RF Shielding Strategies and Its Effectiveness

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Abstract - People get exposed to electromagnetic field from different sources. This field is affecting the health of the people when they get exposed. There is various adverse health effects of electromagnetic field (EMF) radiated from mobile towers. This EMF can be harmful for birds, animals, humans as well as electronic equipments etc. Here the technique to minimize the effect of EMF exposure is presented. To protect the people from this radiation, that is to provide the shield, which reflects and absorbs the electromagnetic field and reduces the EMF exposure at home and other places. Brass, copper, aluminium are the most common materials used for the shielding, the amount of field reflected by the shielding material is shielding effectiveness (SE). The SE is calculated for Brass, copper, aluminium sheets. Experimentation is done for finding the SE and solution is provided to reduce the EMF exposure at home and other places.

Index Terms - Electromagnetic field exposure, Shielding effectiveness, Non-ionizing radiation, dwellings, incident wave, reflected wave, reflection loss.

I. INTRODUCTION

The speedy development in today's present society has been associated with the development of high amount of telecommunication devices such as cellular base station mobile towers. Due to mobile towers installed in residential areas people get exposed to electromagnetic (EM) field. This exposure is called Non-ionizing radiation. It does not ionize the body molecules but still, there are some effects due to non-ionizing radiation on the human body which is unknown to us. In recent years there is more concern about health effects caused by EM field exposure from base stations. Mobile tower base stations radiate the electromagnetic energy, this electromagnetic energy act as an electromagnetic field. The community living around these base stations will come into contact of EM field. Today there is need to find out the impact of EM field exposure on humans or how much health risk is there due to this EM field exposure from base stations. Various analyses asserted the impact of base station radiations on the human body such as a headache, sleep disorder, irritability, depression, dizziness etc. There are two types of exposures: short term and long term exposure. In short term exposure, people are getting exposed to EM field radiation for a short duration may be 10, 15, 30 minutes or 1 hour. In long term, this exposure duration increases up to 5 to 6 hours or even more than that. The residential exposure was measured in different dwellings closer to the base stations; the complete elimination of EM field radiation is impossible as there are N numbers of sources of EM field are available currently.

The electromagnetic field exposure is involved with shielding effectiveness. One can find the SE with the help of reflection, absorption. The fundamental requirement for RF shielding is the materials conductivity, while materials having magnetic or electric dipoles are appropriate entrants for absorption shielding. From the realistic point of view, the shielding by absorption has become the most demanding, as the EM radiation waves are efficiently absorbed by the shield and not emitted back to the surrounding.

II. SHIELDING EFFECTIVENESS

INTRODUCTION

People living in close to the mobile tower base stations may get affected due to the EM field exposure. There are some adverse health effects of this exposure from base stations and other sources. Also to make electronics devices operate satisfactorily in the presence of Electromagnetic exposure, shielding is necessary. Shielding is basically a metallic sheet act as a wall to normalize the transmission of EM field in home. Here one purpose of shielding generally refers to a metallic enclosure that completely encloses the electronic circuit. Another purpose of shielding is to minimize the EM field exposure in houses which is from base stations. Metals used for shielding are copper, aluminum, brass, stainless steel, copper-nickel fabric super alloy, µmetal, etc.

In figure 1.0 transmitter and receiver are shown. Shielding material is placed in between transmitter and receiver. Inside a chamber receiving antenna is placed in front of shielding material and transmitter is at outside the chamber.

Fig 1.0 Shielding effectiveness experimental setup

SHIELDING EFFECTIVENESS

The performance of shielding material depends on various factors such as operating frequency, distance from the source, shield material thickness, and type of shield material. The Shielding effectiveness (SE) is expressed in decibels (dB). Initially electromagnetic field is incident on the shield material, then some field is transmitted in medium 2 and some is reflected back in medium 1. The ratio of incident field and reflected field with proper logarithm is called as SE. SE in terms of electric and magnetic Field is as follows,

$$Shielding\ Effectiveness\ in\ db = 20\log10\left(\frac{Ei}{Et}\right) \text{ ----- (1)}$$

In terms of magnetic field

$$Shielding\ Effectiveness\ in\ db = 20\log10\left(\frac{Hi}{Ht}\right) \text{ ------ (2)}$$

In terms of plane wave field

$$Shielding\ Effectiveness\ in\ db = 10\log10\left(Pi/Pt\right) \text{ -------- (3)}$$

Where i mean incident and t means transmitted, it is the ratio of incident field or power divided by transmitted field or power.

