Evaluation of Techniques for the Reduction of Electromagnetic Power Density around Future Base Stations

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ORIGINAL RESEARCH

Abstract— Electromagnetic (EM) emission poses danger to the health of both man and animals. The future generations of cellular networks poses' higher threats of EM emissions. Evaluation of various techniques for the reduction of EM radiations around base station has become a front burner issue. With the risen awareness in wireless communication technology capabilities, the need to increase speed and bandwidth became necessary in order to accommodate the ever increasing connectivity. Hence, the inherent EM emissions that come along with the technologies have necessitated the search for better techniques to reduce the electromagnetic interference (EMI). Considering the current EMI concerns, the base station is the hub of the interference. This research examined different techniques of reducing the EM power density around the base station such as the grounding, the filtering and the shielding. The result indicated that among these three techniques examined, the filtering techniques gives the least reduction of EM power density of 3.552Wm^{-2} as compared with the shielding which gives 3.755 Wm^{-2} and grounding with 3.783 Wm^{-2} all at a distance of 10m each.
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Keywords— Base station, Filters, Interference, Power density, Radiation.

1 INTRODUCTION

In the current technological world, the society depends mostly on mobile phones for communications purposes at work, school and home. These mobile phones generate the electromagnetic waves like X-ray and visible light. With the popularity of radio equipment in many households, detection of both intentional and unintentional electromagnetic radiations are detected in various places around the base stations. The International special committee on radio interference (CISPR) started producing and distributing specific requirements for wireless cellular transmissions in 1978. These requirements consists of the recommended allowable emissions and immunity limits for electronic devices which have evolved into much of the world's electromagnetic compatibility (EMC) regulation. For electromagnetic interference (EMI) to exist, there must be a source, a transmission path, and a receptor (Akintoye, 2013). The electromagnetic energy from the source propagates through the path and interferes with the operation of the receptor. Electromagnetic emissions are a measure of electromagnetic energy from a radiofrequency source. Immunity concerns the degree of interference from an external electromagnetic energy source on the operation of the electronic device.

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Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
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The device will be immune below a certain level of EMI and become susceptible above that level. The three most common electromagnetic interference (EMI) problems are radio frequency interference, electrostatic discharge, and power disturbances (Nihan, 2014).

In recent years, some residents near cellular phone base stations have reported feeling several unspecific symptoms including radiation sickness, fatigue, sleep disturbance, dizziness, loss of mental attention, headaches, cataracts, and cancer (Osoveheet *al*., 2015; Ilori and Adeleye, 2019; Lennart and Tarmo, 2022). However, there is no convincing scientific evidence that the EM fields emitted from cellular phone base stations cause adverse health effects. On the other hand, EM field intensities at users' locations should be guaranteed above a threshold level in order to meet the best RF (radio frequency) condition where it is free from interference. However, EM field Intensities drop rapidly as the distance increases from a base station because of the attenuation of power with the square of distance. Consequently, it is an important trade-off issue for RF engineers to determine the safety distance for EM radiation from a base station and also to keep EM field intensity above a threshold level. Some advisory authorities have recommended safety guidelines for human exposure to EM energy. These authorities include the Institute of Electrical and Electronics Engineers (IEEE) and American National Standards Institute (ANSI) (Chen &Yianting, 2017), International Commissions on Non-Ionizing Radiation Protection (ICNIRP, 2010), and the National Council on Radiation Protection and Measurements (NCRP). For example, for human exposure in uncontrolled environments to EM energy at radio frequencies from 300MHz to 15GHz, the ANSI/IEEE safety standard is expressed by f/1500mW/cm^2, where frequency f is in MHz. Measurements of RF electric and magnetic fields around cellular phone base stations varies (Chen and Yianting, 2017). There are only a few reports regarding theoretical studies on electric field strengths near cellular phone base stations (Chen *et al.*, 2018). Thus, the needs to have a system that can reduce the level of EMI become a necessity.

An electromagnetic (EM) field is a physical field produced by charged objects and theoretically extends to infinity. An electromagnetic field is a combination of an electric and a magnetic field with the electric field being produced by stationary charges and magnetic charges in motion (electric currents). In the past, theories of electric and magnetic fields were considered separately, and later it was understood that electric and magnetic fields were only two parts of one larger whole of the electromagnetic field (Chen and Yianting, 2017).

