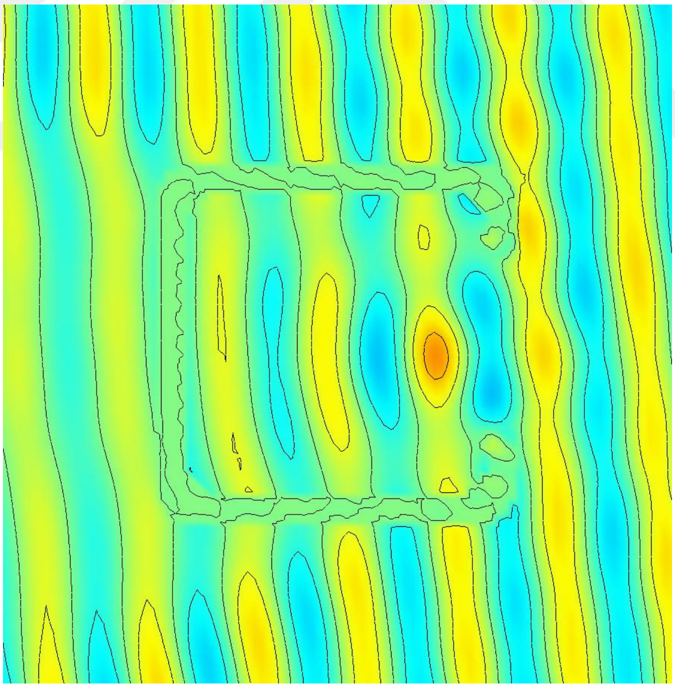

Figure 4.12: Animated version the of the results for f=900MHz.

When the position of the source has been changed to opposite direction for the same frequency, similar results are observed represented in Figure 4.13 and 4.14.

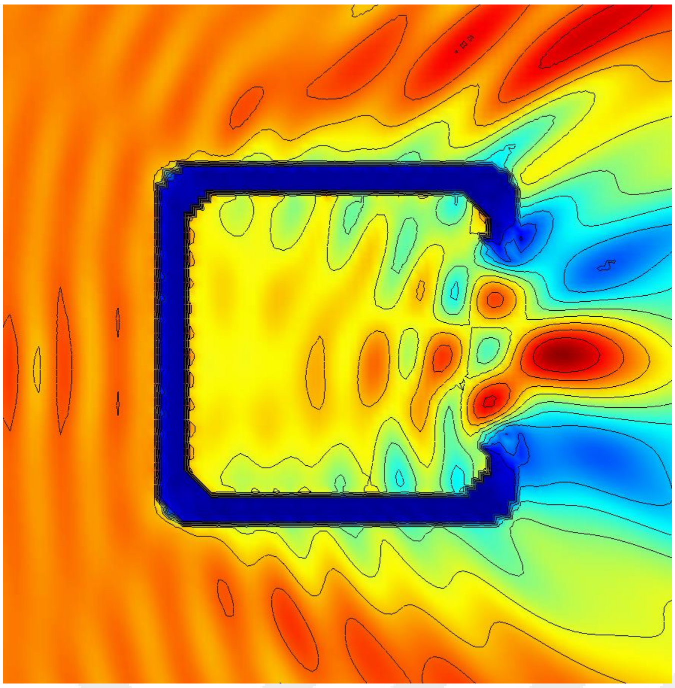

Figure 4.13: Static version of the results for f=900MHz in opposite direction.

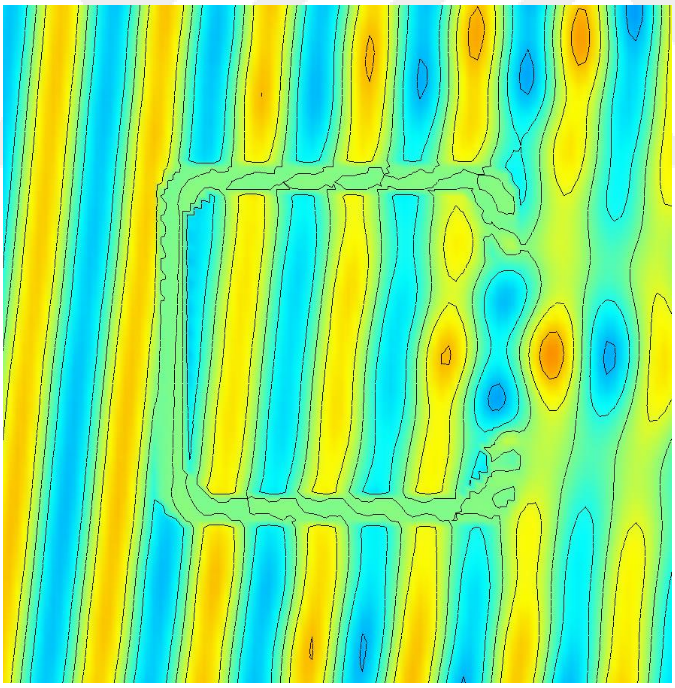

Figure 4.14: Animated version the of the results for f=900MHz in opposite direction.