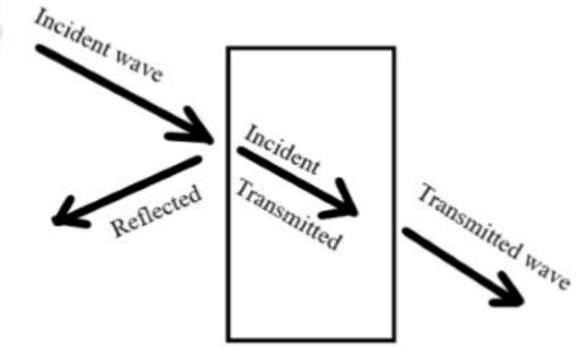

Fig. 1.1 Basic mechanisms behind electromagnetic shielding

There are different phases when electromagnetic field passed through the shielding material. The different phases are absorption, reflection, transmission etc. Material thickness plays important role in transmission and reflection of the electromagnetic field through shielding material. Total shielding effectiveness (SE) of shielding material equals the addition of the absorption (A), reflection (R), and correction (M). Figure 1.1 shows basic mechanism of electromagnetic shielding.

Shielding Effectiveness (SE) in dB= R in dB+ A in dB +M in dB -------------- (4)

REFLECTION LOSS

Reflection is due to mismatch in impedances. It is the mismatch in impedances between the shielding material and electromagnetic field. Reflection is expressed as follows:

R in dB = (168.0+ (10.0) $\log_{10}$ magnitude of (σ/μf) ---- (5)

ABSORPTION LOSS

As shown in Figure 1.1 when an electromagnetic wave passes through a medium its amplitude decreases exponentially. This decays the electric field and warming of the material takes place. Therefore absorption loss can be expressed as:

A in dB= (20.0) $\log_{10}$ ($e^{t/\delta}$) -----------------------(6)

MULTIPLE INTERNAL REFLECTION LOSS

In case of thin shielding material, multiple waves are reflected from material boundary as shown in Fig.1.1. Due to these multiple reflections attenuation takes place which is expressed as follows:

$$M \text{ in db} = (20.0) \log_{10} [1 - e^{-2t/\delta}] \text{-------- } (7)$$

III. METHODOLOGY

To find out shielding effectiveness, experimentation was done on different shielding materials such as copper, aluminum, brass, stainless steel etc.

FINDING SE

As explained in above section first different terms are defined as reflection loss, absorption loss and multi-reflection loss which is defined as:

$$R \text{ in dB} = 168.0 + 10.0 \log_{10} \text{Magn. of } \sigma/\mu f \text{ --------}(8)$$

$$A \text{ in dB} = (20.0) \log_{10} (e^{t/\delta}) = 131.40\, t \sqrt{f\mu\sigma} \text{ ---}(9)$$

$$\text{Multipath Ref. in db} = (20.0) \log_{10} (1 - e^{-2t/\delta}) \text{ –}(10)$$

When conductivity of metals is high and frequency is low then losses are higher. Reflection is degraded when μr >> 1. On the other hand A increases with frequency. One can neglect the M when shielding thickness is very less than δ. Above formulae are applicable for different shielding materials like Copper, Nickel, Aluminum and Stainless Steel.

EXPERIMENTAL APPROACH

- Here transmitting antenna is in medium 1 and receiving antenna is medium 2, their distance from the shield is fixed and same for both mediums.
- Their direction of transmission and reception is towards each other. Transmitting antenna transmits EM field from medium 1, receiving antenna receives EM field in medium 2 and it is measured by 3 axis RF meter.
- From this SE of the material is calculated. Figure 1.2 shows the required setup for shielding effectiveness.