Electromagnetic fields occur when electric and magnetic fields which are varying with respect to time come together. As the transmission frequency increases, the wavelength decreases and the energy emitted in the field increases. Electric and magnetic fields which are static, naturally occur in nature. The natural magnetic field is located in the north-south direction around the earth's sphere and consists of undulating waves that help birds and fish to navigate. The natural electric field is emitted by lightning in local part of the atmosphere. Electromagnetic fields, which are emitted from man-made sources as well as natural electric and magnetic fields, impacts the human environment in daily life (Tayaallen, 2021). Low frequency electromagnetic field around the substations is quasi-static. It has a conservative component of the electric field caused by charges and eddy component of the magnetic field caused by currents. The calculation of electric and magnetic fields at the points located far from the source (charges and currents) is obtained with thin-wired approximation and by representation of conductors with linear segments with current distribution calculation, and based on that, in the selected point of the space located in the air or in any ground layer the calculation of potentials is also obtained. The potentials and electromagnetic fields are firstly expressed in the form of components of the vector potentials, as a function of the current in each segment of conductor network. The currents in the conductors segments are determined based on the voltage drop between a pair of network points, based on their own impedance. The ground influence on the conductor potential was taken into account by using a method of mirrors (Phalguni & Sujith, 2020).

The EM radiation is mainly divided into two parts. The ionizing and non-ionizing radiation. Ionizing Radiation is EM wave with high frequency (higher than 10^{14} Hz) which has capability to ionize atomic bonds in cell molecules. For example, X-ray and gamma rays and some sources of ultraviolet (UV) rays are considered in this category. Excessive exposure to this effect can lead to hazardous conditions such as damage to living cells and also DNA chain. Non-ionizing EM radiation have no enough energy to separate atomic bonds. These are visible light, infrared, RF (Radio Frequency), microwave, static and magnetic waves. In other words, they are distributed in range from 1.0 Hz to 10^{14} Hz. However, these waves cause thermal effects on human body depending on distance, frequency power and time according to ICNIRP report (ICNIRP, 2019). But it is claimed that carcinogenic effect has not been proven yet.

According to (Phalguni & Sujith, 2020), the two types of effect that occurs in organism impacted by these waves can be classified as thermal and non-thermal. EM energy absorbed by the body is converted to heat which causes an increase in human temperature gradually. Charged particles in body are moved by using force in electric fields. Body gets hotter because of resistance to these movements. Temperature in body continues to increase until balance of body is provided by blood circulation and perspiration. On the other hand, non-thermal effects encompass a broader range of biological responses that can occur independently of temperature increase. Both types of effects are important consideration in radiation protection and health risk assessment. Although transmitters used for Radio-TV and communication in range of RF spectrum provides benefits for community, each of them is source of continuous exposure involuntarily. By growing up usage of mobile phone, number of base stations has been increased in city centers and streets. For this reason, public attention has been started to focus on them (Phalguni & Sujith, 2020). Mobile communication can be in the range of 450 - 2200 MHz but energy is directly proportional to the wave frequency. The electrical currents of RF in the antenna and the handheld case of the mobile device carries some RF electrical fields into the tissue. Thus, some of this radiation energy may be absorbed by the human tissue, which leads to an increase in the tissue temperature (Abdul-Al, *et al.*, 2022). Such absorption phenomena are produced due to the power loss of dielectric polarization. Due to absorption of energy, RF fields ranged from at a lower level of 10 GHz to 1 MHz exposed into tissues and give heating. The penetration depth based on the frequency of the field and is greater for lower frequencies (Narmadha and Malarkkan, 2016). Specific Absorption Rate (SAR) is the quantity used to measure the absorption of RF energy within a given tissue mass and it is expressed in units of watts per kilogram (W/kg or mW/Kg). The quantity of RF fields between about 1 MHz and 10 GHz is measured using SAR. People who are exposed to RF fields in the SAR at 4 W/kg, produces several adverse health effects. Similarly, the range at 10 GHz of RF fields are absorbed at the surface of the skin, only few energy enter into the deepen tissues, while the above 10 GHz of RF fields exposed at power densities over 1000 W/m^2 produces severe health effects like skin burns and eye cataracts. The ICNIRP reference levels for telecommunication services for general public exposure rms values is shown in table 1.

