Chapter Five : Conclusion and Discussion

Mobile phones have monopole antennas that give rise to omni directional radiation patterns in the plane perpendicular to the monopole. Due to this omni directional property of the radiation pattern, signals are emitted from antennas in all directions. It is possible that some of the signals could enter the brain of the user as well. Energy in the signals that enter the brain can cause heating and therefore damage the brain cells. This is a problem for concern.

Using Specific Absorption Rate (SAR) it was easy to understand the rate of heating. Assuming the brain to be divided into 1000 cubic cells, calculations of SAR values were carried out for three cases of brain alone; for the brain and skull together; and for the brain, skull and the ears all together. The SAR values seem to be higher at middle than at the periphery of the brain and the maximum value of the SAR is below the safety standards set by British safety levels.

Even then, since some people are using these instruments for long periods of time, and since children are using them it is better to minimize the SAR as far as possible.

To minimize such absorption an attempt was made to design a suitable antenna for the mobile unit, which would reduce the electromagnetic waves propagation to the head of a user.

The general trend of miniaturization, microstrip patch antennas on small size substrates give rise to many practical applications. In mobile communication systems, the antenna size has often to be reduced as far as possible. For convenience I selected microstrip antenna because of its small size and due to its low cost.

There are two types of antennas in use, rectangular and circular. For easy calculations a rectangular shape was selected for the antenna design.

Initially phase difference (δ) and distance between two patches (d) were kept constant but number of patches were varied. In this regard a single patch antenna, a two-patch array and a four patch linear array were considered. The most appropriate broad beam is given by two patches antenna.

Then the two elements square-patch microstrip antenna was designed, fabricated and tested and the phase difference (δ) and the distance between two patches (d) were varied. The antenna showed a broad beam with empty radiation regions when the two elements were separated by a $\lambda/2$ (λ is the wave length) and when the two elements were fed by units of equal magnitude by $\pi/2$. We applied shielding effect for selected antenna. Then the radiation pattern is broader than the earlier one and there was a region which receives , less amount of back radiations or no radiations passing through this area. This area is more suitable to keep our head. This method reduces the electromagnetic radiation absorbed by the brain.

Normally the frequency of the signal is in the range of (824-900) MHz. But using the material with permitivity as 2.91, it is difficult to make an antenna for the cellular phones, because the dimension of the antenna is too large. Then it is possible to design an antenna for the frequency of 9.4GHz to demonstrate the principle.

The effective design of components related to the mobile phones mounted on hand held units should have the following requirements,

It should be small and flat, low cost, attractive in appearance, easy to construct and thus following shape of the radiation pattern is recommended.

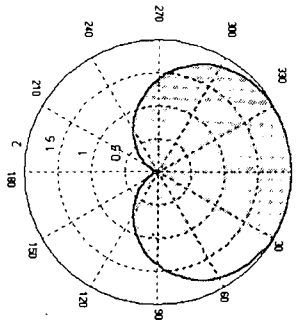

Figure 5.1: Required radiation pattern for the antenna

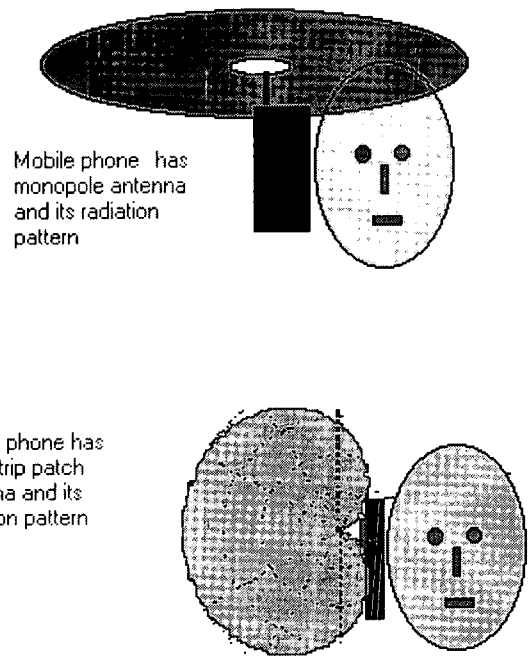

Figure 5.2: Radiation pattern that EM emitted by monopole antenna and microstrip antenna

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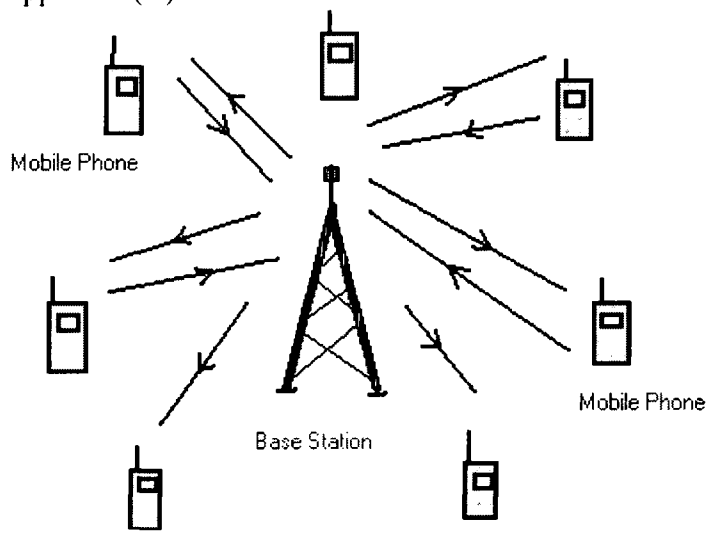
Appendix

Appendix (A)



Cellular Environment

Appendix (B)

****

BRAIN2( ) – calculation of EM radiation absorb by the human brain using MOM

****

```
function  brain2(nn)
ncell=2*(nn^3);
h=.1/real(nn);
nn2=nn*2;
sig=1.29;
raw=1050.;
f=0.9e9;
w=2.*pi*f;
epso=(1.e-9)/(36.*pi);
```

```
eps=50.11*epso;
[v,x]=geometry(nn);
for n=1:ncell
  tau(n)=sig+i*w*(eps-epso);
end
[g1]=green(x,v,tau,nn);
[g2]=inv(g1);
for ics=1:6
   if ics==1
     e0=87.
    else
     e0=100.+(ics-2)*100.;
   end
   ve0(ics)=e0;
   [ei]=material(e0,nn);
   [e]=(g2)*(-ei)';
     for n=1:nn2
         sax(n)=0.;
         say(n)=0.;
         saz(n)=0.;
         htx(n)=0.;
         hty(n)=0.;
         htz(n)=0.;
      end
   n=0;
   spow=0.;
   shta=0.;
   for jj=1:nn
     for ii=1:nn2
       for kk=1:nn
         n=n+1;

                  pow=(abs(e(n)))^2+(abs(e(n+ncell)))^2+(abs(e(n+2*ncell)))^2;
         sa=(sig/raw)*pow;
         sar(n)=sa;
         hta(n)=.5*sig*pow*1.e-3;

         ssar(ii,jj,kk)=sa;
         spow=spow+sa;
         shta=shta+hta(n);
         sax(ii)=sax(ii)+sa;
         say(jj+nn)=say(jj+nn)+sa;
         j1=nn-jj+1;
         say(j1)=say(j1)+sa;
         saz(kk+nn)=saz(kk+nn)+sa;
         k1=nn-kk+1;
```

```
          saz(k1)=saz(k1)+sa;
        end
      end
    end
     e0
     sar;
     max(sar,[],2)
     mean(sar,2)
     hta;
     max(hta,[],2)
     mean(hta,2)
sam=-.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;
end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
text(.025,.85,'Fld. Int.      V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
r(ics)=power(ics)/tht(ics);
end
ve0
power
tht
r
input zz;
```

```
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900 Mhz,')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (W/kg.)')
```

Appendix (C)

****

SKTIS( ) –calculation of EM radiation absorb by the human brain and Skull using MOM

****

```
function sktis(nn)
ncell=2*(nn^3);
h=.1/real(nn);
nn2=nn*2;
sig=1.29;
sig1=0.45;
raw=1050.;
raw1=1000;
f=0.9e9;
w=2.*pi*f;
eps0=(1.e-9)/(36.*pi);
eps=50.11*eps0;
[v,x]=geometry(nn);
 n=0;
 for ii=1:nn2
   for jj=1:nn
     for kk=1:nn
       n=n+1;
       if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
        tau(n)=sig+i*w*(eps-eps0);
       else
         tau(n)=sig1*i*w*(eps-eps0);
       end
     end
   end
end
```

```
[g1]=green(x,v,tau,nn);
[g2]=inv(g1);
for ics=1:6
  if ics==1
    e0=87.
   else
    e0=100.+(ics-2)*100.;
  end
  ve0(ics)=e0;
  [ei]=material(e0,nn);
  [e]=(g2)*(-ei)';
  ei
  for n=1:nn2
       sax(n)=0.;
       say(n)=0.;
       saz(n)=0.;
       htx(n)=0.;
       hty(n)=0.;
       htz(n)=0.;
    end
  n=0;
  spow=0.;
  shta=0.;
  for jj=1:nn
    for ii=1:nn2
      for kk=1:nn
        n=n+1;

                    pow=(abs(e(n)))^2+(abs(e(n+ncell)))^2+(abs(e(n+2*ncell)))^2;
       if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
         sa=(sig/raw)*pow;
         sar(n)=sa;
         hta(n)=.5*sig*pow*1.e-3;

       else
        sa=(sig1/raw1)*pow;
        sar(n)=sa;
        hta(n)=.5*sig1*pow*1.e-3;
       end
        ssar(ii,jj,kk)=sa;
        spow=spow+sa;
        shta=shta+hta(n);
        sax(ii)=sax(ii)+sa;
        say(jj+nn)=say(jj+nn)+sa;
        j1=nn-jj+1;
```

```
            say(j1)=say(j1)+sa;
            saz(kk+nn)=saz(kk+nn)+sa;
            k1=nn-kk+1;
            saz(k1)=saz(k1)+sa;
             end
        end
      end
       e0
       ei
       sar;
       max(sar,[],2)
       mean(sar,2)
       hta
       max(hta,[],2)
       mean(hta,2)
sam=-.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;
end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
text(.025,.85,'Field. Int.    V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
r(ics)=power(ics)/tht(ics);
end
ve0
```

```
power
tht
r
input zz;
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900MHz,')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (W/kg.)')
```

Appendix (D)

****

SKTIS1( ) – calculation of EM radiation absorb by the human Brain, Skull and ear using MOM