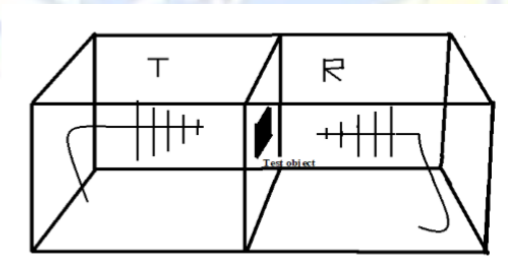

Fig. 1.2 Shielding Effectiveness measurements

EXPERIMENTAL SETUP FOR SHIELDING EFFECTIVENESS AT 2.4 GHZ

As shown in figure 1.3 initially antenna phase array is designed at 2.4 GHz. It is tested for major lobe and minor lobes of the antenna with the help of spectrum analyzer. Four antennas are designed for 2.4 GHz and connected to four phase splitters as shown in figure 1.3. RF source at 2.4 GHz is connected to antenna via phase splitters. Phase of each phase splitter is adjusted by varying DC voltage of each phase splitter. Single RF signal is given to phase splitter input, then each phase splitter generates RF signal of different phase and fed to each antenna.

Fig. 1.3 Antenna phased array Experimental setup at 2.4 GHz.

Figure 1.3 shows the experimental setup for the shielding test. Here spectrum analyzer is set to 2.4 GHz. frequency is varied around the 2.4 GHz and shielding is tested. The total distance between the transmitting antenna and receiving antenna is around two meters and shielding material is placed at one meter distance from source. The material used for shielding is brass. The spectrum analyzer used for the experimentation. The model used is of GW-830 it is a 250 GHz spectrum analyzer.

Fig. 1.4 Patch antenna used as a receiver

Figure 1.4 is of patch antenna used as a receiver in finding the shielding effectiveness. Patch is designed for 2.4 GHz center frequency.

Above two figures shows the experimental setup for the SE calculation. Phased antenna array is used as transmitter antenna. This antenna has a narrow bandwidth and can be used as EMI sensor. The antenna is designed for frequency 2.4 GHz. A rectangular sheet of Aluminum having dimension 12 X 12 cm and thickness 1mm is used as a shield and SE has been calculated. In another experiment a rectangular foil of Aluminum with same dimension but different thickness of 9 micron is used as a shield and SE has been calculated. Disadvantages with this technique are that deliberate power is reliant on the antenna position and the impression of the electromagnetic wave inside the analysis room. The separation between the shield and the transmitter antenna can be fluctuated and SE at the distinctive position has been determined. Same experimentation is done on copper and stainless steel material.

Initially brass material is placed between transmitter and receiver. 2.4 GHz frequency is supplied from the spectrum analyzer. As there are four antennas are used in array total power supplied by spectrum analyzer is divided into four parts. To find the shielding effectiveness (SE) measured the power with and without the shielding.

TABLE I SE OF BRASS

Sr. No.	Frequency in GHz	Power received without shielding	Power received with shielding	Shielding Effectiveness (SE)	Average shielding effectiveness (SE)
1	2.1	61 dB	52 dB	9 dB	14.26 dB
2	2.2	62 dB	49 dB	13 dB	
3	2.3	63 dB	42.7 dB	20.3 dB	
4	2.4	65 dB	54 dB	11 dB	
5	2.5	62 dB	44 dB	18 dB	
6	2.6	61 dB	51 dB	10 dB	

TABLE II SE OF COPPER

Sr. No.	Frequency in GHz	Power received without shielding	Power received with shielding	Shielding Effectiveness (SE)	Average shielding effectiveness (SE)
1	2.1	76	55	21 dB	21.16 dB
2	2.2	70	50	20 dB	
3	2.3	64	44	20 dB	
4	2.4	57	41	16 dB	
5	2.5	69	44	25 dB	
6	2.6	70	45	25 dB	

EXPERIMENTAL SETUP FOR SHIELDING EFFECTIVENESS AT 900, 1800 and 2100 MHZ

As shown in figure 1.5 experimental setup is arranged for frequencies 900MHz, 1800MHz and 2100 MHz to study the effect of shielding, shielding is placed in between RF source and detector. The materials used for shielding are brass, copper, aluminum, stainless steel, and GI. For studying the shielding effect due to these materials Yagi-Uda, dish and simple dipole are used. The distance between Source antenna and shielding material is kept constant. While the distance between detector and shielding material is varied as 5, 10 15 20 and 25 cm.

