FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://fjet.fudutsinma.edu.ng/index.php/fjet/
Volume 2, Issue 1, 2026, 538-546

Reducing Electromagnetic Radiation Around the Fourth Generation Base Stations

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Abstract
Electromagnetic radiations and interferences, poses health hazards both to man and his environment the importance of reducing it cannot be over emphasized. This work focused on the reduction of electromagnetic interference (EMI) around 4G base station using filter techniques. The projected rise in wireless communication network generations and the inherent electromagnetic emission that come along with the technologies have necessitated the search for better ways of reducing the electromagnetic interference. Considering the current electromagnetic interference concerns, the base station is the hub of the electromagnetic interference. This research examined different ways of deploying the finite impulse response filters (FIR) at the base station level to help reduce the impact of EMI around the 4G base stations. The research adopted the finite impulse response (FIR) filter technique, which is connected at the transceiver point at the base station level. The data used for analysis in the developed model were extracted from the daily collection of data from the service provider operators. Electromagnetic interference (EMI) for the filtered and unfiltered base stations were analyzed using the International Commission on Non-Ionizing Radiation Protection (ICNIRP) model. Data for five 4G base station within the Umuahia metropolis were used. The results obtained for 4G base stations showed that the deployment of Filter reduced the electromagnetic power density around a 4G base station. As without the filters the power densities were 3.755, 2.708, 1.280, 0.681, 0.412, 0.273, 0.193, 0.144, 0.111, 0.088 and 0.072. On the deployment of the FIR filters the power densities were reduced to 3.552, 2.562, 1.211, 0.645, 0.390, 0.258, 0.183, 0.105, 0.083 and 0.068 respectively.

Keywords: *Electric field strength, Magnetic Field strength, Power density, electromagnetic radiation, filters.*

1.0 Introduction

In this day and age, the use and necessity of electrical energy are increasing due to industrialization and new technologies. Every device that consumes or produces electricity uses electromagnetic energy. As a result of this reality, it ideal to say that the world is surrounded by electromagnetic fields emitting from radio antennas, satellites, wireless devices, cell phones, computer monitors, television, photocopier machines, microwave ovens, and even nature creates remarkable effects like lightning strikes. All these electrical and electronic equipment emit the electromagnetic (EM) field in various frequency bands. With the popularity of radio in every house hold, the electronics community began to notice both intentional and unintentional electromagnetic radiation in 1934. CISPR started producing and distributing specific requirements. These requirements consisted of the recommended allowable emissions and immunity limits for electronic devices which have evolved into much of the world's EMC regulation. For EMI to exist there must be a source, a transmission path, and a receptor. The electromagnetic energy from the source propagates through the path and interferes with the operation of the receptor. All three must exist to have an EMI problem. The path can be conducted, radiated, inductive, or coupled with a capacitor or with electrostatic discharges, or a combination of any of the above. Therefore, to understand the effects of EMI, we consider two factors: Emissions and immunity (susceptibility). 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.

Fatigue, sleep disturbance, dizziness, lack of mental focus, and headaches are among the symptoms that some locals near cell phone base stations have reportedly been suffering in recent years. Nevertheless, there isn't any solid scientific proof that the electromagnetic fields released by cell phone base stations have a negative impact on human health. However, in order to achieve the optimal RF (radio frequency) condition where it is free from interference, EM field intensities at users' locations should be assured above a threshold level. However, due to the attenuation of power with the square of distance, EM field intensities rapidly decrease as one gets farther away from a 4G base station. Determining the safety distance for electromagnetic radiation from a 4G base station and maintaining EM field intensity over a threshold level are therefore crucial trade-off issues for RF engineers.

An electromagnetic (EM) field is a physical field produced by of charged objects and theoretically extends to infinity. It acts by the Lorenz force on the charged objects found in it.An electromagnetic field is a combination of an electric and a magnetic field with the electric field being produced by stationary charges and magnetic

Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026

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.

Electromagnetic fields occur when electric and magnetic fields which are varying with respect to time come together. As the frequency increases, the wavelength decreases and the energy emitted in the field increases. Electric and magnetic fields which are static are 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 occurred 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, have covered the whole environment in daily life [1], [2].

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 have 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.