****

```
function  sktis1(nn)
ncell=2*(nn^3);
h=.05/real(nn);
nn2=nn*2;
sig=1.29;
sig1=0.45;
raw=1050.;
raw1=1000;
f=0.9e9;
w=2.*pi*f;
eps0=(1.e-9)/(36.*pi);
eps=50.11*eps0;
[v,x]=geometry(nn);
 n=0;
 for ii=1:nn2
   for jj=1:nn
     for kk=1:nn
       n=n+1;
       if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
        tau(n)=sig+i*w*(eps-eps0);
       elseif (ii==1 & ii==nn*2) & (jj==nn) & (kk==nn)
         tau(n)=sig+i*w*(eps-eps0);
       else
         tau(n)=sig1*i*w*(eps-eps0);
       end;
```

```
    end
  end
end
[g1]=green(x,v,tau,nn);
[g2]=inv(g1);
for ics=1:6
  if ics==1
    e0=87.
   else
    e0=100.+(ics-2)*100.;
  end
  ve0(ics)=e0;
  [ei]=material(e0,nn);
  [e]=(g2)*(-ei)';
  ei
  for n=1:nn2
       sax(n)=0.;
       say(n)=0.;
       saz(n)=0.;
       htx(n)=0.;
       hty(n)=0.;
       htz(n)=0.;
    end
  n=0;
  spow=0.;
  shta=0.;
  for jj=1:nn
    for ii=1:nn2
      for kk=1:nn
        n=n+1;
                    pow=(abs(e(n)))^2+(abs(e(n+ncell)))^2+(abs(e(n+2*ncell)))^2;
        if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
           sa=(sig/raw)*pow;
           sar(n)=sa;
           hta(n)=.5*sig*pow*1.e-3;
                 elseif (ii==1 & ii==nn*2) & (jj==nn) & (kk==nn)
           sa=(sig/raw)*pow;
           sar(n)=sa;
           hta(n)=.5*sig*pow*1.e-3;
           else
                sa=(sig1/raw1)*pow;
            sar(n)=sa;
            hta(n)=.5*sig1*pow*1.e-3;
       end;

        ssar(ii,jj,kk)=sa;
```

```
            spow=spow+sa;
            shta=shta+hta(n);
            sax(ii)=sax(ii)+sa;
            say(jj+nn)=say(jj+nn)+sa;
            j1=nn-jj+1;
            say(j1)=say(j1)+sa;
            saz(kk+nn)=saz(kk+nn)+sa;
            k1=nn-kk+1;
            saz(k1)=saz(k1)+sa;

          end
        end
      end
       e0
       ei
       sar
      hta
sam=-.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;

end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
text(.025,.85,'Field. Int.     V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
```

```
r(ics)=power(ics)/tht(ics);
end
ve0
power
tht
r
input zz;
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900MHz,')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (W/kg.)')
```

Appendix (E)

****

GREEN( )

****


```
function [g1]=green(x,v,tau,nn)
f=0.9e9;
eps0=(1.e-9)/(36*pi);
u0=(4.e-7)*pi;
w=2*pi*f;
k0=w*((u0*eps0)^(.5));
c=-i*w*u0*k0;
c1=-2*i*w*u0/(3*(k0^2));
c2=3*i*w*eps0;
ncell=2*(nn^3);
for p=1:3
  for q=1:3
    x1=(p-1)*ncell;
    for m=1:ncell
      x1=x1+1;
      x2=(q-1)*ncell;
      for n1=1:ncell
        x2=x2+1;
        if m==n1
          an=(3*v(n1))/(4*pi)^(1/3);
          c3=i*k0*an;
          c4=tau(n1)/c2;
          gg=c1*tau(n1)*((1+c3)*exp(-c3)-1)-(1+c4);
```

```
            if p==q
              del=1;
              g1(x1,x2)=del*gg;
            else
              del=0;
              g1(x1,x2)=del*gg;
            end
          else
            d=(x(1,n1)-x(1,m))^2+(x(2,n1)-(x(2,m))^2+(x(3,n1)-x(3,m))^2;
            d=d^(.5);
            if d==0
              s='distance same'
            end
            amn=k0*d;
            if p==q
              del=1;
            else
              del=0;
            end
            c3=(c*tau(n1)*v(n1)*exp(-1*amn))/(4*pi*amn^3);
            cs=(x(p,m)-x(p,n1))*(x(q,m)-x(q,n1))/(d^2);
            g1(x1,x2)=c3*((amn-1-i*amn)*del)+cs*(3-amn^2+3*i*amn);
          end
        end
      end
    end
  end
```

Appendix (F)

****

GEOMETRY( )

****

```
function [v,x]=geometry(nn)
h=.1/nn;
vv=h^3;
n2=2*nn;
n=0;
for jj=1:nn
  for ii=1:n2
    for kk=1:nn
      n=n+1;
      v(n)=vv;
      x(1,n)=(ii-1)*h+h/2;
      x(2,n)=(jj-1)*h+h/2;
      x(3,n)=(nn-(kk-1))*h-h/2;
    end
  end
end
```

Appendix (G)

****

MATERIAL( )

****

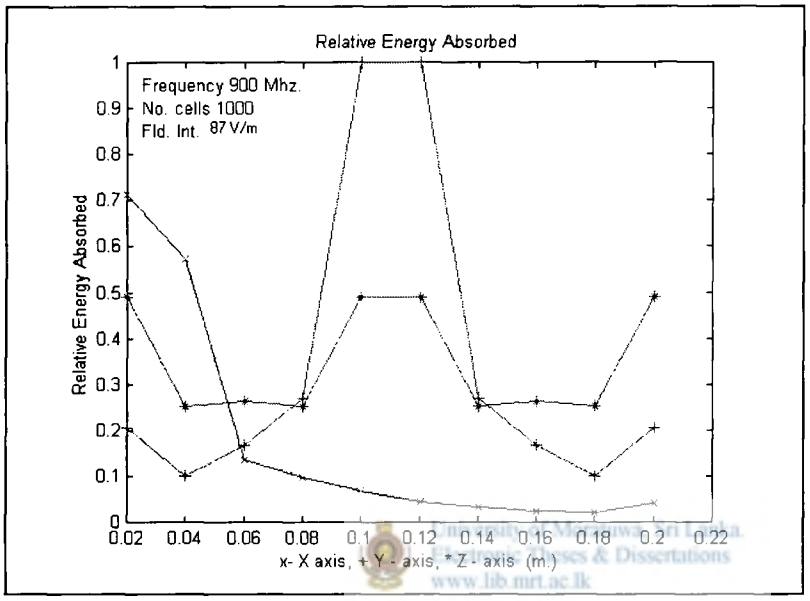
```
function [ei]=material(e0,nn)
ncell=2*(nn^3);
n2=nn*2;
h=.1/nn;
ncell3=ncell*3;
for ii=1:ncell3
  ei(ii)=0;
end
n=0;
for jj=1:nn
  for ii=1:n2
    for kk=1:nn
      n=n+1;
      ei(n)=0;
      if ii==1
        ei(n)=e0*.03/((.03^2+(jj*h)^2)^.5);
      end
      ei(n+ncell)=0;
      ei(n+2*ncell)=0;
    end
  end
end
```

Appendix (H)

Using brain2.m Matlab program the graphical outputs

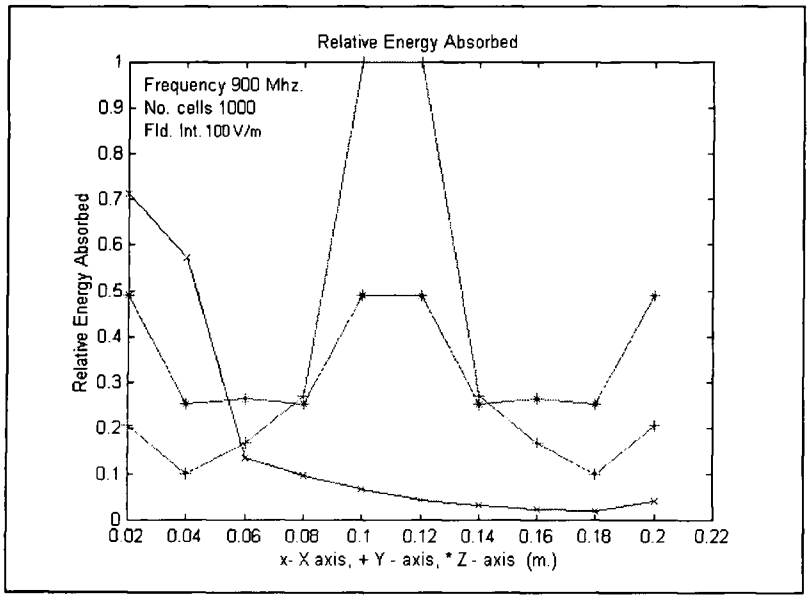
When E0=87 V/m

The energy absorption (considering brain tissues only) along X, Y, Z-axis due to entering EM radiations



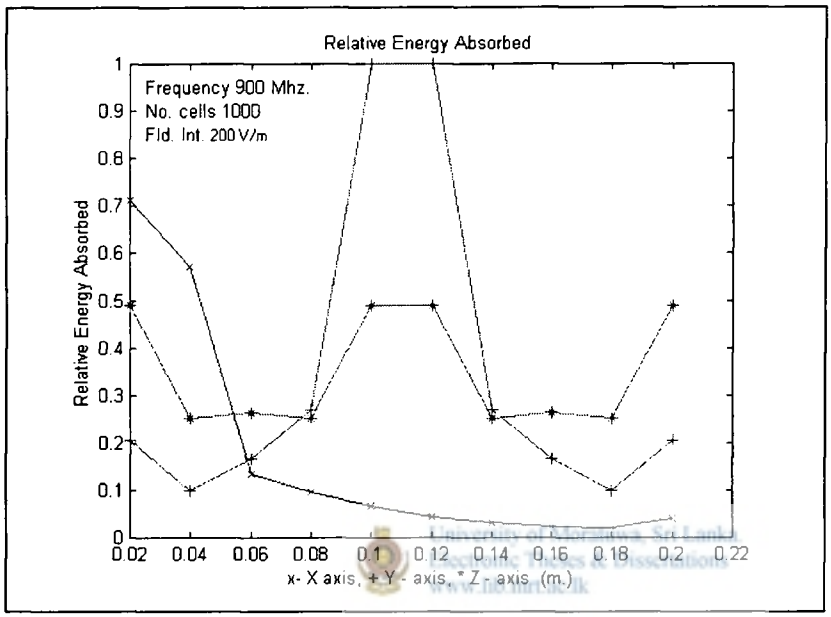
When E0=100 V/m

The energy absorption (considering brain tissues only) along X, Y, Z-axis due to entering EM radiations

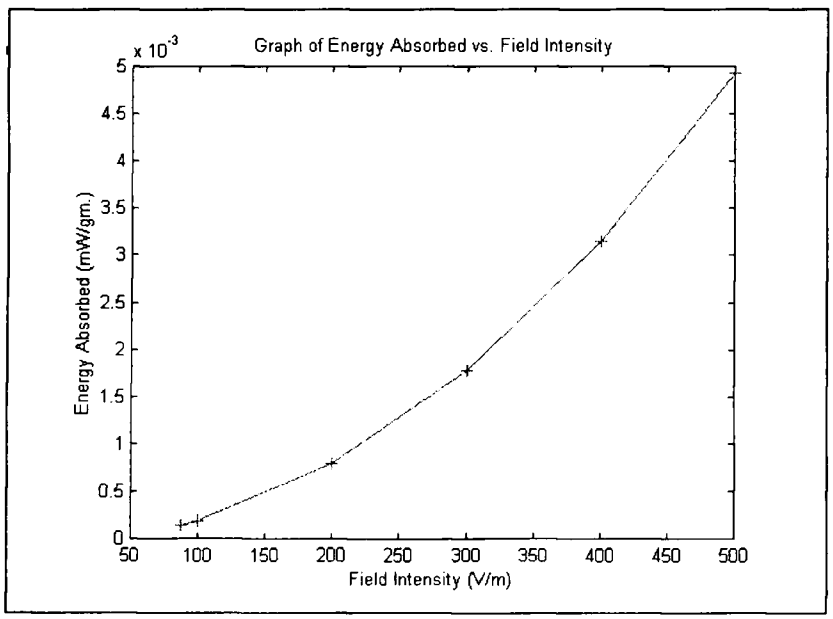


When E0=200 V/m

The energy absorption (considering brain tissues only) along X, Y, Z-axis due to entering EM radiations