Fig. 1.5 Experimental set up for SE with stainless steel at 900, 1800 and 2100 MHz.

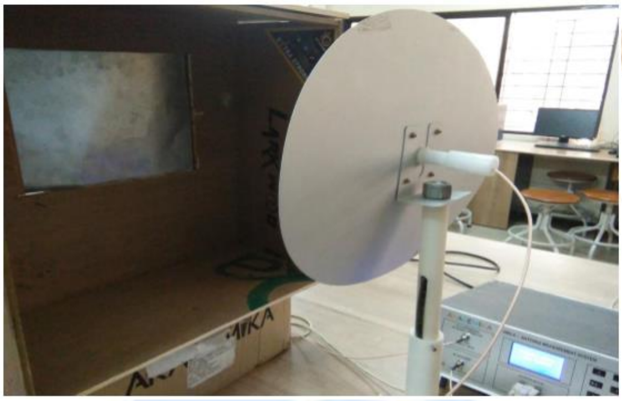

Fig. 1.6 Experimental set up for measurement of SE with aluminum shield

Figures 1.5, 1.6, show the experimental setup for the SE calculation. In fig 5.9 Yagi-Uda antennas is used as transmitter and parabolic reflector as a receiver antenna. Yagi-Uda antenna has a broad bandwidth and can be used as an EMI sensor. The Frequency range of this antenna is from 3 MHz to 3 GHz. A rectangular sheet of Aluminum, copper, brass, stainless steel having dimension 30 cm X 23cm is used as a shield and SE has been calculated. The distance between the shield and the transmitter antenna can be varied and SE at the different position has been calculated. The distance of transmitter from the shield is constant, which are 19 cm. we take readings at 2100 MHz. Place receiving antenna at 5cm, 10 cm, 15 cm, 20 cm, 25 cm and measure output.

In another experiment, an antenna power supply is used and takes readings at different frequencies. A rectangular sheet of Aluminum, copper, brass, stainless steel having dimension 30 cm X 23cm is used as a shield and SE has been calculated. The shield and the transmitter antenna can be varied and SE at a different position has been calculated. The distance between the shield and the transmitter antenna can be varied and SE at a different position has been calculated.

The following table shows that power received by receiving antenna at frequencies 900MHz, 1800MHz, 2100MHz with and without shielding. The distance between the shield and the transmitter antenna is kept constant which is 19cm. shielding effectiveness is measured at 2100MHz. Place receiving antenna at 5cm, 10cm, 15cm, 20cm, 25cm and measure output for 900MHZ and 1800MHZ. The distance between the shield and the transmitter antenna can be varied and SE at a different position has been calculated. The distance of transmitter from the shield is constant which is 30cm .we take readings at 900MHz and 1800MHz. Place receiving antenna at 30cm, 35cm, 40cm and measure output.

TABLE III SE AT DIFFERENT FREQUENCIES

Frequency in MHz	Distance	Without shield (dBm)	Aluminum (dBm)	Brass (dBm)	Copper (dBm)	Steel (dBm)
900MHz	30cm	-20	-25.8	-29.34	-25.63	-27.43
900MHz	35cm	-21.79	-23.12	-27.08	-26.12	-25.80
900MHz	40cm	-21.80	-21. 7	-24.24	-26.90	-23.51
1800MHz	30cm	-47.29	-49.98	-49.07	-50.22	-48.97
1800MHz	35cm	-47.65	-49.64	-49.77	-49.41	-49.75
1800MHz	40cm	-49.64	-49.60	-50.20	-49.87	-50.32
2100MHz	5cm	27.74	-10.45	-3.012	-20	-4.4369
2100MHz	10cm	25.2014	-1.9382	-4.4369	-6.0206	2.9225
2100MHz	15cm	22.5420	3.5218	0.8278	-0.9151	2.9225
2100MHz	20cm	24.5577	6.0206	-3.0980	0.827	3.5218
2100MHz	25cm	20.9843	7.2345	-0.9151	4.0824	5.10545

SHIELDING EFFECTIVENESS CHARACTERISTICS

Here two types of SE characteristics are plotted one is frequency versus SE and second is distance verses SE. in first type frequency is varied and SE is noted by placing shielding material in between RF source and recording instrument. In second type distance of receiving and transmitting antenna is varied from the shielding material. Figure 1.7, 1.8 and 1.9 shows shielding effectiveness of aluminum, brass, copper, and steel at 900, 1800 and 2100 MHz respectively. In these characteristics, SE decreases as distance increases.