Table 1: The ICNIRP reference levels for telecommunication services-general public exposure rms values (ICNIRP, 2019)

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Services	Frequency Range (MHz)	E-field Strength (V/m)	B-field (A/m)	Equivalent plane wave Power density Seq(Wm-2)
FM broadcast	88-108	28	0.092	2.0
VHF TV	54 – 88 174 – 216	28	0.092	2.0
UHF	407 – 806	29.8	0.099	2.0
Trunking 800 MHz	806 – 869	30.0	0.13	2.05
Mobile telephony 800 MHz	824 – 894	40.6	0.14	2.1
UMTS	1710 – 1900	30	0.19	2.5
LTE	2450 - 2700	30.5	0.20	2.5

Managing EMI makes up a large number of different solutions at both the emitter and victim devices. Various methods have been proposed in the literatures for reducing the EMI around cellular base stations. These methods can broadly be classified into two categories:

a) Active method
b) Passive method

a) Active methods

Active methods involve the use of electronic devices such as filters, absorbers and shielding to reduce the EMI. Filters are used to reduce the EMI by blocking the unwanted signals. Absorbers are used to absorb the EMI by converting it into heat energy. Shielding is used to block the EMI by creating a barrier between the source of the EMI and the receiver.

b) Passive methods

Passive methods involve the use of physical materials such as metals, foams and fabrics to reduce the EMI. Metals are used to reflect the EMI away from the receiver. Foams are used to absorb the EMI by converting it into heat energy. Fabrics are used to absorb the EMI by creating a barrier between the source of the EMI and the receiver. In addition to the above mentioned methods, some other techniques have also been proposed for reducing the EMI around 4G cellular base stations. These techniques include the use of antenna diversity, beam forming and signal processing techniques.
Antenna diversity is used to reduce the EMI by using multiple antennas to receive the signal by focusing the signal in a desired direction. Signal processing techniques are used to reduce the EMI by processing the signal to remove the unwanted signals.

2 Materials and Methods

The equipment deployed in this research work include (i) Control amplifier with negative feedback, (ii) power supply unit (iii) Filter(iv) Network analyzer (v) Spectrum analyzer

2.1 Methods

The following techniques were deployed in the reduction of electromagnetic power density around base stations
(i) Grounding
(ii) Filtering
(iii)Shielding

(i) Grounding

An ideal ground is a zero potential, zero impedance body that can be used as a reference for all signals. Signal grounding is often needed on a circuit board to provide a reference for the signal voltage. The goal of a good signal grounding is to maintain a low impedance over the entire frequency range of operation. For EMI reduction, it is crucial that the current paths are known to all grounds and their locations.
Signal grounding topologies include:

(a) Series connected single point

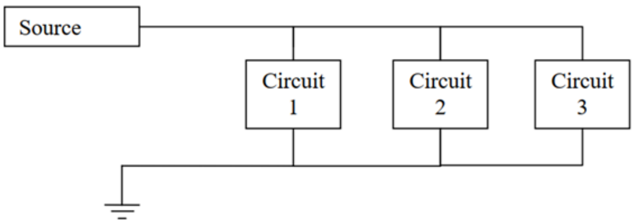

Figure 1: Series connected single point grounding

(b) Parallel Connected single point

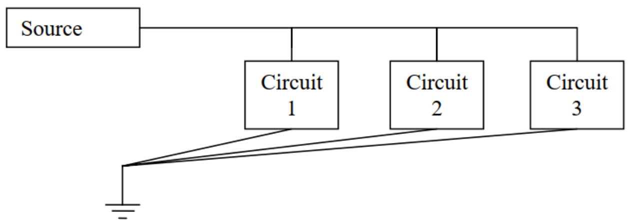

Figure 2: Parallel connected single point grounding

(c) Multipoint Grounding arrangements

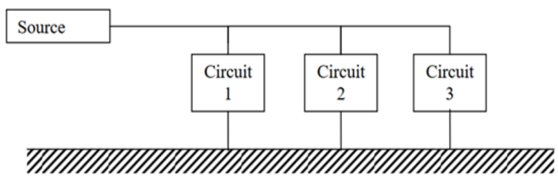

Figure 3: Multipoint Grounding

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(d) Ground looping

Uneven ground potentials create ground loops which can be a problem in audio and video equipment if multiple outlets are used to plug in interconnected electronic components. This led to some of the 60Hz current returning through the audio system. Hence, there is a low hum at the output. A circuit containing a source, connecting wire, load and ground creates a loop that resembles a loop antenna. It can serve as an unintentional source of radiated emissions and is also susceptible to reception of incident fields. Power radiated is proportional to the loop area squared, care should be taken to minimize area enclosed to reduce EMI.
Metal or metal screen box that impedes the transmission of radiated fields. Modeled as normal incidence or Transmission lines with mismatch impedance.