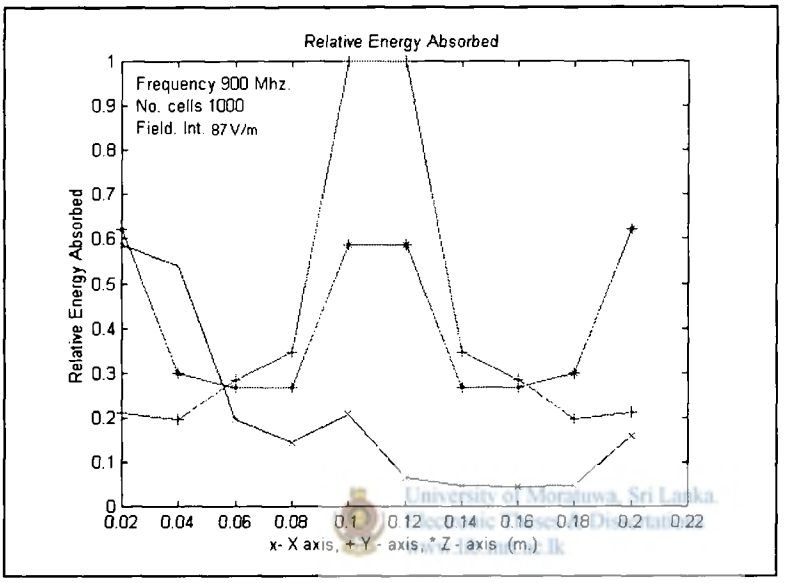
SAR variation due to entering EM radiations



Using sktis.m matlab program the graphical outputs

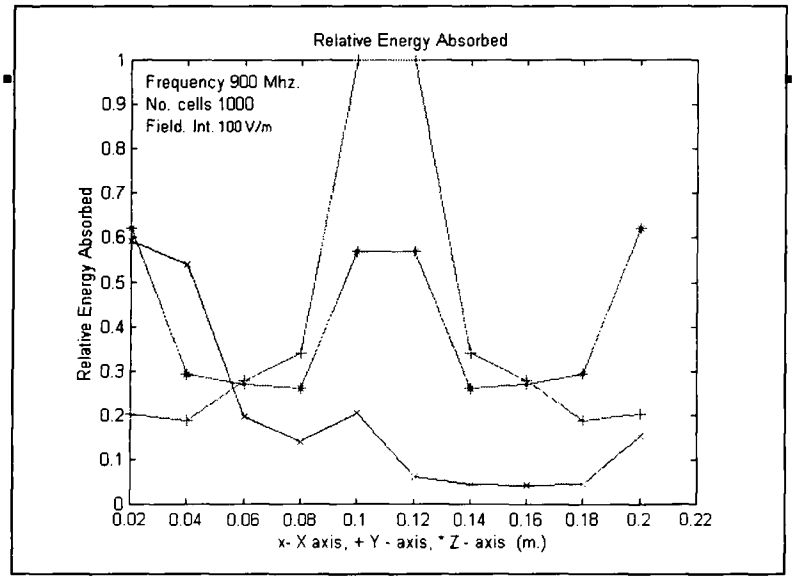
When E0=87 V/m

The energy absorption (considering brain tissues, skull) along X, Y, Z-axis due to entering EM radiations



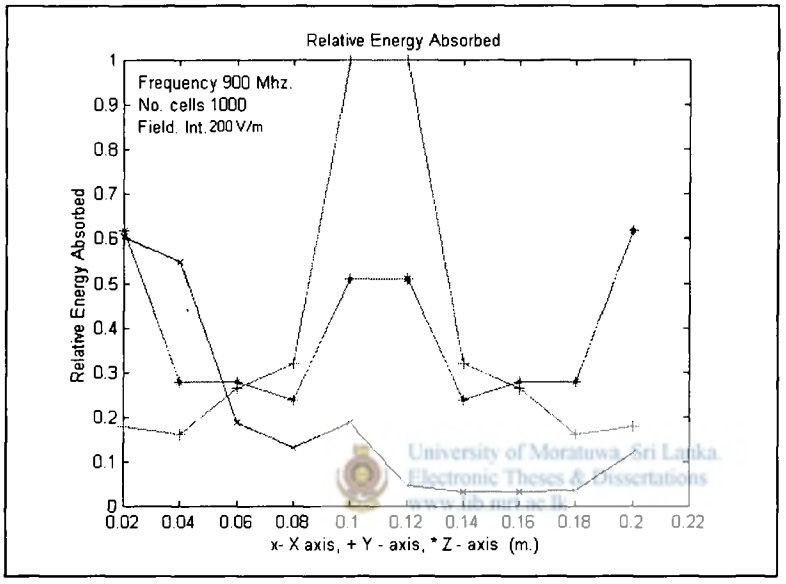
When E0=100 V/m

The energy absorption (considering brain tissues, skull) along X, Y, Z-axis due to entering EM radiations



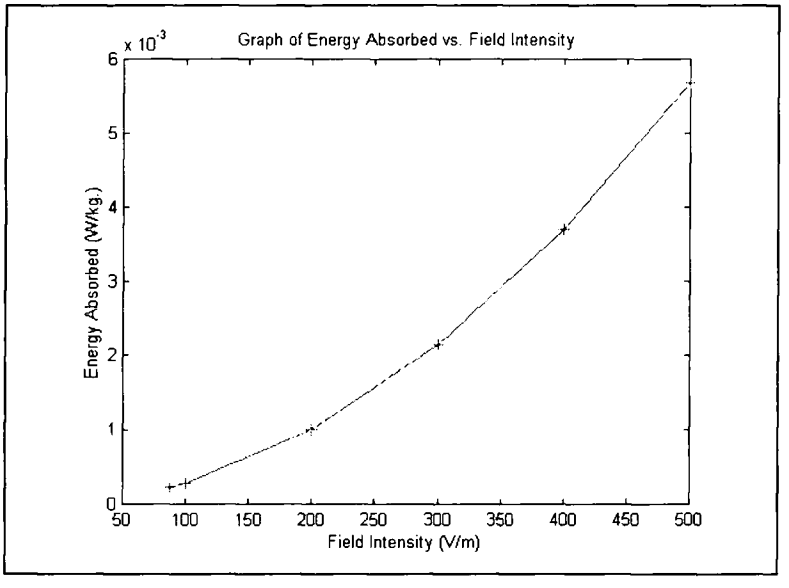
When E0=200 V/m

The energy absorption (considering brain tissues, skull)along X, Y, Z-axis due to entering EM radiations



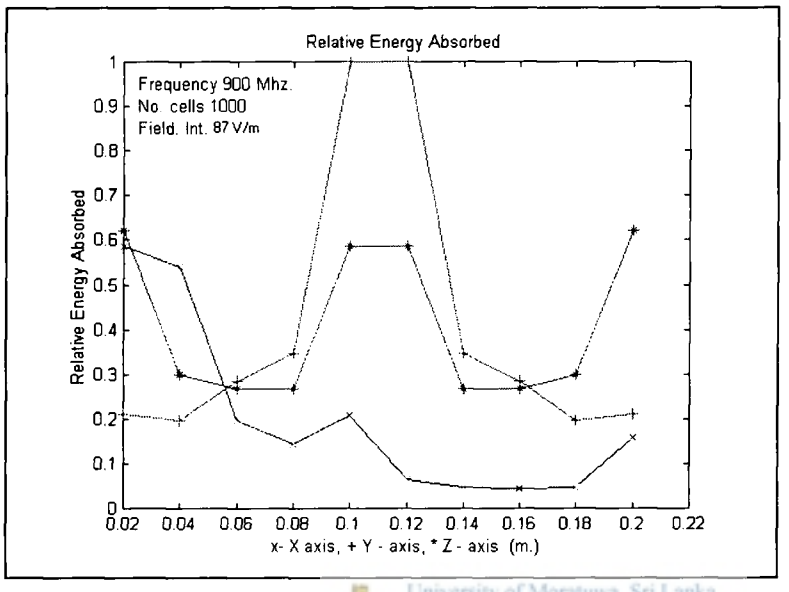
SAR variation due to entering EM radiations

Using sktis1.m Matlab program the graphical outputs



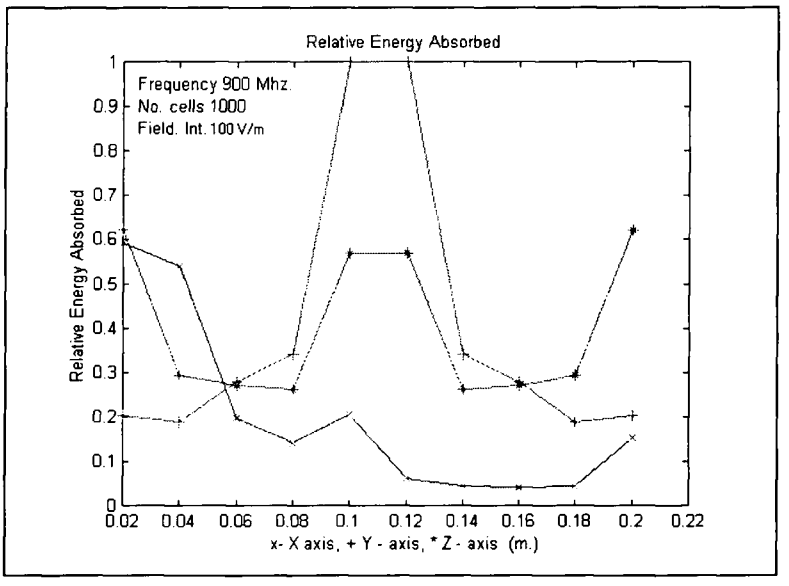
When E0=87 V/m

The energy absorption (considering brain tissues, skull and ear as a tissue) along X, Y, Z-axis due to entering EM radiations