One strong area of concern in mobile communication is the radiation emitted by the fixed infrastructure used in mobile telephony. Such as base stations and their antennas, which provide the link to and from mobile phones.Owing to growing subscriber demand and diversifying services, the number of units and systems that emit EM waves in cellular systems increases day by day in and around the residential areas, resulting in the formation of EM field sources and intensity in the environment. The power dissipated from these devices through environment may reach 400W. As the number of users increases, it is inevitable that the number of base stations will increase. This, in contrast to mobile handsets radiation is emitted continuously and is more powerful at close range. On the other hand, field intensities drop rapidly with distance away from the base of the antenna because of the attenuation of power with the square of distance. Several surveys have identified increases of certain health related symptoms depending upon proximity to electromagnetic sources such as mobile phone base stations [3]. With all of these, the EMI around base station required reduction.

1.1 Radiation Effects and EMF Emissions

Generally, radiation is exhibited by both man-made and natural radiation and they are electromagnetic in nature. Conversely, there are two categories of electromagnetic radiation which includes the ionizing and non-ionizing radiation. From a research it is evident that the ionizing radiation has a capability to eradicate the electron which is from the atom's orbit of an atom, where it becomes an ionized atom to cause health hazard [4]. For instance, X-rays are perceived as ionized material due to high EMF frequency. However, in the case of non-ionizing radiation it lacks sufficient energy to ionize the atoms. Some of the non-ionizing radiations are microwave radiation such as visible light and radio wave frequency (RF) energy.

In the current technological world, the society depends mostly on mobile phones for communications purpose at work, school and home. These mobile phones generate the electromagnetic waves like X-ray and visible light. However, the range of electromagnetic radiation falls between non-ionizing and ionizing ranges of frequency, especially for mobile communication can be in the range of 450 -2200 MHz but energy is directly proportional to the wave frequency. 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 [4],[5]. 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/m² produces severe health effects like skin burns and eye cataracts.

Table 1: ICNIRP reference levels for telecommunication services- general public exposure rms values

Services	Frequency range (MHz)	E-field strength (V/m)	B-field (A/m)	Equivalent plane wave power density $S_{eq}(Wm^{-2})$
FM broadcast	88-108MHz	28	0.092	2.0
VHF TV	54 – 88 MHz 174 – 216 MHz	28	0.092	2.0

Services	Frequency range (MHz)	E-field strength (V/m)	B-field (A/m)	Equivalent plane wave power density $S_{eq}(Wm^{-2})$
UHF	407 – 806 MHz	29.8	0.099	2.0
Trunking 800 MHz	806 – 869 MHz	30.0	0.13	2.05
Mobile telephony 800 MHz	824 – 894 MHz	40.6	0.14	2.1
UTMS1	1710 – 1900 MHz	30	0.19	2.5
LTE	2450 - 2700	30.5	0.20	2.5

Source:*Phalguni and Sujith, (2020)*

1.2 EMI Reduction Techniques

Managing EMI makes up a large number of different solutions at both the emitter and victim devices. Various methods have been proposed in the literature for reducing the EMI around 4G cellular base stations. These methods can be broadly 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 [9].

1.3 Filters

Analog and digital filters are the two categories of filters. According to [6], a filter's job in signal processing is to either extract valuable portions of the signal, like the components that fall inside a specific frequency range, or eliminate undesirable portions of the signal, like random noise. The main idea is shown in the block diagram that follows.

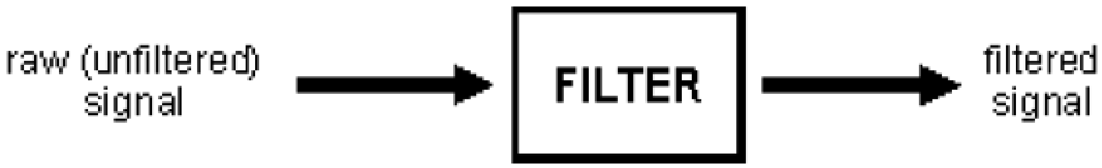

Figure 1: Block diagram of a filter (Source: *Phalguni and Sujith, (2020))*

Analog and digital filters are the two primary types. Their physical characteristics and methods of operation are very different. To provide the necessary filtering effect, an analog filter employs analog electronic circuits composed of parts like resistors, capacitors, and op-amps. These filter circuits are widely utilized in many different applications, including graphic equalizers in hi-fi systems, noise reduction, and video signal enhancement. For the purpose of creating an analog filter circuit, there are recognized standard methods. The signal being filtered at every stage is an electrical voltage or current, which is the direct analog of the physical quantity (such as a sound, video, or transducer output) involved [6], [7].