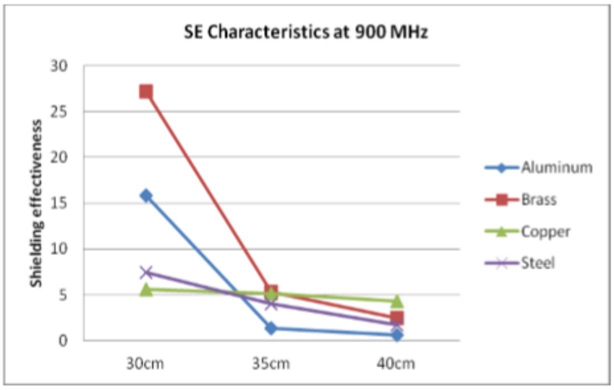

Fig. 1.7 SE characteristics at 900 MHz

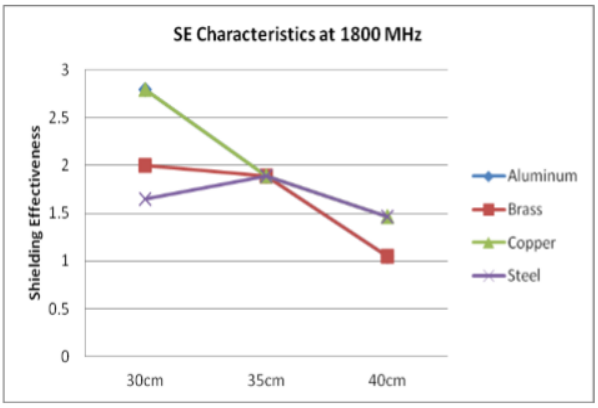

Fig. 1.8 SE characteristics at 1800 MHz

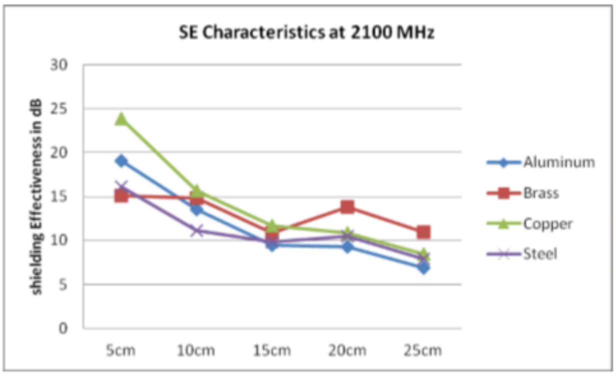

Fig. 1.9 SE characteristics at 2100 MHz

IV. EXPERIMENAL RESULTS

Experimentation is done on different materials such as copper, aluminum, brass, stainless steel etc and SE is calculated. Also the SE is tested at various mobile tower frequencies at home. The experimentation results are summarized as follows

The test of shielding material is taken in the home which is closer to mobile tower and windows facing the mobile tower. Shielding material is fitted to the curtains of the window and then shielding effectiveness is measured. Initially in the absence of shielding material power density and an electric field is measured in the home. Then shielding material is placed between a mobile tower and home that is at the window. Shielding material is fitted to the window or curtain. Power density and the electric field is measured with help of KM 195 three axis RF power meter. Then the distance between shield and power meter is varied from 1 foot to 5 feet. Readings are recorded before and after placing the shielding material.

TABLE IV SE AT 900 MHZ FOR BRASS (POWER DENSITY)

Frequency in MHz	Distance	Without shield power density (µw/m2)	After placing Brass shield (µw / m2)	Shielding Effectiveness in (µw / m2)	S.E. in dB
900MHz	1 feet from window	1215.3	789.4	425.9	1.8
900MHz	5 feet from window	1127.1	349.4	777.7	5.07

Table IV shows the power density variation before and after the brass shield is placed. S.E. increases as distance increases.