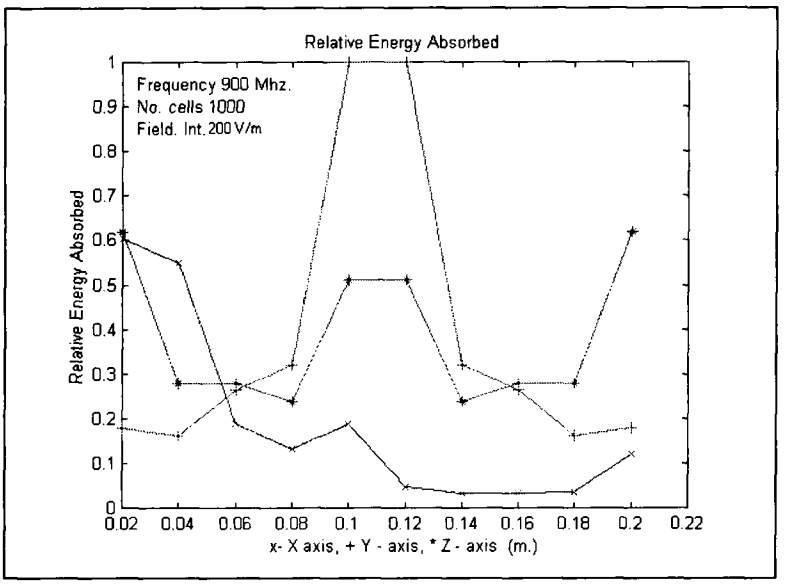
When E0=100 V/m

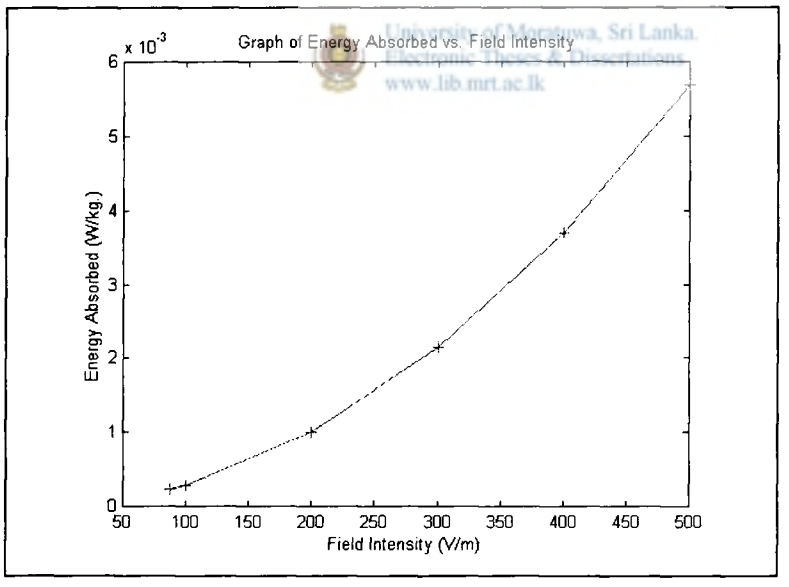
The energy absorption (considering brain tissues, skull and ear as a tissue) along X,Y, Z-axis due to entering EM radiations



When E0=200 V/m

The energy absorption (considering brain tissues, skull and ear as a tissue) along X, Y, Z-axis due to entering EM radiations





SAR variation due to entering EM radiations

Appendix (I) –Method of Moment

$$\nabla \times E^S = -J_{eq} - j\omega H^S \quad \text{.....}(4a)$$

$$\nabla \times H^S = j\omega E^S \quad \text{.....}(4b)$$

where Es, Hs and Jeq are all in phasor (complex) form. Elimination of Es or Hs in equation (4) leads to

$$\nabla \times \nabla \times E^S - k_0^2 E^S = -j\omega\mu_0 J_{eq} \quad \text{.....}(5a)$$

$$\nabla \times \nabla \times H^S - k_0^2 H^S = \nabla \times J_{eq} \quad \text{.....}(5b)$$

where $k_0^2 = \omega^2 \mu_0 \varepsilon_0$ *The solutions to equation* (5) *are*

$$E^S = j\omega [1 + (1/k_0^2)\nabla.\nabla] A \quad \text{.....}(6a)$$

and hence from 4(*b*)

$$H^S = (1/\mu)[\nabla \times A] \text{.....}(6b)$$

where

$$A = \mu_0 \int_v G_0(r,r').J_{eq}(r')dv' \text{.....}(7)$$

and the free space Green's function,

$$G_0(r,r') = \frac{e^{-jk_0(r-r')}}{4\pi|r-r'|} \text{.....}(8)$$

is the free-space scalar Green's function. By the operator $\nabla\nabla$., we mean that $\nabla\nabla.A = \nabla(\nabla.A)$. It is evident from eq.(6) that Es and Hs depend on Jeq is an infinitesimal, elementary source at r' pointed in the x direction so that

$$J_{eq} = \delta(r-r')a_x \text{.....}(9)$$

the corresponding vector potential is obtained from eq. (7) as

$$A = \mu_0 G_0(r,r').a_x \text{.....}(10)$$

If $G_{0x}(r,r')$ is the electric field produced by the elementary source, then $G_{0x}(r,r')$ must satisfy

$$\nabla \times \nabla \times G_{0x}(r,r') - k_0^2 G_{0x}(r,r') = -j\omega\mu_0 \delta(r,r') \text{.....}(11)$$

and has the solution

$$G_{0x}(r,r') = -j\omega\mu_0 (1 + \frac{1}{k_0^2}\nabla.\nabla)G(r,r') \text{.....}(12)$$

$G_{0x}(r,r')$ is referred to as a free-space vector Green function with a source pointed in the x direction. We could also have $G_{0y}(r,r')$ and $G_{0z}(r,r')$ corresponding to infinitesimal, elementary sources pointed in the y and z direction, respectively. We now introduce a dyadic function which can store the three vector Green functions $G_{0x}(r,r')$, $G_{0y}(r,r')$ and $G_{0z}(r,r')$, i.e.

$$G_0(r,r') = G_{0x}(r,r')\,\mathrm{i} + G_{0y}(r,r')j + G_{0z}(r,r')k \quad \text{.....(13)}$$

$G_0(r,r')$ is a solution to the dyadic differential equation,

This is called free-space dyadic Green 's function. It is a solution to the dyadic differential equation

$$\nabla \times \nabla \times G_{0x}(r,r') - k_0^2 G_0(r,r') = \bar{I}\delta(r,r') \quad \text{.....(14)}$$

Where $\bar{I}$ denotes the unit dyad (or idem factor).

The physical meaning of $G_0(r,r')$ is rather obvious. $G_0(r,r')$ is the electric field at a field point r due to an infinitesimal source at r'.

From equations (5a) and (13), the solution of E is evidently,

$$E^s(r) = -j\omega\mu_0 \int G_0(r,r').J_{eq}(r')\,dv' \quad \text{.....(15)}$$

$G_0(r,r')$ has a singularity of the order $|r = r'|^3$, the integral in eq. (14) diverges if the field points r is inside the volume v of the body (or source region). This difficulty is over come with by excluding a small volume approach zero. The process entails defining the principal value (P V) and adding a correction term needed to yield the correct solution.

$$E^s(r) = PV \int J_{eq}(r) G_0(r,r').\,dv' + [E^s(r)] \quad \text{.....(16)}$$

The correction term has been evaluated to be $-Jeq / j3\omega\varepsilon_0$ so that

$$E^s(r) = PV \int J_{eq}(r) G_0(r,r').\,dv' + J_{eq}(r)/(3j\omega\varepsilon_0) \quad \text{.....(17)}$$

The total electric field inside the body is the sum of the incident field E^i and scattered field E^s,

$$E(r) = E^i(r) + E^s(r) \quad \text{.....(18)}$$

Combining eqs. (2),(16)and (17) gives the desired tensor integral equation for $E(r)$:

$$\left(1+\frac{\tau}{3j\omega\varepsilon_0}\right)E(r)-PV\int\tau.\,E(r')\,G_0(r,r').dv'=E^i(r\ )\ldots\ldots\ldots(19)$$

Appendix (J) _FDTD Method

First is the Hooke's law with the thermal stress term,

$$\frac{\partial\sigma_{xx}}{\partial t}=(\lambda+2\mu)\frac{\partial v_x}{\partial x}+\lambda\frac{\partial v_y}{\partial y}+\lambda\frac{\partial v_z}{\partial z}-\alpha(3\lambda+2\mu)\frac{\partial T}{\partial t}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

$$\frac{\partial\sigma_{yy}}{\partial t}=(\lambda)\frac{\partial v_x}{\partial x}+(\lambda+2\mu)\frac{\partial v_y}{\partial y}+\lambda\frac{\partial v_z}{\partial z}-\alpha(3\lambda+2\mu)\frac{\partial T}{\partial t}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(iii)$$

$$\frac{\partial\sigma_{zz}}{\partial t}=(\lambda)\frac{\partial v_x}{\partial x}+(\lambda)\frac{\partial v_y}{\partial y}+(\lambda+2\mu)\frac{\partial v_z}{\partial z}-\alpha(3\lambda+2\mu)\frac{\partial T}{\partial t}\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(iv)$$

And the second is the equations of the motion

$$\frac{\partial\sigma_{xy}}{\partial t}=\mu\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(v)$$

$$\frac{\partial\sigma_{yz}}{\partial t}=\mu\left(\frac{\partial v_y}{\partial z}+\frac{\partial v_z}{\partial y}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(vi)$$

$$\frac{\partial\sigma_{zx}}{\partial t}=\mu\left(\frac{\partial v_z}{\partial x}+\frac{\partial v_x}{\partial z}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(vii)$$

$$\rho\frac{\partial v_x}{\partial t}=\left(\frac{\partial\sigma_{xx}}{\partial x}+\frac{\partial\sigma_{xy}}{\partial y}+\frac{\partial\sigma_{zx}}{\partial z}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(viii)$$

$$\rho\frac{\partial v_y}{\partial t}=\left(\frac{\partial\sigma_{xy}}{\partial x}+\frac{\partial\sigma_{yy}}{\partial y}+\frac{\partial\sigma_{yz}}{\partial z}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ix)$$

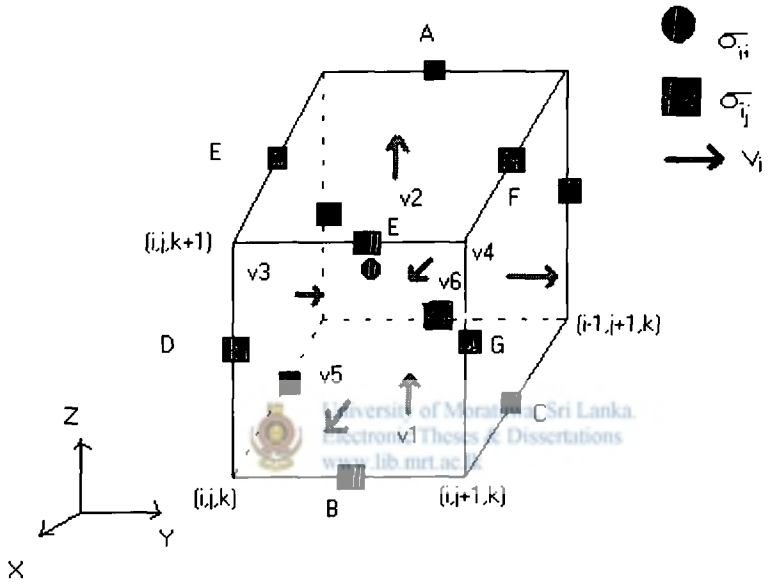
$$\rho\frac{\partial v_x}{\partial t}=\left(\frac{\partial\sigma_{zx}}{\partial x}+\frac{\partial\sigma_{yz}}{\partial y}+\frac{\partial\sigma_{zz}}{\partial z}\right)\quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(x)$$

Where ($\sigma_{i,j}$) is the stress tensor, v_i is the particle velocity, λ and μ are the Lame's constants, α is the coefficient of linear thermal expansion, and ρ is the mass density of the tissue.