A digital filter calculates the signal's sampled values numerically using a digital processor. Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters fall into two categories. The processor could be a specialized DSP (Digital Signal Processor) chip or a general-purpose computer like a PC.

An ADC (analog to digital converter) must first be used to sample and digitize the analog input signal. The processor receives the binary integers that represent successive sampled values of the input signal and performs

Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026

numerical computations on them. Usually, these computations entail multiplying the input numbers by constants and then adding the results.If required, a DAC (digital to analog converter) is used to output the results of these computations, which now represent sampled values of the filtered signal, in order to return the signal to analog form. Keep in mind that instead of a voltage or current, the signal in a digital filter is represented by a series of integers [7], [8].

The diagram in figure 2. shows the basic setup of such a system.

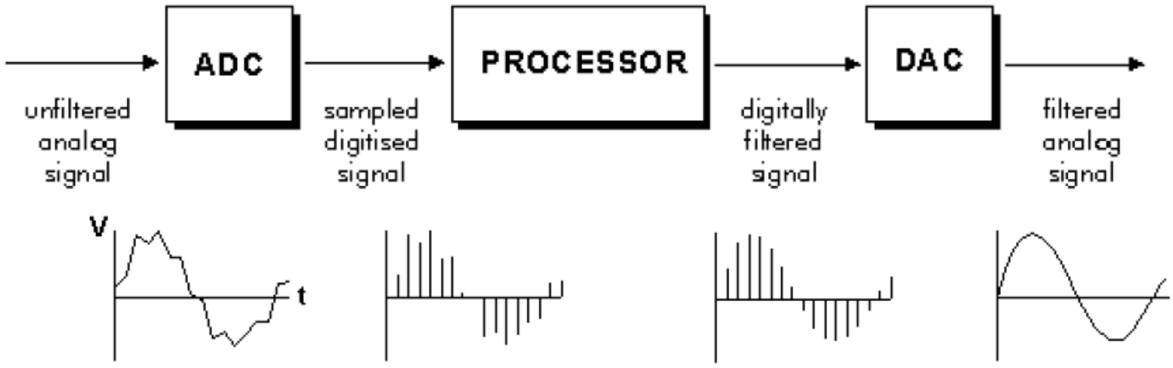

Figure 2: Basic system setup of a digital filter with their signal at each stage
(Source:Narmadha, and Malarkkan, (2016))

2.0 Material and Methods

The materials used for the research work with respect to the specific objectives are presented below:

(i) Electromagnetic field Analyzer
(ii) An operational 4G base station
(iii) Electromagnetic Probes
(iv) (iv) Optical fiber cables
(v) Laptop
(vi) Frequency selective meter
(vii) Watt meter
(viii) Coupler/EM clamps
(ix) Network Analyzer

