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MATHEMATICAL ANALYSIS OF ELECTROMAGNETIC RADIATION EMIT FROM A CELLULAR BASE STATION

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ABSTRACT:-*The mathematical expressions for electric field, magnetic field and power density of electromagnetic radiation source, at the various distances, are derived and hence computed the field intensities and total radiated power of the particular source at a given distance. From these computed values, one can identify the hazardous level of Electromagnetic radiation. The computations of field intensities, radiated power with different Effective Radiated Power at different operating frequencies and different distances from the cellular base station are presented.*

Key words: *Power density, Electric Field Intensity, Directive gain, intrinsic impedance:*

I.INTRODUCTION:

Nowadays there is a tremendous increase in the number of mobile communications and broadcasting radio and TV systems. Obviously public concerns of repercussions of wireless phones, antenna masts and other environmental RF transmitters to the health have increased. There is a strong opposition to the acceptance of RF transmitters operation near or inside urban areas [1, 2, 4, and 6].
Cell phone technology has several advantages and has grown rapidly in the last decade. In India, there are nearly 100 crores cell phone subscribers and around 12 lakhs cell phone towers. Numbers of cell phones and cell towers are increasing without considering its disadvantages. All over the world, people have been debating about associated health risks due to electromagnetic radiation from cell phones and cell towers. There are several reports in the media and scientific literature, which are conflicting in nature. In West Bengal, cell towers are mushrooming all over the places. People have been complaining to West Bengal Pollution Control Board and other agencies regarding electromagnetic radiation from cell towers, structural stability, noise and air pollution from Diesel Generators (DG), etc. The new West Bengal Government, which came into power in May 2011 and happens to be people friendly, decided to look into cell phone towers radiation hazards in a scientific manner[3,5,7,8,9and10].

It is believed that a systematic and Mathematical analysis of the EM radiation can help to stop the mistrust of the public about its existing level.

II. THEORETICAL DERIVATION OF ELECTRIC FIELD AND MAGNETIC FIELD INTENSITY: RADIO WAVES

A radio wave is a type of electro-magnetic field and existed in nature before man came into existence. There are electro-magnetic fields of various frequencies from outer space reaching the earth besides the ultraviolet rays or visible light. Radio wave is not felt, but is something quite natural like the air or water. “Our relationship with radio waves for use in communication has over 100 years of history”.

The electric and magnetic fields are formed due to smooth motion of the charged objects. Here, energy is regarded as being transferred continuously through the electromagnetic field between any two locations. Electric fields come from the electric potential that is used to make electric current flow in a wire. Electric field occurs around a conductor, such as power transmission cable, electric line/wire when voltage is put in. The strength/intensity of electric field is expressed with the unit volt per meter (V/m). When there is an electric current in a conductor, a magnetic field is generated around it. The strength of the magnetic field is expressed with the unit ampere per meter (A/m).

Electromagnetic (EM) field intensity decreases greatly with distance. There are many variables involved in precisely calculating the anticipated intensity of an EM field from a given distance. To simplify the mathematics involved, it can be reasonably stated that the intensity of an EM wave, which is three-dimensional, decreases exponentially at a rate of approximately the square of the distance from its source. This is well known as the inverse-square law, expressed as a mathematical formula by Average power per unit area

$$P_{Avg} = \frac{P_t}{4\pi d^2} \qquad (1)$$

P_t = Transmitter power

The directive gain of Transmitter antenna (G_t) is given by

$$G_t = \frac{\text{power density}}{\text{Avg power per unit area}}$$

$$G_t = \frac{P_d}{P_{avg}} \qquad (2)$$

Therefore, the power density $P_d = G_t \times P_{avg}$ (3)

Where, the Power density is

$$P_d = \frac{\text{Received power}}{\text{Effective area of Receiving antenna}}$$

$$P_d = \frac{P_r}{A_e} \qquad (4)$$

Hence, the received power,

$$P_r = P_d \times A_e \qquad (5)$$

And, the gain of the receiving antenna (G_r) is given as,

$$G_r = \frac{4\pi}{\lambda^2} \times A_e \qquad (6)$$

$$\therefore A_e = \frac{G_r \lambda^2}{4\pi} \qquad (7)$$

On substituting the equation (3) in the equation (5),

$$P_r = G_t P_{avg} A_e$$

Substituting the expressions for P_{avg} and A_e, in the above equation,

$$P_r = G_t \frac{P_d}{4\pi d^2} \frac{G_r \lambda^2}{4\pi}$$

On simplifying this expression, using the equations (1) and (3)