TABLE V SE AT 900 MHZ FOR BRASS (ELECTRIC FIELD)

Frequency in MHz	Distance	Without shield (mv/m)	Brass (mv/m)	Shielding Effectiveness	Average S.E. in dB
900MHz	1 feet from window	932.1	684.5	247.6	1.33
900MHz	5 feet from window	739.8	179.5	560.3	6.14

TABLE VI SE AT 900 MHZ FOR STAINLESS STEEL (POWER DENSITY)

Frequency in MHz	Distance	Without shield (µw/m2)	Stainless steel (µw/m2)	Shielding Effectiveness in (µw/m2)	S.E. in dB
900MHz	2 feet from window	1040.9	261.6	779.3	5.98
		593.8	167.92	425.88	6.00
		594.8	204.4	390.4	5.47
		360.6	158.37	202.23	3.56
		463.7	140.76	322.94	5.17
		602.9	112.74	490.16	7.27

TABLE VII SE AT 900 MHZ FOR ALUMINIUM (POWER DENSITY)

Frequency in MHz	Without shield (µw/m2)	Aluminum (µw/m2) 1 feet	Aluminum (µw/m2) 2 feet	Aluminum (µw/m2) 3 feet	Aluminum (µw/m2) 4 feet	Aluminum (µw/m2) 5 feet
900MHz	382	20	26	30	40.73	58.26
	221.6	15	24	31	36.71	32.26
	270.7	17	28	30	40.17	39.86
	211.7	16	25	32	44	57.77
	310.2	14	25	27	43	41.20
	306.1	15	20	32	39.82	37.68
	228.6	16	22	33	32	36.77
	352.9	18	25	35	37.26	48.57
	468.8	16	22	31	29	40.43
	436.4	14	20	27	26	39.60

TABLE VIII SE AT 900 MHZ FOR COPPER (POWER DENSITY)

Frequency in MHz	Without shield (µw/m2)	Copper (µw/m2) 1 feet	Copper (µw/m2) 2 feet	Copper (µw/m2) 3 feet	Copper (µw/m2) 4 feet	Copper (µw/m2) 5 feet
900MHz	260.7	55	106	129	137	143
	349	50	98	129	142	147
	312	44	101	135	151	147
	372	58	104	131	146	145
	350	54	94	123	150	162
	333	48	90	128	138	168
	345	49	98	125	153	164
	346	51	84	126	151	174
	395	53	78	122	160	164
	379	38	84	124	157	149

- Two metals were tested for shielding against RF radiation at 2.4 GHz copper and aluminum.
- Out of these two metals copper is much better than aluminum for shielding against RF waves at 2.4 GHz.
- From above results the SE of copper is 21.16 dB while for brass it is 14.26 dB.
- Also one important outcome of the experiment is that as thickness of the material decreases the SE increases.
- Four metals were tested for shielding against RF radiation at 900, 1800 and 2100 MHz, such as copper, aluminum, brass and stainless steel.
- Brass is having good SE for a distance of 30 cm, followed by aluminum. Copper and steel they are having low SE.
- Also as distance increases from shield the value SE decreases.
- So from above table one can conclude that brass is the best material for shielding the EM waves from base station antennas.
- Here copper is having highest SE value than other three metals, while brass has low value. Also as distance goes on increasing the SE value decreases.

Shielding effectiveness of metallic rectangular enclosure with apertures is investigated in this work. The shielding effectiveness was estimated for different material with different thicknesses, frequencies, and position inside the box.

The result shows that shielding effectiveness of brass is higher at lower frequencies than other metals also aluminum shows the same properties as brass. Steel and copper have low SE but as frequency increases, SE is increased slightly. Aluminum and brass were the weakest for frequencies greater than 1 GHz. SE of material decreases with increasing the distance from a shield. It was observed that the orientation of the incident electric field along a particular axis results in higher excitation of that component of the cavity electric field. The scattered fields are greatly affected by the frequency of the incident waves and resemble those radiated by an aperture array and hence are greatly affected. The location inside the cavity has a significant effect upon the shielding effectiveness values. However, due to the modal structure of the fields, it may not be valid to assume that field intensities will be higher at points near to the apertures than at larger distances from them.

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