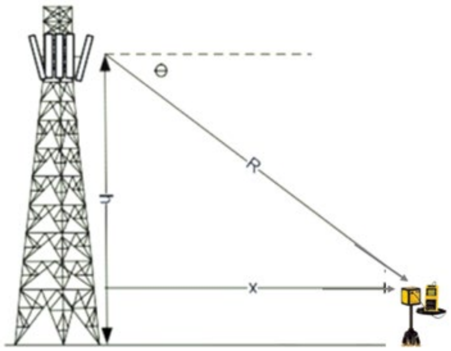

Figure 3: 4G tower with masts and a Network analyzer for measurement

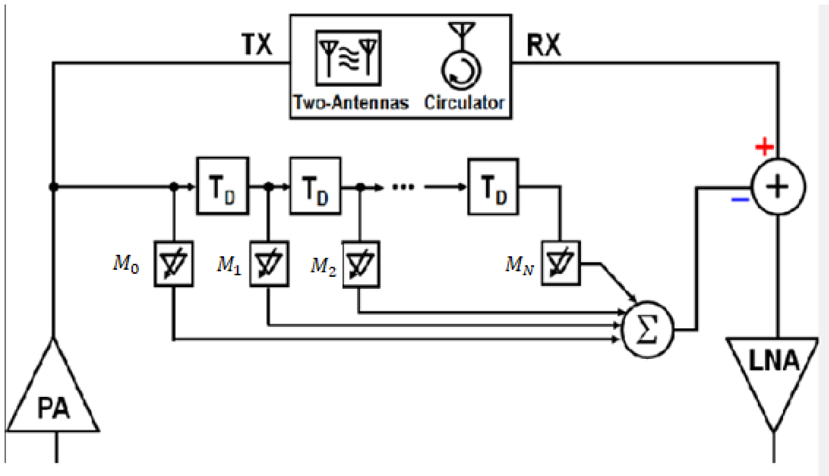

Figure 4: Block Diagram of an FIR filter connection to a 4G base station

Before the input to a FIR filter propagates through the filter and produces the stop band, a finite amount of time must pass. In the frequency domain, a phase shift of $e^{-j2\pi T}$ corresponds to a time delay of T (seconds). The type of filter (FIR/IIR) and its impulse response determine the phase shift that the filter produces. The temporal delay of an order M FIR filter with M+1 coefficients is M/2.

Considering an FIR filter for the 4G base station with an impulse response as

$$h(k) = h(M-k) \quad (1)$$

where k= 0, 1, 2, 3, ……, M

The frequency response of the 4G BS filter will be the Fourier transform of its impulse response (IR), given as:

$$H(f) = \sum_{k=0}^{M} h(k)e^{-j2\pi k} \quad (2)$$

Expanding equation (3.10) and using the assumed symmetry of the filters' impulse response. h(0)=h(M), h(1)=h(M−1) ………. we have

$$H(f) = h(0) + h(1)e^{-j2\pi f} + h(2)e^{-j4\pi f} + h(3)e^{-j6\pi f} + \cdots + h(M-1)e^{-j2(M-1)\pi f} + h(M)e^{-j2M\pi f} \quad (3)$$

$$H(f) = e^{-jM\pi f}\left[h\left(\frac{M}{2}\right) + h(0)e^{jM\pi f} + h(M)e^{jM\pi f} + h(1)e^{j(M-2)\pi f} + h(M-1)e^{j(M-2)\pi f}\right]$$

$$= e^{-jM\pi f}\left[h\left(\frac{M}{2}\right) + 2h(0)\cos(M\pi f) + 2h(1)\cos((M-2)\pi f)\right] \quad (4)$$

Here it is assumed that the filter length M+1 is an odd integer. Hence the frequency response of the filter H(f) can be expressed as

$$H(f) = e^{-jM\pi f}\left[h\left(\frac{M}{2}\right) + \sum_{m=0}^{(M-1)/2} 2h(m)\cos((M-2m)\pi f)\right] \quad (5)$$

The term in the bracket is real-valued. The filter phase is the term $e^{-jM\pi f}$, and the filter phase response is given by

$$\emptyset(f) = \begin{Bmatrix} -M\pi f & if\ H_o(f) \geq 0 \\ -M\pi f + \pi & if\ H_o(f) < 0 \end{Bmatrix} \quad (6)$$

where the real-valued term inside the equation's bracket is represented by Ho(f). (6). As a result, the frequency variable (f) determines the phase response of a FIR filter with a symmetric IR. The phase shifts by π radians when the amplitude of the frequency response from equation (6) becomes negative.

Therefore, for a 4G base station with a symmetric impulse response, the transfer function of a finite impulse response filter can be rewritten as

$$H(z) = \sum_{m=0}^{M} h(m)z^{-m} = h(0) + h(1)z^{-1} + \cdots + h(M)z^{-M}$$
$$= h(M) + h(M-1)z^{-1} + \cdots + h(0)z^{-M}$$
$$= z^{-M}\sum_{m=0}^{M} h(m)z^{m} = z^{-M}H(z^{-1}) \quad (7)$$

From equation (7) the relationship between H and z emerges as H(z)= $z^{-M}H(z^{-1})$ which implies that if H(z) has a zero at z=z^1 then it must also have a zero at z=1/z^1.