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (8)$$

The power density, in terms of Electric(E) and Magnetic Field(H) strength, is given by,

$$P_d = \boldsymbol{E} \times \boldsymbol{H} \qquad (9)$$

And, the intrinsic impedance is given as,

$$\eta = \frac{\boldsymbol{E}}{\boldsymbol{H}} \qquad (10)$$

$$\therefore P_d = \frac{E^2}{\eta} \qquad (11)$$

And, hence, $E^2 = \eta P_d$

Substituting P_d from the equation (3) and (1)

$$E^2 = \frac{P_t G_t}{4\pi d^2} * \eta$$

The intrinsic impedance for free space is given by

$$\eta = 120 * \pi = 377\,\Omega$$

Therefore,

$$E^2 = \frac{120\pi}{4\pi} \frac{P_t G_t}{d^2} = 30 \frac{P_t G_t}{d^2}$$

As the Effective Radiated Power (ERP) of an RF source is given as

$$\mathrm{ERP} = \mathrm{P_t} \times \mathrm{G_t}$$

Thus, $E^2 = \frac{30 \times ERP}{d^2}$

On applying the Square root on both sides of this equation, $$E\sqrt{\frac{30 \times ERP}{d^2}} \quad (12)$$

Thus, the Electric Field Intensity of RF source is,

$$E\frac{5.47\sqrt{ERP}}{d} \quad (13)$$

III.ESTIMATION OF POWER DENSITY AROUND BASE STATIONS

The power density is the rate of flow of electromagnetic energy per unit area used to measure the amount of radiation at a given point from a transmitting antenna. This quantity is expressed in units of watts per square meter (W/m^2) or milli-watts per square cm (mW/cm^2).

The received power (P_r) from an RF source can be expressed as the product of the observed power density (P_d) at a distance from the RF source, and effective aperture area (A_e) of the receiving antenna.

$$P_r = P_d \times A_e$$

On simplifying the above equation, using the expression for Ae.

$$P_r = P_d G_r \frac{\lambda^2}{4\pi} \quad (14)$$

Substituting the λ as $\lambda = \frac{c}{f} = P_d G_r \frac{\frac{c^2}{f^2}}{4\pi}$

Where f is operating frequency

$$P_r = P_d G_r \frac{(3 \times 10^8)^2}{4\pi \times f^2} \qquad P_r = 7.16 \times 10^{15} \times \frac{P_d G_r}{f^2} \quad (15)$$

By taking the frequency in MHz,

$$P_r = \frac{7.16 \times 10^{15} \times P_d G_r}{(10\text{^}6)^2 \times f^2\ (MHZ)}$$

$$P_r = \frac{7.16 \times 10^{15} \times P_d G_r}{10^{12} \times f^2\ (MHZ)}$$

$$P_r = 7161.97 \frac{P_d G_r}{f^2\ (MHZ)} \quad (16)$$

The P_d value is calculated from the equations (11) and (13).And, the Gain of the receiving antenna is assumed as 4 dB.
The total power of the different RF sources operating with different ERPs at different frequencies is given as Total Power $P_{total} = (Pr_1 + P_{r2} + P_{r3} + \text{-------} + P_{rn})$ (17)

VI. RESULTS AND DISCUSSIONS ELECTROMAGNETIC RADIATIONS FROM DIFFERENT BASE STATIONS

From the theoretical derivations presented in the equations (1-17), the electric, magnetic field intensities, power density, the total radiated power are calculated at the various distances from a cellular base station operating with particular Effective Radiated Power (ERP) and at the particular operating frequency.

The following tables shows the evaluated results for electric and magnetic field intensities observed from the different base stations operating at different frequencies, determined at different distances. From the results, it is obvious that the values of electric and magnetic field intensities decreases with increase in the distance and hence the power density and received power.