We assume that the temperature rise T is given by

$$T(x,y,z,t) = \begin{cases} \dfrac{SAR(x,y,z)}{C_h(x,y,z)}t, & 0 \le t \le t_0 \\ \dfrac{SAR(x,y,z)}{C_h(x,y,z)}t_0 & t > t_0 \end{cases} \quad \text{..... ....(xi)}$$

Where $C_h(x,y,z)$ is the specific heat of the tissue at the point (x,y,z) and t_0 is the pulse duration. These two sets of governing equations are discretized to the FDTD form. Following Yee's notation [20], a point in a cartesian grid is expressed as



Staggered cell geometry for elastic-wave computation

$$(i,j,k) \equiv (i\Delta x, j\Delta y, k\Delta z) \quad \text{.....(xii)}$$

and any field value F of discrete space and time is expressed as

$$F^n(i,j,k) \equiv F(i\Delta x, j\Delta y, k\Delta z, n\Delta t) \quad \text{.....(xiii)}$$

Where $A = \sigma_{zx}(i-1, j+1/2, k+1)$ and $v2 = v_z(i-1/2, j+1/2, k+1)$

$B = \sigma_{zx}(i, j+1/2, k)$ $v4 = v_y(i-1/2, j+1, k+1/2)$

$C = \sigma_{zy}(i-1/2, j+1, k)$ $v5 = v_x(i, j+1/2, k+1/2)$

$D = \sigma_{xy}(i, j, k+1/2)$

$E = \sigma_{zx}(i, j+1/2, k+1)$

$F = \sigma_{yz}(i-1/2, j+1, k+1)$

$G = \sigma_{xy}(i, j+1, k+1/2)$

Where Δt is time increment, and i, j, k, n are integers. The staggered cell for the FDTD method for elastic waves is shown in above figure.

The field equations are discretized using Yee's leapfrog scheme with centered finite difference, and then the update equations are obtained. From equation ii,v,viii we have

$$\sigma_{xx}^{n}(i+\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}) = \sigma_{xx}^{n-1}(i+\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}) + \frac{(\lambda+2\mu)\Delta t}{\Delta x}[v_x^{n-(1/2)}\left(i+1,j+\frac{1}{2},k+\frac{1}{2}\right) - v_x^{n-(1/2)}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)] + \frac{\lambda\Delta t}{\Delta y}[v_y^{n-(1/2)}\left(i+1,j+1,k+\frac{1}{2}\right) - v_y^{n-(1/2)}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) + \frac{\lambda\Delta t}{\Delta z}[v_z^{n-(1/2)}\left(i+\frac{1}{2},j+\frac{1}{2},k+1\right) - v_z^{n-(1/2)}\left(i+\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}\right)] - \alpha(3\lambda+2\mu)\Delta t\frac{\partial T\left(i+\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}\right)}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (xiv)$$

$$\sigma_{xy}^{n}(i,j,k+\frac{1}{2}) = \sigma_{xy}^{n-1}(i,j,k+\frac{1}{2}) + \frac{\mu\Delta t}{\Delta x}[v_y^{n-(1/2)}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) - v_y^{n-(1/2)}\left(i-\frac{1}{2},j,k+\frac{1}{2}\right)] + \frac{\mu\Delta t}{\Delta y}[v_x^{n-(1/2)}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) - v_x^{n-(1/2)}\left(i,j-\frac{1}{2},k+\frac{1}{2}\right)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (xv)$$

$$v_x^{n+(1/2)}(i,j+\frac{1}{2},k+\frac{1}{2}) = v_x^{n-(1/2)}(i,j+\frac{1}{2},k+\frac{1}{2}) + \frac{\Delta t}{\rho\Delta x}[\sigma^{n}{}_{xx}\left(i+\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}\right) - \sigma_{xx}^{n}\left(i-\frac{1}{2},j+\frac{1}{2},k+\frac{1}{2}\right) \frac{\Delta t}{\rho\Delta y}[\sigma_{xy}^{n}\left(i,j+1,k+\frac{1}{2}\right) - \sigma_{xy}^{n}\left(i,j,k+\frac{1}{2}\right)] + \frac{\Delta t}{\rho\Delta z}[\sigma_{zx}^{n}\left(i,j+\frac{1}{2},k+1\right) - \sigma_{zx}^{n}\left(i,j+\frac{1}{2},k\right)] \quad \ldots\ldots\ldots\ldots (xvi)$$

The source term $\partial T/\partial t$ should be derived from (xi). Instead of simply taking a time derive of (xi) ,we used the following functional form for this term in order to reduce higher frequency components that cannot be efficiently computed by the finite difference method:

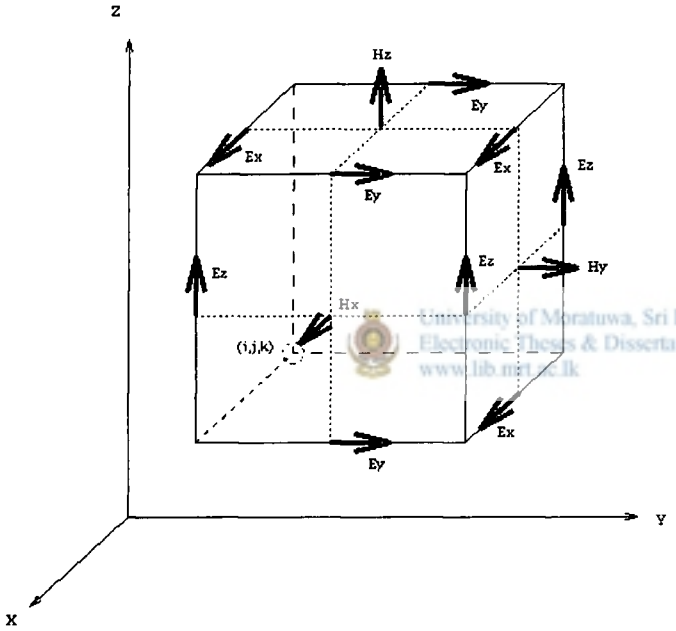
$$\frac{\partial T(x,y,z,t)}{\partial t} = \frac{SAR(x,y,z)}{2C_h(x,y,z)}\{erf(at) - erf(a(t-t_0))\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (xvii)$$

The parameter a in (xvii) represents the steepness of the microwave pulse. We assumed $a=0.4\times10^6$ in the following analysis.

Elastic properties of the tissues

	Tissues	**Skull**
Density(ρ)[kg/m^3]	1050	1000
Specific heat(C_h)[J/kg^{0}C]	3860	1600
Lame's constant(λ)[Gpa]	2.240	6.923
Lame's constant(μ)[Gpa]	1.052×10^{-6}	4.615
Coefficient of thermal expansion (α)[1/^{0}C]	4.1×10^{-5}	1.06×10^{-5}

Appendix K



FDTD cell geometry with interleaved electric (E fields on edges) and magnetic (H fields on faces) fields. Note that four magnetic field vectors circulate around each electric field vector and vice versa.

Considering first a region of space without electric or magnetic current sources, the curl equations are:

$$\frac{\partial B}{\partial t} = -\nabla \times E - J_m \quad \text{.....(1)}$$

and

$$\frac{\partial D}{\partial t} = -\nabla \times H - J_e \quad \text{.....(2)}$$

Here E is the electric field vector(Vm^{-1}), D is electric flux density vector(Cm^{-2}), H is the magnetic field vector(Am^{-1}), B is the magnetic flux density(Wm-2), J_e is the electric conduction current density(Vm^{-2}) and J_m is the equivalent magnetic conduction current density(Vm^{-2}). To account for losses due to the dissipation of fields in materials we can introduce an electric conductivity σ (Sm^{-1}) and an equivalent magnetic resistivity ρ′(Ωm^{-1}) and equate them to the field vectors above using:

$$J_e = \sigma E \quad \text{.....(3)}$$

and

$$J_m = \rho' H \quad \text{.....(4)}$$

For linear, isotropic and non-dispersive materials, there are simple relations between flux density and fields. Defining μ as magnetic permeability (Hm-1) and ε as electric permitivity (Fm^{-1}), we can write

$$B = \mu H \quad \text{.....(5)}$$

and

$$D = \varepsilon E \quad \text{.....(6)}$$

Substituting equations 3-6 in equations 1 and 2, we obtain:

$$\frac{\partial H}{\partial t} = -\frac{1}{\mu}\nabla \times E - \frac{\rho'}{\mu} H \quad \text{.....(7)}$$

and

$$\frac{\partial D}{\partial t} = -\frac{1}{\varepsilon}\nabla \times H - \frac{\sigma}{\varepsilon} E \quad \text{.....(8)}$$

Using the explicit expression for the curl operator and setting the magnetic loss ρ' to zero, we can derive a system of scalar equations for a rectangular co-ordinate system *(x,y,z)* applicable to non-magnetic materials:

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y}\right) \quad \text{.....(9}a\text{)}$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z}\right) \quad \text{.....(9}b\text{)}$$

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x}\right) \quad \text{.....(9}c\text{)}$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x\right) \quad \text{.....(10}a\text{)}$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y\right) \quad \text{.....(10}b\text{)}$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right) \quad \text{.....(10}c\text{)}$$

In the FDTD method, the time and space derivatives in equations 9 and 10 are replaced with central differences, requiring space and time interleaving of E and H. The general central difference approximations of time and space derivatives are:

$$\frac{\partial f}{\partial t} \equiv \lim_{\Delta t \to 0} \frac{f(x,t_2) - f(x,t_1)}{\Delta t} \approx \frac{f(x,t_2) - f(x,t_1)}{\Delta t} \quad \text{.....(11)}$$

$$\frac{\partial f}{\partial t} \equiv \lim_{\Delta x \to 0} \frac{f(x_2,t) - f(x_1,t)}{\Delta x} \approx \frac{f(x_2,t) - f(x_1,t)}{\Delta x} \quad \text{.....(12)}$$

Magnetic field equations

Applying equations 11 and 12 to equation 9, we can derive a set of finite difference equations for updating the magnetic field vectors. Considering equation 9a for a location *(i,j,k)* we can write:

$$\frac{H_x|_{i,j,k}^{n+1/2} - H_x|_{i,j,k}^{n-1/2}}{\Delta t} = \frac{1}{\mu_{i,j,k}}\left(\frac{E_y|_{i,j,k+1/2}^{n} - E_y|_{i,j,k-1/2}^{n}}{\Delta z}\right) - \left(\frac{E_z|_{i,j+1/2,k}^{n} - E_z|_{i,j-1/2,k}^{n}}{\Delta y}\right) \quad \text{...(13)}$$

Note that at time step n+1/2, the new value of H_x can be directly calculated from the values of E_y and E_z at time step n and the last value of H_x (time step n-1/2) Rearranging equation 13 gives the explicit update equation for H_x:

$$H_x\,|_{i,j,k}^{n+1/2} = H_x\,|_{i,j,k}^{n-1/2} - \frac{\Delta t}{\Delta y.\mu_{i,j,k}}\left(E_y\,|_{i,j+1/2,k}^{n} - E\,|_{i,j-1/2,k}^{n}\right) + \frac{\Delta t}{\Delta z.\mu_{i,j,k}}\left(E_y\,|_{i,j,k+1/2}^{n} - E_y\,|_{i,j,k-1/2}^{n}\right)\text{...(14)}$$