(ii) Filtering Technique

The filtering technique is used to reduce passed noise by reflecting the noise, attenuate the noise or both. Reflective filters use a sharp impedance discontinuity to target the noise frequency.

(a) T-Filter Technique

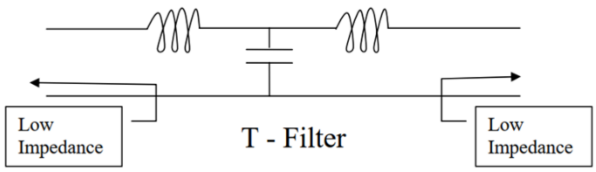

Fig. 4: T-Filter

(b) π-Filter Technique

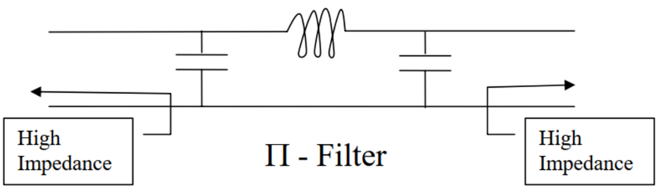

Figure 5: π-Filter

(c) Ferrite Chokes

Ferrite chokes are used to reduce common mode currents on power lines entering EMI-sensitive equipment. Wires are wound in opposite directions. The induced flux is contained in the toroid core that opposes the common mode current.

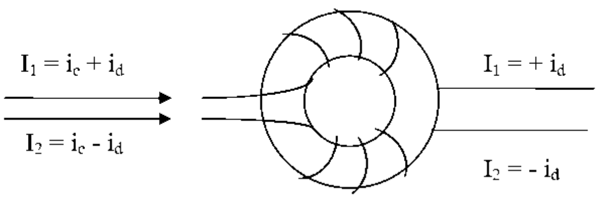

Figure 6: Ferrite Chokes

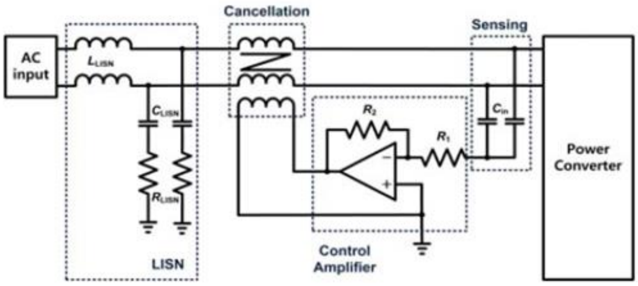

Figure 7: Filtered system with feedback

$$\frac{V_o}{V_o} = \frac{(1-A)R_L}{(1-A)Z_S+Z_L} \qquad (1)$$

An extremely high value of the forward gain A is required to minimize the noise voltage (V_o) at the line impedance stabilization network (LISN) terminal for the feedback. However, the noise voltage tends to drop to zero as the forward gain 'A' approaches unity (A = 1) for the feed-forward. The feed-forward structure is chosen for the implementation.

(iii) **Shielding**

Electromagnetic shielding is the process of lowering the electromagnetic field in an area by barricading it with conductive or magnetic material. Copper is used for radio frequency (RF) shielding because it absorbs radio and other electromagnetic waves. Properly designed and constructed RF shielding enclosures satisfy most RF shielding needs, from computer and electrical switching rooms to hospital CAT-scan, MRI facilities and base station. There are many shielding devices such as caps, lead glasses, thyroid protectors, aprons, radiation reducing gloves etc., for radiation safety during C-arm fluoroscopy-guided interventions. The radiation shielding devices are expensive, and the use of shielding materials can be itchy (Hsing-Yi and Tsung-Han, 2014).
This exposure control could also be based on the proper radiation shields, automatic interlock devices, and in-place radiation monitoring instruments. Except for temporary or portable shields, protective drapes, lead or lead equivalent aprons, this type of control is usually built into the particular facility, such as concrete walls next to a radiation oncology accelerator. For portable x-ray devices. Reducing the time of radiation exposure, a greater distance from radiation sources, and the use of shielding devices for radiation protection are important (Ozovehe *et al.*, 2015).
The use of membrane shielding material is a very effective electromagnetic/radiation protection method, which can reduce the radiation by reflection or absorption, especially when the distance and time are limited. In order to obtain a good shielding effect, appropriate shielding materials should be selected that are appropriate for the given application. Therefore, it is necessary to study the performance characteristics of membrane shielding materials with potential electromagnetic compatibility. In order to handle the environmental pollution caused by electromagnetic radiation, different membrane shielding materials have