Hence, the z-transfer function of a linear phase of the FIR filter can be given as

$$H(z) = G(1 - r_k e^{-j\emptyset_k}z^{-1})(1 - r_k e^{-j\emptyset_k}z^{-1})\left(1 - (\tfrac{1}{r_k})e^{-j\emptyset_k}z^{-1}\right)\left(1 - (\tfrac{1}{r_k})e^{-j\emptyset_k}z^{-1}\right) \quad (8)$$

Where $(1 - r_k e^{-j\emptyset_k}z^{-1})(1 - r_k e^{-j\emptyset_k}z^{-1})$ is the complex conjuage zero pair and $\left(1 - (\tfrac{1}{r_k})e^{-j\emptyset_k}z^{-1}\right)\left(1 - (\tfrac{1}{r_k})e^{-j\emptyset_k}z^{-1}\right)$ is the reciprocal zero pair

Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026

The radius and angular frequency of the kth complex pair of zeros are denoted by rk and ϕk, respectively. As a result, a linear phase filter's zeros appear in reciprocal pairs.

This is the proposed model for calculating the electromagnetic power density (S) using FIR filter

$$S = \frac{3(1-\rho)^2}{4\pi} F(\theta) \frac{EIRP_{max}}{x^2+h^2} = \frac{3(2.56)}{4\pi} F(\theta) \frac{EIRP_{max}}{x^2+h^2} \quad (9)$$

Where ρ (rho) is the coefficient of refection. The filter suppresses the power density with a factor of (1-∝) to give F(θ).

Table 2: Characterization of the 4G Base Station sites

SITE DATA	ITEMS	UNITS	BTS1	BTS2	BTS3	BTS4	BTS5	REMARKS
	SITE ID		UL001	UL002	UL003	UL004	UL005	
	ADDRESS		ICCU	Gate	Research Umudike	Ubakala park	Govt. House	
	TOWER HEIGHT	METERS (M)	28	28	37	37	28	
	ANTENNA HEIGHT	(M)	26	26	26	26	28	
TECHNICAL PARAMETERS	SYSTEM TYPE	LTE	LTE	LTEA	LTE	LTE	LTE	
	Base Channel freq	(MHz)	2500	2700	2500	2500	2500	
	Carriers/sector		3	3	3	3	3	
	Model of antenna		Ghe Ant P2	Ghe Ant P2	Ghe Ant P2	Ghe Ant P2	Ghe Ant P3	
	Antenna Gain	(dBi)	18.00	18.00	18.00	18.00	22.50	
	Total Tilt	(Deg)	22.5	25.0	22.5	22.5	25.0	
	Tx power	(dBm)	46	46	46	46	53	
	Antenna Loss/Unit length	(dBm)	3	3	3	3	6	
	EIRPmax	(dBm)	74.00	74.00	74.00	74.00	75.00	

3.0 Results

Table 3: Average Readings from five 4G Base Station Sites

Distance (m)	**E-Field (V/m)**	**M-Field (A/m)**	**Power density (S) W/sqr m**
10	37.83	0.100	3.756
20	18.91	0.050	2.708
40	9.46	0.025	1.281
60	6.30	0.017	0.680
80	4.73	0.013	0.411
100	3.78	0.010	0.273
120	3.15	0.008	0.193
140	2.70	0.007	0.144
160	2.36	0.006	0.110
180	2.10	0.006	0.088
200	1.89	0.005	0.072