Table 1 3/3/3 GSM single carrier f=900 MH$_Z$

ERP	d (m)	E (V/m)	H (A/m)	P_d (Watts/m^2)	P_r(Watts)	P_r (dBm)=10log$_{10}$(P_r)
28 watts	10	4.34	0.01115	0.0477	$1.33X10^{-03}$	-1.2047
	20	2.170	5.758	0.01249	$3.48X10^{-04}$	-4.60
	30	1.447	$3.838x10^{-3}$	0.00555	$1.53X10^{-04}$	-8.13
	40	1.085	$2.879x10^{-3}$	0.003123	$8.66X10^{-05}$	-10.62
	50	0.868	$2.302x10^{-3}$	0.00199	$5.3X10^{-05}$	-12.75
	60	0.7235	$1.919x10^{-3}$	0.001388	$3.63X10^{-05}$	-14.39
	70	0.620	$1.645x10^{-3}$	0.00102	$2.84X10^{-05}$	-15.45
	80	0.5426	$1.439x10^{-3}$	0.000781	$2.18X10^{-05}$	-16.61
	90	0.4823	$1.279x10^{-3}$	0.000617	$1.72X10^{-05}$	-17.632
	100	0.434	$1.151x10^{-3}$	0.000499	$1.39X10^{-05}$	-18.55
	150	0.289	$7.665x10^{-4}$	0.000222	$6.20X10^{-6}$	-22.07
	200	0.2170	$5.755x10^{-4}$	0.000125	$3.49X10^{-06}$	-24.56
	250	0.173	$4.583x10^{-4}$	$7.92X10^{-05}$	$2.21X10^{-06}$	-26.55
	300	0.144	$3.819x10^{-4}$	$5.49X10^{-05}$	$1.53X10^{-06}$	-28.14
	350	0.124	$3.290x10^{-4}$	$4.07X10^{-05}$	$1.13X10^{-06}$	-29.44
	400	0.1085	$2.879x10^{-4}$	$3.00X10^{-05}$	$8.3X10^{-07}$	-30.76
	450	0.0964	$2.559x10^{-4}$	$2.46X10^{-05}$	$6.87X10^{-07}$	-31.6
	500	0.0868	$2.303x10^{-4}$	$2.00X10^{-05}$	$5.58X10^{-07}$	-32.52
	550	0.0789	$2.093x10^{-4}$	$1.65X10^{-05}$	$4.61X10^{-08}$	-33.36
	600	0.07235	$1.919x10^{-4}$	$1.39X10^{-05}$	$7.12X10^{-08}$	-34.10
	700	0.062	$1.64\ x10^{-4}$	$1.01\ x10^{-5}$	$2.84\ x10^{-7}$	-35.45
	800	0.054	$1.43\ x10^{-4}$	$7.72\ x10^{-6}$	$2.17\ x10^{-7}$	-36.63
	900	0.048	$1.27\ x10^{-4}$	$6.14\ x10^{-6}$	$1.71\ x10^{-7}$	-37.65
	1000	0.043	$1.15\ x10^{-4}$	$4.95\ x10^{-6}$	$1.38\ x10^{-7}$	-38.59
	1100	0.039	$1.04\ x10^{-4}$	$4.08\ x10^{-6}$	$1.14\ x10^{-7}$	-39.42
	1200	0.036	$9.59\ x10^{-5}$	$3.45\ x10^{-6}$	$9.65\ x10^{-8}$	-40.15
	1300	0.033	$8.85\ x10^{-5}$	$2.92\ x10^{-6}$	$8.16\ x10^{-8}$	-40.87
	1400	0.031	$8.22\ x10^{-5}$	$2.54\ x10^{-6}$	$7.12\ x10^{-8}$	-41.17
	1500	0.028	$7.67\ x10^{-5}$	$2.14\ x10^{-6}$	$6\ x10^{-8}$	-42.21
	1600	0.027	$7.19\ x10^{-5}$	$1.94\ x10^{-6}$	$5.42\ x10^{-8}$	-42.65
	1700	0.025	$6.77\ x10^{-5}$	$1.69\ x10^{-6}$	$4.73\ x10^{-8}$	-43.38
	1800	0.024	$6.39\ x10^{-5}$	$1.53\ x10^{-6}$	$4.28\ x10^{-8}$	-43.67
	1900	0.022	$6.06\ x10^{-5}$	$1.33\ x10^{-6}$	$3.725\ x10^{-8}$	-44.28
	2000	0.021	$5.75\ x10^{-5}$	$1.2\ x10^{-6}$	$3.37\ x10^{-8}$	-44.71

Table 1 shows the computed radiated power at the distances ranging from 10 m to 2000 m for 3/3/3 single carrier with 28 Watts of ERP operating at 900 MHz frequency. From the table, it can be depicted that the radiation of the base station is more than -30 dBm within a zone of radius 400m from the base station; this zone is indicated as hazardous zone.