Likewise, FDTD update equations may be derived for H_y and H_z

Electric field equations

Similarly, we can apply finite differences to equation 10, considering E_x(equation 10a) we can write:

$$\frac{E_x\,|_{i,j,k}^{n+1} - E_x\,|_{i,j,k}^{n}}{\Delta t} = \frac{1}{\varepsilon_{i,j,k}}\left(\frac{H_z\,|_{i,j+1/2,k}^{n+1/2} - H_z\,|_{i,j-1/2,k}^{n+1/2}}{\Delta y} - \frac{H_y\,|_{i,j,k+1/2}^{n+1/2} - H_y\,|_{i,j,k-1/2}^{n}}{\Delta z} - \sigma\, E_x\,|_{i,j,k}^{n+1/2}\right)\text{..(15)}$$

In this case rewriting for an updated E_x at time step $n+1$ is not straightforward due to the presence of E_x at time step $n+1/2$(rather than n or $n+1$) on the right hand side. The solution is to employ a semi implicit approximation for E_x(at $n+1/2$) by averaging of the values of E_x at n and $n+1$ and rewriting as:

$$E_x\,|_{i,j,k}^{n+1} = \left(\frac{1 - \frac{\sigma\,\Delta t}{2\varepsilon}}{1 + \frac{\sigma\,\Delta t}{2\varepsilon}}\right) E_x\,|_{i,j,k}^{n} + \left(\frac{\frac{\Delta t}{\varepsilon}}{\left(1 + \frac{\sigma\,\Delta t}{2\varepsilon}\right)\Delta y}\right)\left(H_z\,|_{i,j+1/2,k}^{n+1/2} - H_z\,|_{i,j-1/2,k}^{n+1/2}\right)$$
$$- \left(\frac{\frac{\Delta t}{\varepsilon}}{\left(1 + \frac{\sigma\,\Delta t}{2\varepsilon}\right)\Delta z}\right)\left(H_y\,|_{i,j,k+1/2}^{n+1/2} - H_y\,|_{i,j,k-1/2}^{n}\right)\text{.....(16)}$$

Where ε and σ are specific at the cell location *(i,j,k)*. In practice, the multipliers on the right-hand side of equation 16 are calculating for each material type and stored for use during time- stepping.

The FDTD electric field update equations may be simplified further for perfectly conducting materials or free space. In equation 15 if σ becomes zero (for free space), the E_x update equation becomes:

$$E_x|_{i,j,k}^{n+1} = E_x|_{i,j,k}^{n} + \frac{\Delta t}{\Delta y\, \varepsilon_{i,j,k}}\left(H_z|_{i,j+1/2,k}^{n+1/2} - H_z|_{i,j-1/2,k}^{n+1/2}\right) - \frac{\Delta t}{\Delta z\, \mu_{i,j,k}}\left(H_y|_{i,j,k+1/2}^{n+1/2} - H_y|_{i,j,k-1/2}^{n}\right) \quad \text{.....(17)}$$

This speeds computation, as fewer floating-point calculations are required. For a perfect conductor, σ is infinite and equation 16 becomes zero,

General FDTD algorithm

To implement the FDTD algorithm the problem space is subdivided into small (volume) cells each with an assigned conductivity, permittivity and permeability. Time is also discretised and the time step duration is determined by stability criterion known as the Courant Limit. Each cell is given initial values for its electric and magnetic field components: at each subsequent time step these are updated, taking account of the previous values and those of its neighbours(using the update equations). Source cells can be programmed with preset sinusoidal or impulse functions. The update process is repeated until a steady state is reached. In bioelectromagnetic, lossy tissue speeds up convergence (typically<10 sinusoidal cycles) compared with #D metal objects. One drawback is that the computational domain must have good absorbing boundaries otherwise waves propagating out will be reflected back, causing errors. Post processing of results occurs when time stepping is complete. This often includes near-to far-field conversion for the generation of radiation patterns.

Modelling of electromagnetic interactions with biological tissue.

Biological tissue is, for practical purposes, non-magnetic with permeability μ (Hm^{-1}) close to that of free space. Interaction between radio frequency electromagnetic waves and living systems therefore requires consideration of the influence of both external and internally induced fields. Energy exchanges may occur with either free charges or dipolar (asymmetrically charged) structures such as water. In a rapidly alternating field, free charges may be accelerated, giving rise to conduction currents and corresponding resistive losses, while dipoles suffer reorientation, producing frictional resistance caused

by the viscous biological medium. Both phenomena result in tissue temperature rise and account for the bulk absorption of RF energy by the biological body.

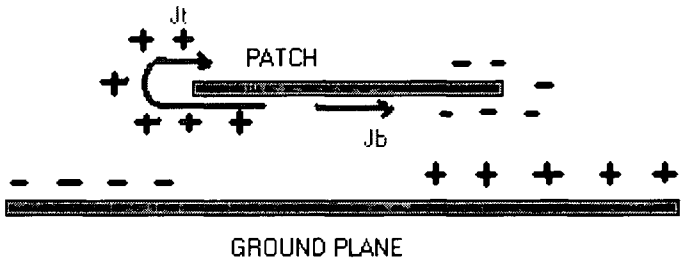
Appendix (L)

Rectangular patch using Cavity model

Microstrip antenna resemble dielectric loaded cavities, and they exhibit higher order resonance. The normalized fields within the dielectric substrate can be found more accurately by treating that region as a cavity bounded by electric conductors and by magnetic walls along the perimeter of the patch.

The cavity model consists of a box with electric walls at the upper and bottom surface and magnetic walls normal to the edges of the patch, height of it is h.

When an oscillating current is injected into a microstrip element a charge distribution is established on the surface of the ground plane and the two surfaces (upper and lower) of the patch is shown below.



Charge distribution is established on the surface of the ground plane and the two surfaces of the patch

Here are two opposing tendencies, which shape this charge distribution. There is an attractive tendency between the opposite charges at corresponding points on the lower side of the patch and on the ground plane.

Therefore it can be used to compute the field distributions inside the patch. The tangential E- field is zero at the metallic surface of the patch and the H field tangential to the wall surround the patch edge is zero. The fields of the rectangular resonator for TMm,n can be expressed as follows and it is convenient to begin with the wave equation [29]

$\partial^2 Ez/\partial x^2 + \partial^2 Ez/\partial y^2 + kc^2\, Ez = 0$.....(1)

Where $kc^2 = \gamma^2 + w^2\mu\varepsilon$

The solutions of this partial differential equation is

$Ez = (C_1 \cos(k_x x) + D_1 \sin(k_x x))\,(C_2 \cos(k_y x) + D_2 \sin(k_y x))$.....(2)

Where $kc^2 = kx^2 + ky^2$

For any TM mn mode fields inside the patch

$Ex = (\gamma / kc^2)\, \partial Ez/\partial x$.....(3)

$Ey = (\gamma / kc^2)\, \partial Ez/\partial y$.....(4)

$Hx = (j\omega\varepsilon / kc^2)\, \partial Ez/\partial y$.....(5)

$Hy = (-j\omega\varepsilon / kc^2)\, \partial Ez/\partial x$.....(6)

Substituting (2) in (3)

$Ex = k_x / \omega\varepsilon\mu\,(-C1 \sin(k_x x) + D1 \cos(k_x x))\,(C2 \cos(k_y x) + D2 \sin(k_y x))$.....(7)

Substituting (2) in (4)

$Ey = -k_y / \omega\varepsilon\mu\,(C1 \cos(k_x x) + D1 \sin(k_x x))\,(-C2 \sin(k_y x) + D2 \cos(k_y x))$.....(8)

Substituting (2) in (5)

$Hx = k_y / \mu \, (C1 \cos(k_x x) + D1 \sin(k_x x)) \, (- C2 \sin(k_y x) + D2 \cos(k_y x))$.....(9)

Substituting (2) in (6)

$Hy = -kx / \mu \, (-C1 \sin(k_x x) + D1 \cos(k_x x)) \, (C2 \cos(k_y x) + D2 \sin(k_y x))$.....(10)

The tangential E field is zero at the metallic surface of the patch, hence the boundary conditions are

$Ex \; (0 \le x \le a, \; 0 \le y \le b) = 0$ .....(11)

$Ey \; (0 \le x \le a, \; 0 \le y \le b) = 0$ .....(12)

The tangential H field to the wall that surround the patch is zero , creating a perfect magnetic wall

$Hx(0 \le x \le a, \; y =0) = Hx(0 \le x \le a, y = b) = 0$ .....(13)

$Hy(x =0, \; 0 \le y \le b) = Hy(x = a, \; 0 \le y \le b) = 0$ .....(14)

Applying the above boundary conditions to the equations (7),(8),(9) and (10) and putting a=a1 and b= b1 because of the line extension due to the fringing fields

$Ez = (-j \, C1 \, C2 / \varepsilon\mu\varepsilon) \, ((m\pi/a_1)^2 + (n\pi/b_1)^2) \cos(m\pi x /a) \cos(n\pi y /b)$.....(15)

$Hx= ((n\pi/b)C1 \, C2 / \mu) \cos(m\pi x /a_1 1) \sin(n\pi y /b_1)$.....(16)

$Hy= ((n\pi/a)C1 \, C2 / \mu) \sin(m\pi x /a_1) \cos(n\pi y /b_1)$.....(17)

Where

C1 C2 = constants

The patch resonant frequency for TM mn mode is

$f = c\sqrt{(m/a1)2 + (n/b1)2} / 2\sqrt{\varepsilon r}$ .....(18)

Therefore, for TM 01 (m=0,n=1) (15) and (18) become

$Ez = (-j\ Cc\ C2 / \varepsilon\mu\varepsilon)\ (n\pi/b1)2\ \cos(n\pi\ y\ /b1)$.....(19)

$f = c / 2\ b1\sqrt{\varepsilon r}$ .....(20)

The effect of the substrate thickness

The effect of the substrate thickness h, can be examined in the patch model using image theory

The field due to the image of the two z directed source is

$E = I_z E_z\ (\ \exp(-jkr1)/ 4\ \pi\ r1 + \exp(-jkr2)/ 4\ \pi\ r2\ )$.....(21)

Where $k= 2\pi / l$

For magnitude terms

$r1 = r2 = r$ .....(22)

For phase terms,

$r1 = r - h\ \cos(\theta)$.....(23)

$r2 = r + h\cos(\theta)$.....(24)

Substituting (19),(20),and(21) in (18) gives

$E = IzEz\ (\ (\exp(-jr)/ 4\pi r)\ Ez\ 2\cos(kh\cos(\theta))$.....(25)

Substituting (15) in (22)

$E = -IzEz\ (\ (\exp(-jr)/ 2\pi r)\ (-j\ C1\ C2 / \varepsilon\mu\varepsilon)(\ (m\pi/a)^2 + (n\pi/b)^2)\ \cos(m\pi x/a)\ \cos(n\pi$

$y/b)\cos(kh\cos(\theta))$.....(26)

$E = -IzE0\cos(m\pi x/a)\cos(n\pi y/b)\cos(kh\cos(\theta))$.....(27)

Where

$E0 = (\ (\exp(-jr)/ 2\pi r)\ (-j\ C1\ C2 / \varepsilon\mu\varepsilon)(\ (m\pi/a)^2 + (n\pi/b)^2 ...)$.....(28)

Appendix (M) _Calculations

(I) If frequency is 10GHz then $\lambda_0 = (2.997925\times10^{10} / 10^9)$ mm=29.97025 mm

$\lambda_g = \lambda_0 \times (\varepsilon_r)^{-1/2}$
$= 29.97925\times (2.91)^{-1/2}$ mm
$= 17.5741$ mm

$w=a = \lambda_g$ the input impedance can be calculated as following.