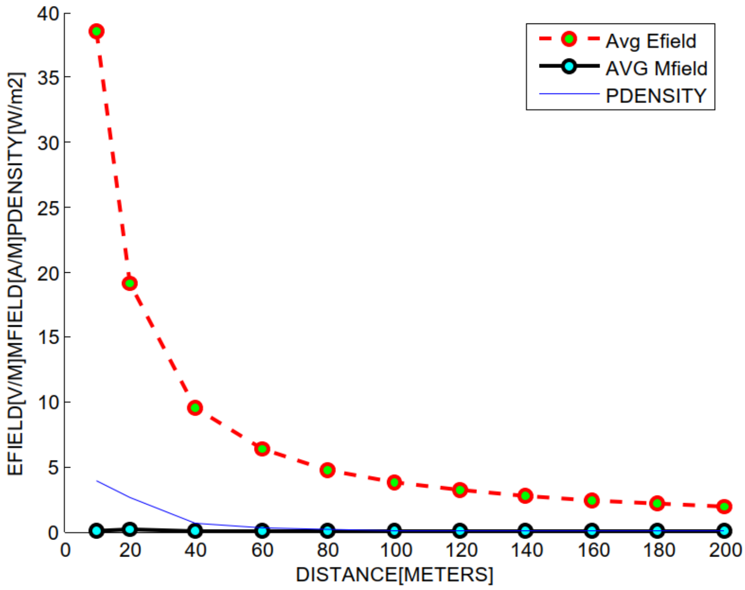

Figure 5. Average measured E-field, M-field with the site power density

Figure 5 displays the average power density, magnetic field strength, and electric field strength for 4G base stations as reported by the operator in Table 3. Both the magnetic and electric fields become weaker as distance increases. An area's electromagnetic intensity is determined by its power density.

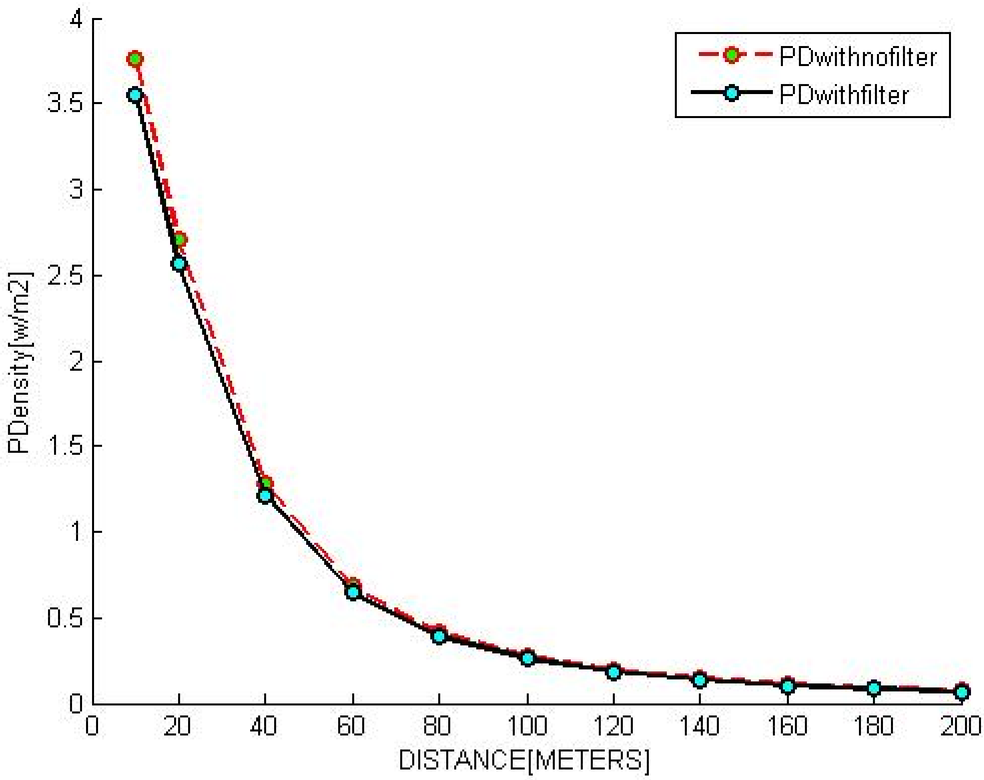

Figure 6: Power Density Values with filter and without filter for 4G Base Station Site 1

Table 3 and figure 6 shows the power density of 4G BS site 1 without FIR filter and with FIR filter. The results show that the introduction of an FIR filter reduced the electromagnetic (EM) power density. It was also observed that as the distance increases from the base station the electromagnetic power density reduces.

Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026

Table 4: Power density with filter and without filter for 4G base station site 2

Distance (m)	E-Field (V/m)	M-Field (A/m)	Power density (S) without F W/sqr m S	Power density with F(S) W/sqr m
10	37.82	0.101	3.755	3.552
20	18.92	0.050	2.708	2.562
40	9.46	0.025	1.280	1.211
60	6.31	0.017	0.681	0.645
80	4.73	0.013	0.412	0.390
100	3.78	0.010	0.273	0.258
120	3.15	0.008	0.193	0.183
140	2.69	0.007	0.144	0.136
160	2.36	0.006	0.111	0.105
180	2.10	0.006	0.088	0.083
200	1.89	0.005	0.072	0.068