As the graphical interpretation of the data is more clearer than the tabular representation of the data, the computed radiation power values for the distance values upto 1 km, are represented graphically (using MATLAB 7.6) in the following Figures1 (a), (b), (c), (d), and (e).

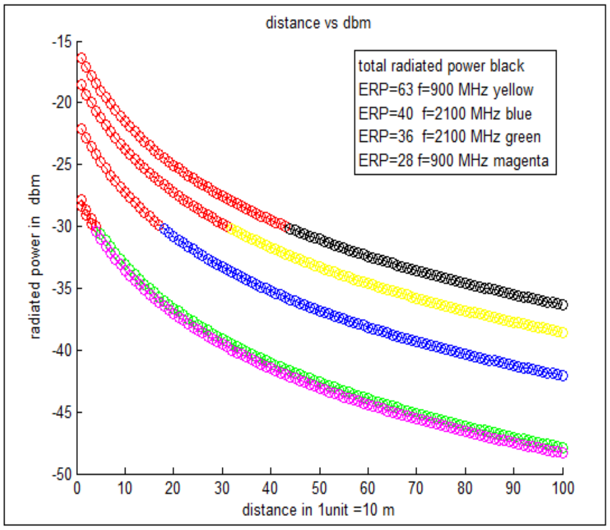

Figure 1 (a) Computed Radiation Power (dBm) of different cellular base stations with 63 W, 40 W, 36 W and 28 W of ERPs operating
at different frequencies

The Figure 1 (a) shows the the graph plotted between the calculated radiation power values and the distances upto 1 km, for the different cellular base stations with ERPs of 63 W, 40 W, 36 W and 28 W. From this figure, it is clear that, greater the ERP of the cellular base station, the more is radiated power from it. Also, the radii of the zones affected by hazardous electromagnetic radiation(danger level of radiation are indicated by red color), of the different cellular base stations are 300 m, 200m, 80 m and 70 m respectively. The total radiated power for these four base stations (assumed that they are colocated in a place) is hazardous with in the distance of 440 m from the base stations.

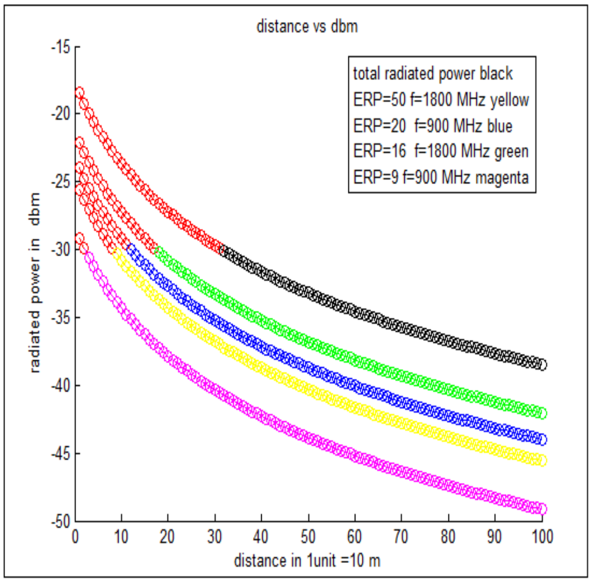

Figure 1 (b) Computed Radiation Power (dBm) of different cellular base stations with 50 W, 20 W, 16 W and 9 W of ERPs operating
at different frequencies

The Figure 1 (b) shows the the graph plotted between the calculated radiation power values and the distances upto 1 km, for the different cellular base stations with ERPs of 50 W, 20 W, 16 W and 9 W. From this figure, it is clear that, greater the ERP of the cellular base station, the more is radiated power from it. Also, the radii of the zones affected by hazardous electromagnetic radiation, of the different cellular base stations are 150 m, 120m, 90 m and 60 m respectively. The total radiated power for these four base stations (assumed that they are colocated in a place) is hazardous with in the distance of 300 m from the base stations.