In conclusion, for all sources with different frequencies and different positions, it is common that all signals can propagate through the dielectric walls.

On the other hand, there is another room builded by ferro-concrete material. Analysis is made with the same frequencies for this room. The room built by ferro-concrete material has resonant effect and field may be amplified because of resonant effect.

Electromagnetic field distribution inside the room is affected by size of the window and frequency of the source.

If the size of window is selected as 2.6x2.0 meters, below results are obtained in the room built by ferro concrete material when a signal penetrate trough the wall with 300MHz shown in Figure 4.15.

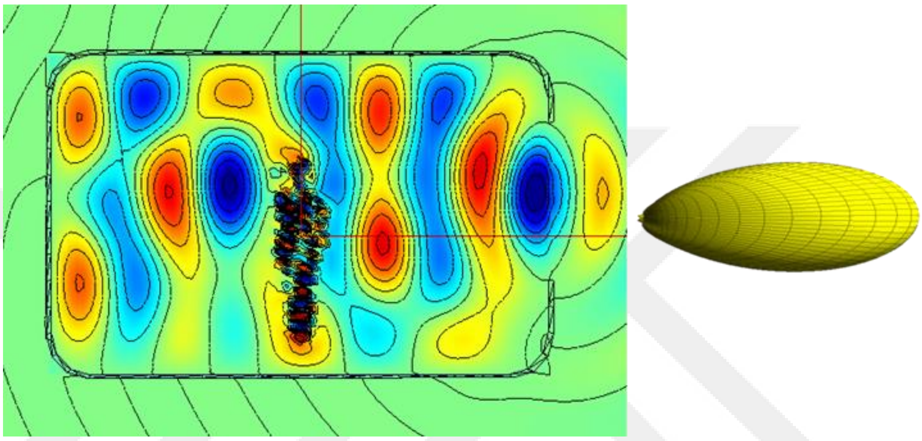

Figure 4.15: Distribution with 300Mhz source.

If the size of the room is reduced when all other elements are kept as same, below results are monitored in Figure 4.16.

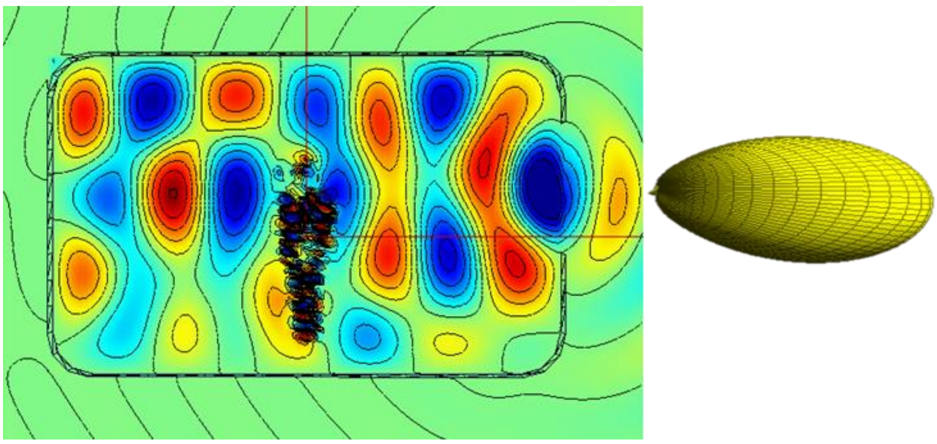

Figure 4.16: Distribution with 300MHz when window size reduced to 2.0 x 1.6m.

If there is not any room, there is not any effect of resonator by signal served by the source. Thus, there is not any peak on the field observed as can be seen in Figure 4.17.

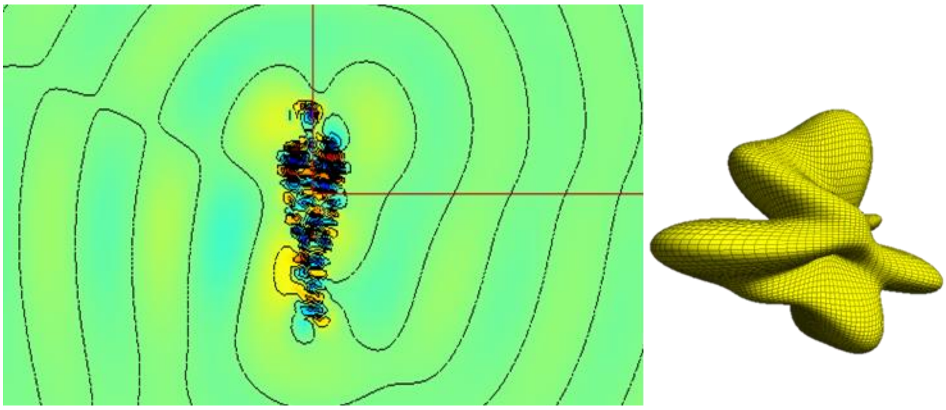

Figure 4.17: Distribution when there is no room.