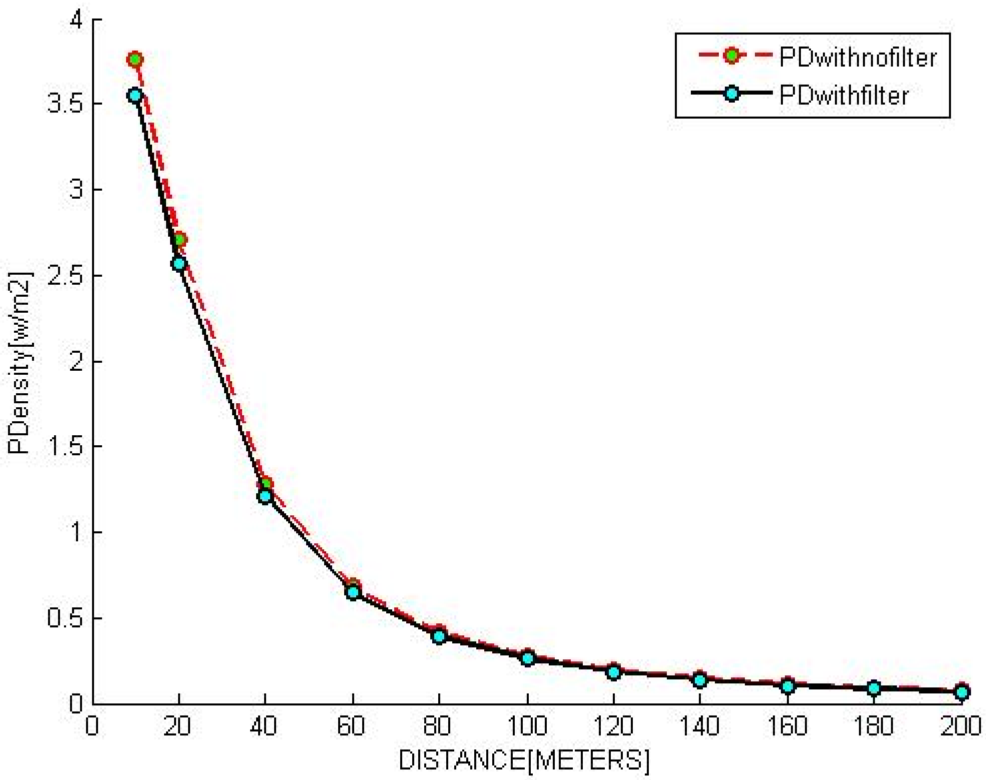

Figure 7: Power Density Values with filter and without filter for 4G Base Station Site 2

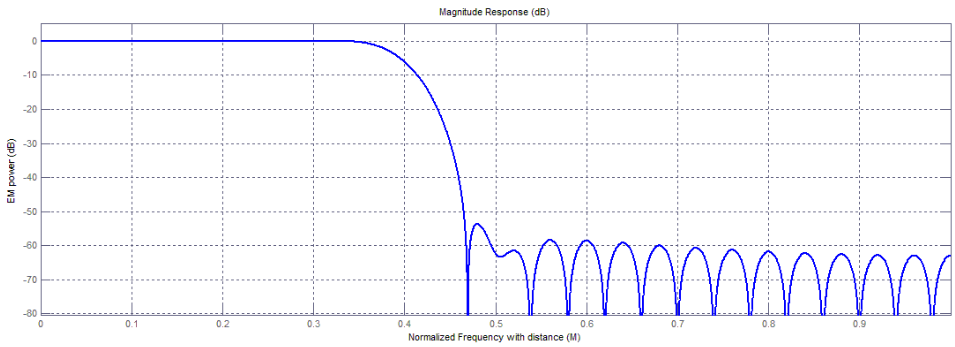

Figure 8: The Output of a filtered signal

Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026

4.0 Conclusion

When compared to a 4G base station without a filter, the performance of this FIR filter design produced better electromagnetic radiation. Additionally, this filter interface can be used to other switching devices, power converters, or EMI sources. Lastly, it will lessen the strength of the EM power density surrounding the base station.

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Received: 26/03/2026; Revised: 13/04/2026; Accepted: 17/04/2026; Published: 25/04/2026