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been produced to protect human beings and their environment from the destructive effects of electromagnetic interference and radiation. When looking for suitable membrane shielding materials, the weight, space, and cost of membrane shielding materials are the primary problems faced by researchers. More importantly, lightweight, non-toxic, and flexible membrane shielding materials with robust mechanical properties and good shielding effects are the common goal pursued by researchers. Metal or metal screen box that impedes the transmission of radiated fields. Modeled as normal incidence or Transmission lines with mismatch impedance.

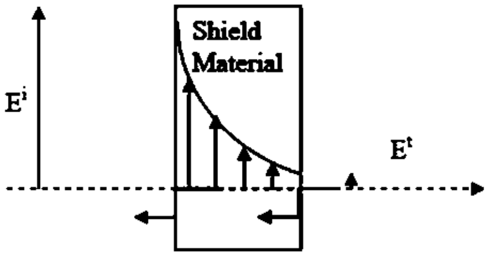

Figure 8: Electric field strength with distance using shield method

$$Shield\ Effectiveness: SE = 10Log\left(\frac{P_{noShield}}{P_{withShield}}\right) \quad (2)$$

4.0 Results and Discussion

Table 2: Electromagnetic power density using shield, filter and grounding techniques

Distance (m)	Power density (S) in Wm^{-2} Shieding	FIR Filter	Grounding
10	3.755	3.552	3.783
20	2.708	2.562	2.845
40	1.280	1.211	1.311
60	0.681	0.645	0.690
80	0.412	0.39	0.421
100	0.273	0.258	0.279
120	0.193	0.183	0.196
140	0.144	0.136	0.113
160	0.111	0.105	0.111
180	0.088	0.083	0.887
200	0.072	0.068	0.073

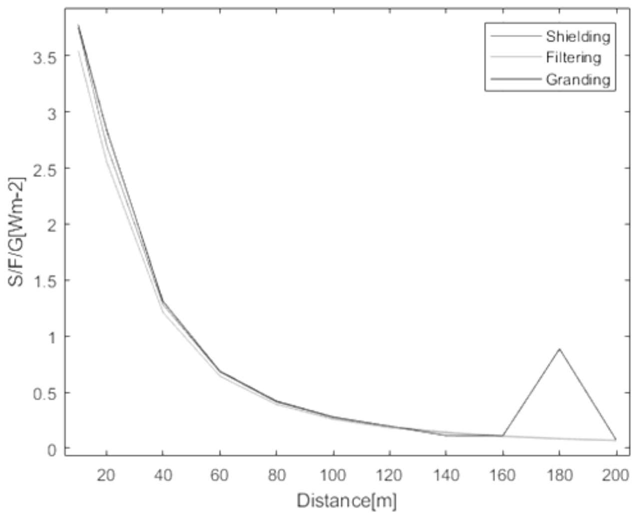

Figure 9: Electromagnetic power density using shield, filter and grounding techniques

Figure 9 shows the electromagnetic power densities measured using the FIR filter, the grounding and shielding techniques respectively. It showed that the Electromagnetic power density is less when the FIR filter was deployed as compared with the grounding and the shielding techniques. Table 2, revealed that at a distance of 10m from the base of the tower, filtering technique recorded 3.552 Wm^{-2} whereas shielding and grounding recorded 3.755 Wm^{-2} and 3.783 Wm^{-2} respectively. This shows that the filtering technique gives a better reduction in EM power density as compared with other techniques.

5 Conclusion

Considering the negative impact of electromagnetic emission on both human and animals, this work critically evaluated a better technique to reduce the emission thereby reducing the hazards that comes with the exposures. Three techniques were considered in this work. From the techniques considered the FIR filter technique proves to be better when compared to the grounding and shielding techniques. Reduction in the Electromagnetic power density leads to a safer environment.

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