Length of the patch (a)=17.5741mm

Width of the patch (b) = $\lambda_g \times 0.451$

= 7.9259mm

The effective dielectric constant due to the length a

$\varepsilon_{e,a} = 2.6459$

The effective dielectric constant due to the length b

$\varepsilon_{e,b} = 2.5047$

The fringing field length due to the width a

$\Delta a = 0.744mm$

The fringing field length due to the width b

$\Delta b = 0.775mm$

Therefore the effective patch dimensions are,

$a' = a + \Delta a = 18.3181mm$

$b' = b + \Delta b = 8.7009mm$

The patch resonance frequency for TM01 mode

$f_r = 10.0987$ GHz

(II)

If frequency is 9.4GHz then $\lambda_0 = (2.997925\times10^{10} / 9.4\times10^{8})$ mm=31.8928 mm

$\lambda_g = \lambda_0 \times (\varepsilon_r)^{-1/2}$

$= 31.8928\times (2.91)^{-1/2}$ mm

$= 18.6957$ mm

$w=a = \lambda_g$ the input impedance can be calculated as following.

Length of the patch (a)= 18.6957 mm

Width of the patch (b)= $\lambda_g \times 0.451$

$= 8.4318$mm

The effective dielectric constant due to the length a

$\varepsilon_{e,a} = 2.4825$

The effective dielectric constant due to the length b

$\varepsilon_{e,b} = 2.6258$

The fringing field length due to the width a

$\Delta a = 0.7499\text{mm}$

The fringing field length due to the width b

$\Delta b = 0.7786\text{mm}$

Therefore the effective patch dimensions are,

$a' = a + \Delta a = 19.4456\text{mm}$

$b' = b + \Delta b = 9.2104\text{mm}$

The patch resonance frequency for TM01 mode

$f_r = 9.5403\ \text{GHz}$

By using (13)

$$Yin = \frac{w}{60\lambda_0}$$

$$= \frac{\lambda_g}{60\lambda_0}$$

$$Zin = 1/Yin = 60\lambda_0/\lambda_g$$

(*I*)

$Zin = 102.3524$ ohm

(*II*)

$Zin = 102.3523$ ohm

(I)

If Zin is given by (15) and Zf equals to 50 ohm, Z_t is computed as

$Zt = \sqrt{50 \times 102.3524} = 71.5375\ ohm$ .....(16)

Using figure 8,

Then the width of the transformer is = 1.9600mm

Length of the λ/4 transformer = 4.394 mm

Width of the 50 ohm line for single patch antenna = 4.16mm

When Zin =25 ohm Zf = 50 ohm

Therefore by (14)

$Z_t = 35.35$ ohm…

The impedance of the 2nd and 3rd quarter wave matching transformer = 35.35 ohm

The width of the 2nd and 3rd quarter wave matching transformer =6.125mm

(II) If Z_{in} is given by (15) and Z_f equals to 100 ohm, Z_t is computed as

$Zt = \sqrt{100 \times 102.3523} = 101.1693\ ohm$

Using figure 14,

Then the width of the transformer is = 1mm

Width of the 50 ohm line for single patch antenna = 4.16mm

(II) (i) [14]

$$\phi = \frac{2\pi}{\lambda} d \sin\theta + \pi, \quad d = \lambda/2$$

(ii)

$$\phi = \frac{2\pi}{\lambda} d \sin\theta + \pi, \quad d = \lambda$$

(iii)

$$\phi = \frac{2\pi}{\lambda} d \sin\theta + \pi, \quad d = \lambda$$

(iv)

$$\phi = \frac{2\pi}{\lambda} d \sin\theta + 0, \quad d = \lambda$$

The theoretical and practical far field radiation patterns are on page 68

Appendix (N)

****

fdtd6()-calculation of EM radiation absorb by the human brain using FDTD

****

```
function hfdtd2(nn)
ncell=2*(nn^3);
h=0.1/real(nn);
nn2=nn*2;
sig=1.29;
raw=1050.;
f=0.9e9;
w=2*pi*f;
eps0=(1e-9)/(36*pi);
eps=50.11*eps0;
u=4*pi*1e-7;
cl=3e8;
rb=1/2*u*cl;
delta=1e-2;
dt=delta/2*cl;
ra=((dt^2)/(u*eps0*delta^2));
r=dt/eps0;
ca=1-r*sig/eps;
cb=ra/eps;
cbmrb=cb/rb;

for n=1:ncell
  tau(n)=sig+i*w*(eps-eps0);
end
for ics=1:6
   if ics==1
     e0=87;
    else
     e0=100+(ics-2)*100;
   end
   ve0(ics)=e0;
       for n=1:nn2
         sax(n)=0.;
         say(n)=0.;
```

```
        saz(n)=0.;
        htx(n)=0.;
        hty(n)=0.;
        htz(n)=0.;
         end
 n=0;
 spow=0.;
 shta=0.;
  Ex(1)=1;
  Ey(1)=1;
  Ez(1)=1;
  Hx(1)=1;
  Hy(1)=1;
  Hz(1)=1;
for t=2:10
 for jj=1:nn
  for ii=1:nn2
    for kk=1:nn
        Hx(t)=Hx(t-1)+rb*(Ey(t-1)+Ez(t-1));
        Hy(t)=Hy(t-1)+rb*(Ez(t-1)+Ex(t-1));
        Ex(t)=ca*Ex(t-1)+cbmrb*(Hz(t-1)-Hy(t-1));
        Ey(t)=ca*Ey(t-1)+cbmrb*(Hx(t-1)-Hz(t-1));
        Ez(t)=ca*Ez(t-1)+cbmrb*(Hy(t)-Hx(t));
        Hz(t)=Hz(t-1)+rb*( Ex(t-1)-Ey(t-1));
        n=n+1;
      pow=((abs(Ex(t)))^2+(abs(Ey(t)))^2+(abs(Ez(t)))^2);
      sa=0.5*pow*(sig/raw);
      sar=sa;
      hta(n)=0.5*sig*pow*1.e-3;
      ssar(ii,jj,kk)=sa;
      spow=spow+sa;
      shta=shta+hta(n);
      sax(ii)=sax(ii)+sa;
      say(jj+nn)=say(jj+nn)+sa;
      j1=nn-jj+1;
      say(j1)=say(j1)+sa;
      saz(kk+nn)=saz(kk+nn)+sa;
      k1=nn-kk+1;
      saz(k1)=saz(k1)+sa;
    end
  end
end
 e0
 sar
 max(sar,[],2)
 mean(sar,2)
```

```
    hta
    max(hta,[],2)
    mean(hta,2)
end
sam=-0.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;
end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
text(.025,.85,'Fld. Int.     V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
r(ics)=power(ics)/tht(ics);
end
ve0
power
tht
r
input zz;
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900 Mhz.')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (mW/gm.)')
```

Appendix (O)

****

fdtd7()-calculation of EM radiation absorb by the human brain and skull using FDTD

****

```
function hfdtd3(nn)
ncell=2*(nn^3);
h=0.1/real(nn);
nn2=nn*2;
sig=1.29;
raw=1050.;
f=0.9e9;
w=2*pi*f;
eps0=(1e-9)/(36*pi);
eps=50.11*eps0;
u=4*pi*1e-7;
cl=3e8;
rb=1/2*u*cl;
delta=1e-2;
dt=delta/2*cl;
ra=((dt^2)/(u*eps0*delta^2));
r=dt/eps0;
ca=1-r*sig/eps;
cb=ra/eps;
cbmrb=cb/rb;

for ii=1:nn2
   for jj=1:nn
     for kk=1:nn
       n=n+1;
       if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
        tau(n)=sig+i*w*(eps-eps0);
       else
         tau(n)=sig1*i*w*(eps-eps0);
       end
     end
   end
 end
for ics=1:6
   if ics==1
     e0=87;
    else
     e0=100+(ics-2)*100;
```

```
end
ve0(ics)=e0;
    for n=1:nn2
     sax(n)=0.;
     say(n)=0.;
     saz(n)=0.;
     htx(n)=0.;
     hty(n)=0.;
     htz(n)=0.;
      end
n=0;
spow=0.;
shta=0.;
 Ex(1)=1;
 Ey(1)=1;
 Ez(1)=1;
 Hx(1)=1;
 Hy(1)=1;
 Hz(1)=1;
   for t=2:10
         Hx(t)=Hx(t-1)+rb*(Ey(t-1)+Ez(t-1));
       Hy(t)=Hy(t-1)+rb*(Ez(t-1)+Ex(t-1));
       Ex(t)=ca*Ex(t-1)+cbmrb*(Hz(t-1)-Hy(t-1));
       Ey(t)=ca*Ey(t-1)+cbmrb*(Hx(t-1)-Hz(t-1));
       Ez(t)=ca*Ez(t-1)+cbmrb*(Hy(t)-Hx(t));
       Hz(t)=Hz(t-1)+rb*( Ex(t-1)-Ey(t-1));
       n=n+1;
     pow=((abs(Ex(t)))^2+(abs(Ey(t)))^2+(abs(Ez(t)))^2);
for jj=1:nn
 for ii=1:nn2
   for kk=1:nn
     n=n+1;
     pow=(abs(e(n)))^2+(abs(e(n+ncell)))^2+(abs(e(n+2*ncell)));
     if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
      sa=(sig/raw)*pow;
      sar(n)=sa;
      hta(n)=.5*sig*pow*1.e-3;

     else
        sa=(sig1/raw1)*pow;
        sar(n)=sa;
        hta(n)=.5*sig1*pow*1.e-3;
     end
     if (ii>1 | ii<nn2) & (jj<nn) & (kk>-nn | kk< -nn2)
      sa=(sig2/raw2)*pow;
      sar(n)=sa;
```

```
            hta(n)=0.5*sig2*pow*1.e-3;
          end
          ssar(ii,jj,kk)=sa;
          spow=spow+sa;
          shta=shta+hta(n);
          sax(ii)=sax(ii)+sa;
          say(jj+nn)=say(jj+nn)+sa;
          j1=nn-jj+1;
          say(j1)=say(j1)+sa;
          saz(kk+nn)=saz(kk+nn)+sa;
          k1=nn-kk+1;
          saz(k1)=saz(k1)+sa;
          end
        end
      end
    end
     e0
     sar
     max(sar,[],2)
     mean(sar,2)
     hta
     max(hta,[],2)
     mean(hta,2)
end
sam=-0.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;
end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
```

```
text(.025,.85,'Fld. Int.      V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
r(ics)=power(ics)/tht(ics);
end
ve0
power
tht
r
input zz;
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900 Mhz.')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (mW/gm.)')
```

Appendix (P)

****

fdtd8( )-calculation of EM radiation absorb by the human brain, skull and ear using FDTD