For the same steps, when source frequency increased to 450Mhz, results are changed as below in Figure 4.18,

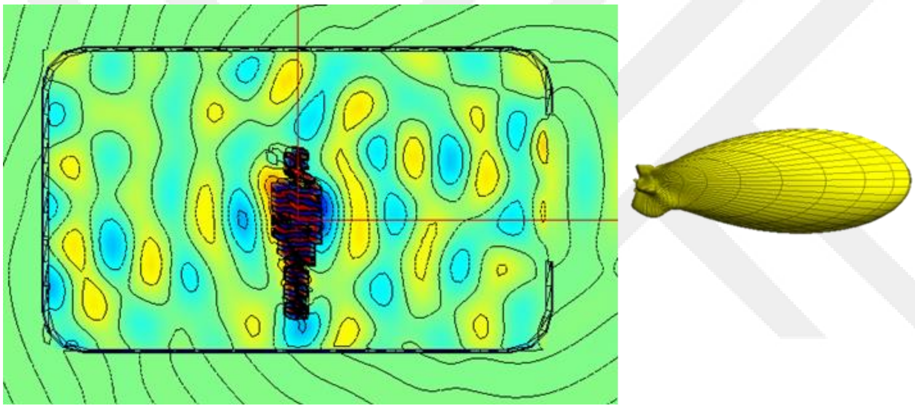

Figure 4.18: Distribution with 450MHz.

Similarlar, when source frequency increased to 900MHz, penetration become smoother as shown in Figure 4.19.

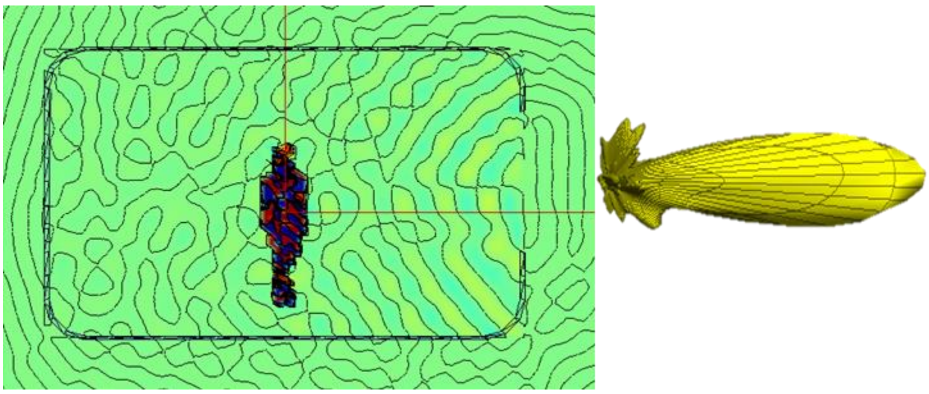

Figure 4.19: Distribution with 900MHz.

In conclusion, if dielectric material is used on the building of a room, regardless of position of the source or frequency, signal can penetrate trough the wall. There is not any resonant effect on a room built by dielectric material.

Otherwise, room which is built by ferro-concrete material creates resonant effect when a signal received trough the wall. Thus, electromagnetic field can be amplified and human inside a room may affect because of it. Frequency of the signal may change the effect of resonant. Based on test results it is obviously seen that if frequency is become higher, signal may penetrate through the walls and resonant and amplifying effects are decreased.

In the end, it can be said that if there is a room built by dielectric material, signals can penetrate trough the walls. There will not be any dense electromagnetic field inside the room. If room is built by ferro-concreate material, there is a resonant effect posibility which may cause dense electromagnetic field inside the room.

5. CONCLUSION

During the thesis, there are different use cases handled to find the resonator effect reason for the room.

To analyze the base station, there are different frequencies used for testing. To test different frequency and wavelength affect, 300 MHz, 450Mhz and 900 MHz frequencies are used.

On the other hand, to analyze the building material of the room, there are two types of building material used; one of them ferro-concrete and one of them dielectric material.

On the same conditions, only one of the analysis elements has been changed and results are stated. For example, for the 900MHz frequency case, there are two separate room considered with same size. One of the rooms are built by ferro-concrete material and other one built by dielectric material. On the results, it is obtained that room built by ferro-concrete material acts like a resonator when signal received from the window of the room. On the other hand, room built by dielectric material does not affect the signal and signal could penetrate through the walls.

In conclusion, results showed that room behaves as resonator if built by ferro-concrete material, although there is not any resonator effect when dielectric material is used regardless which frequency is radiated by base station.

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