****

```
function  hfdtd4(nn)
ncell=2*(nn^3);
h=0.1/real(nn);
nn2=nn*2;
sig=1.29;
raw=1050.;
f=0.9e9;
w=2*pi*f;
eps0=(1e-9)/(36*pi);
eps=50.11*eps0;
u=4*pi*1e-7;
cl=3e8;
rb=1/2*u*cl;
delta=1e-2;
dt=delta/2*cl;
ra=((dt^2)/(u*eps0*delta^2));
r=dt/eps0;
```

```
ca=1-r*sig/eps;
cb=ra/eps;
cbmrb=cb/rb;

n=0;
 for ii=1:nn2
   for jj=1:nn
     for kk=1:nn
       n=n+1;
       if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
        tau(n)=sig+i*w*(eps-eps0);
       else
         tau(n)=sig1*i*w*(eps-eps0);
       end
       if (ii==1 & ii==nn*2) & (jj==nn) & (kk==0)
         tau(n)=sig+i*w*(eps-eps0);
       end;
     end
   end
 end
for ics=1:6
   if ics==1
     e0=87;
    else
     e0=100+(ics-2)*100;
   end
   ve0(ics)=e0;
       for n=1:nn2
         sax(n)=0.;
         say(n)=0.;
         saz(n)=0.;
         htx(n)=0.;
         hty(n)=0.;
         htz(n)=0.;
          end
   n=0;
   spow=0.;
   shta=0.;
    Ex(1)=1;
    Ey(1)=1;
    Ez(1)=1;
    Hx(1)=1;
    Hy(1)=1;
    Hz(1)=1;
    for t=0.2:1
         Hx(t)=Hx(t-1)+rb*(Ey(t-1)+Ez(t-1));
```

```
        Hy(t)=Hy(t-1)+rb*(Ez(t-1)+Ex(t-1));
        Ex(t)=ca*Ex(t-1)+cbmrb*(Hz(t-1)-Hy(t-1));
        Ey(t)=ca*Ey(t-1)+cbmrb*(Hx(t-1)-Hz(t-1));
        Ez(t)=ca*Ez(t-1)+cbmrb*(Hy(t)-Hx(t));
        Hz(t)=Hz(t-1)+rb*( Ex(t-1)-Ey(t-1));
        n=n+1;
  for jj=1:nn
   for ii=1:nn2
     for kk=1:nn
      n=n+1;
      pow=(abs(e(n)))^2+(abs(e(n+ncell)))^2+(abs(e(n+2*ncell)));
      if (ii>1 | ii<nn2) & (jj<nn) & (kk<nn)
       sa=(sig/raw)*pow;
       sar(n)=sa;
       hta(n)=.5*sig*pow*1.e-3;

      else
      sa=(sig1/raw1)*pow;
      sar(n)=sa;
      hta(n)=.5*sig1*pow*1.e-3;
     end
      if (ii==1 & ii==nn*2) & (jj==-nn) & (kk==0)
                sa=(sig/raw)*pow;
                     sar(n)=sa;
                hta(n)=.5*sig*pow*1.e-3;
      end;

      ssar(ii,jj,kk)=sa;
      spow=spow+sa;
      shta=shta+hta(n);
      sax(ii)=sax(ii)+sa;
      say(jj+nn)=say(jj+nn)+sa;
      j1=nn-jj+1;
      say(j1)=say(j1)+sa;
      saz(kk+nn)=saz(kk+nn)+sa;
      k1=nn-kk+1;
      saz(k1)=saz(k1)+sa;
            end
     end
    end
end
 e0
 sar
 max(sar,[],2)
 mean(sar,2)
 hta
```

```
    max(hta,[],2)
    mean(hta,2)
end
sam=-0.000001;
for ii=1:nn2
   cd(ii)=real(ii)*h;
   if sax(ii) > sam
     sam=sax(ii);
   end
   if say(ii) > sam
     sam=say(ii);
   end
   if saz(ii) > sam
     sam=saz(ii);
   end
end
for ii=1:nn2
   sax(ii)=sax(ii)/sam;
   say(ii)=say(ii)/sam;
   saz(ii)=saz(ii)/sam;
end
plot(cd,sax,cd,say,cd,saz,cd,sax,'rx',cd,say,'r+',cd,saz,'r*')
title('Relative Energy Absorbed ')
text(.025,.95,'Frequency 900 Mhz.')
text(.025,.90,'No. cells 1000 ')
text(.025,.85,'Fld. Int.      V/m')
xlabel('x- X axis, + Y - axis, * Z - axis  (m.)')
ylabel('Relative Energy Absorbed')
input z
power(ics)=spow/ncell;
tht(ics)=shta;
r(ics)=power(ics)/tht(ics);
end
ve0
power
tht
r
input zz;
plot(ve0,power,'r-',ve0,power,'r+')
title('Graph of Energy Absorbed vs. Field Intensity')
text(55.,19.,'Frequency 900 Mhz.')
text(55.,17.,'No cells 1000')
xlabel('Field Intensity (V/m)')
ylabel('Energy Absorbed (mW/gm.)')
```

Appendix (Q)

****

prog()- Dimensions of the patches

****

```
function prog()
f=input('DESIGN FREQUENCY IN GHz     ');
u1=0.29979/f;
uu=u1*1000;
h=1.6;
ee=sqrt(2.91);
u=uu/ee;
a=u;
b=u*0.451;
DESIGN_FREQUENCY_____GHz = f
WIDTH_OF_THE_PATCH_____mm  = a
LENGTH_OF_THE_PATCH____mm  = b
E=2.91;
Ea=((E+1)/2)+((E-1)/2)*(1/sqrt(1+(10*h/b)));
Eb=((E+1)/2)+((E-1)/2)*(1/sqrt(1+(10*h/a)));
La=0.412*h*((Ea+0.3)/(Ea-0.258))*(((b/h)+0.262)/ ((b/h)+0.813));
Lb=0.412*h*((Eb+0.3)/(Eb-0.258))*(((a/h)+0.262)/ ((a/h)+0.813));
a1=a+La;
b1=b+Lb;
bb=(b1)/1000;
fr=((299.79e6)/(2*bb*ee))/1e9;
RESONANCE_FREQUENCY___GHz = fr
z=60*uu/a1;
INPUT_IMPEDANCE_OF_THE_PATCH___ohms =z
Zt=sqrt(50*z);
IMPEDANCE_OF_THE_QUATER_WAVE_TRANSFORMER_ohms = Zt
W_h_RATIO =input('ENTER THE W/H RATIO      ')
WI =W_h_RATIO*1.6;
WIDTH_QUATER_WAVE_TRANSF__mm =WI
IN=2.588235*1.6;
WDTH_50_TRANSMISSION_LINE__mm  =IN
```

Appendix(R)

****

impedance()-graph of the impedence

****

```
function antenna1()
z=102.9
e=2.91
%a=.1
t=0.01;
wq=0;
for a= 0.05:.1:9,
wq=wq+1;
A=a;
t=t+0.01;
w=a*1.5;
SS(1,wq) = (377/sqrt(e))/((a)+0.8825+0.1645*((e-1)/e*e) +
((e+1)/(pi*e))*(1.451+log((a/2)+0.94)));
end
plot(SS)
axis([0 90 0 120])
grid on
xlabel('  w/h ratio  ')
ylabel( 'Impedance       ohms ')
title('Graph of impedance of a microstrip transmission line')
```

Appendix (S)

****

array2()- Theoretical radiation patterns

****

```
function array2()
lam0=29.979;
lam=17.5741;
d=2*lam;
n=1;
k0=(2*pi)/lam0;
k=(2*pi)/lam;
h=1.6;
b1=8.7;
b2=0.775;
for ii=54:90
  theta(ii)=(5*ii)*pi/180;
  f(ii)=(2*pi/lam)*d*cos(theta(ii));
  f2(ii)=(1/n)*((sin(n*f(ii)/2))/sin(f(ii)/2));
  f3(ii)=(cos((k*h)*(cos(theta(ii)))))*((sin(k0*(b2/2)*(sin(theta(ii))))./
  (k0*(b2/2)*(sin(theta(ii)))))*(cos(k0*(b1/2)*(sin(theta(ii))))));
  f5(ii)=abs(f2(ii)*f3(ii));
end
theta;
f5;
polar(theta,f5)
```

Appendix (T)

****

Array3()- theoretical radiation patterns

****

```
function array3()
lam0= 31.8928;
lam= 18.6957;
d=lam/2;
n=2;
k0=(2*pi)/lam0;
k=(2*pi)/lam;
h=1.6;
b1= 9.2104;
b2= 0.7786;
for ii=54:90
  theta(ii)=(5*ii)*pi/180;
  f(ii)=((2*pi/lam)*d*cos(theta(ii))+pi);
  f2(ii)=(1/n)*((sin(n*f(ii)/2))/sin(f(ii)/2));
  f3(ii)=(cos((k*h)*(cos(theta(ii)))))*((sin(k0*(b2/2)*(sin(theta(ii))))))./(k0*(b2/2)*(sin
(theta(ii)))))*(cos(k0*(b1/2)*(sin(theta(ii)))));
  f5(ii)=abs(f2(ii)*f3(ii));
end
theta;
f5;
polar(theta,f5)
```

Appendix (U)

August 6th

'MOBILE PHONE GAVE ME CANCER' SAYS DOCTOR

An American doctor suffering from terminal cancer is suing mobile phone companies for £600 million.

Dr Chris Newman (pictured) claims his brain tumour is a direct result of electromagnet radiation from his mobile phone.

In a major testcase with worldwide implications, he is suing mobile phone manufacturers and network operators for damages. "Never use a cell phone – it's not worth the risk; it's not worth going through the hell," he said.

'No evidence'

US health authorities say there is no evidence to prove or disprove any link between mobile phone use and brain tumours.

In the UK, the Government has urged parents and teachers to discourage children from using mobile phones because of the safety fears.

There is also a strong push, in the UK and in the US, for health warnings to be placed on mobile phones.

New UK study

And a new safety study into mobile phones has been launched in the UK following fresh evidence about hands-free kits from Australian researchers.

The Australian evidence suggests hands-free kits can cut radiation levels by 92 per cent, conflicting with an earlier study indicating that hands-free kits could actually triple the amount of radiation to the brain.

The UK Consumers Association has commissioned further research "to clear up the confusion" in light of the Australian Consumers' Association investigation.

Send us your comments

Appendix (V)

Cellular system used in Sri Lanka

Company	System	Frequency
Call Link	TACS A	890-915 m-b 935-960 b-m
Celltel	TACS B	872-888 m-b 917-933 b-m
Mobitel	AMPS A/AMPS B	825-845 m-b 870-890 b-m
Dialog	GSM	890-915 m-b 935-960 b-m

Power of Mobile Phone for AMPS

Power Level	Power of Mobile Phone for AMPS					
	Mobile Station Power Class					
	I		II		III	
	dBW	mW	dBW	mW	dBW	mW
0	6	4000	2	1600	2	630
1	2	1600	2	1600	2	630
2	-2	630	-2	630	-2	630
3	-6	250	-6	250	-6	250
4	-10	100	-10	100	-10	100
5	-14	40	-14	40	-14	40
6	-19	15	-18	15	-18	15
7	-22	6	-22	6	-22	6

Power of Mobile Phone for TACS

Power Level	Power of Mobile Phone for TACS							
	Mobile Station Power Class							
	I		II		III		IV	
	dBW	mW	dBW	mW	dBW	mW	dBW	mW
0	10	10000	6	4000	2	1600	2	630
1	2	1600	2	1600	2	1600	2	630
2	-2	630	-2	630	-2	630	-2	630
3	-6	250	-6	250	-6	250	-6	250
4	-10	100	-10	100	-10	100	-10	100
5	-14	40	-14	40	-14	40	-14	40
6	-19	15	-18	15	-18	15	-18	15
7	-22	6	-22	6	-22	6	-22	6