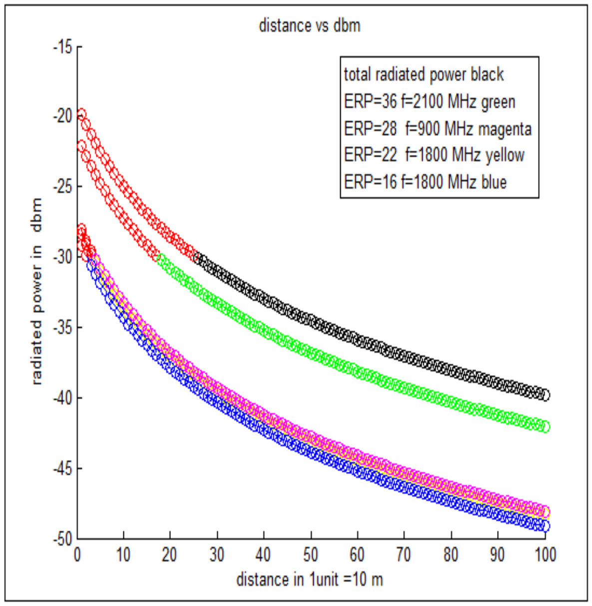

Figure 1 (c) Computed Radiation Power (dBm) of different cellular base stations with 36 W, 28 W, 22 W and 16 W of ERPs operating
at different frequencies

The Figure 1 (c) shows the the graph plotted between the calculated radiation power values and the distances upto 1 km, for the different cellular base stations with ERPs of with 36 W, 28 W, 22 W and 16 W. From this figure, it is clear that, greater the ERP of the cellular base station, the more is radiated power from it. Also, the radii of the zones affected by hazardous electromagnetic radiation, of the different cellular base stations are 130 m, 60m, 50 m and 40 m respectively. The total radiated power for these four base stations (assumed that they are colocated in a place) is hazardous with in the distance of 220 m from the base stations.

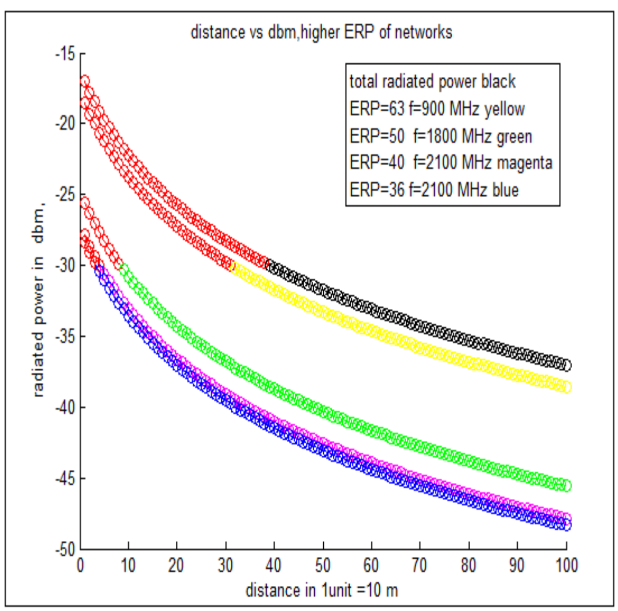

Figure 1 (d) Computed Radiation Power (dBm) of different cellular base stations with 63 W, 50 W, 40 W and 36 W of ERPs (Maximum Possible ERP values) operating at different frequencies

The Figure 1 (d) shows the the graph plotted between the calculated radiation power values and the distances upto 1 km, for the different cellular base stations with the maximum possible ERP values of with 63 W, 50 W, 40 W and 36 W.

From this figure, it is clear that, greater the ERP of the cellular base station, the more is radiated power from it. Also, the radii of the zones affected by hazardous electromagnetic radiation, of the different cellular base stations are 320 m, 100m, 60 m and 50 m respectively. The total radiated power for these four base stations (assumed that they are colocated in a place) is hazardous with in the distance of 400 m from the base stations.

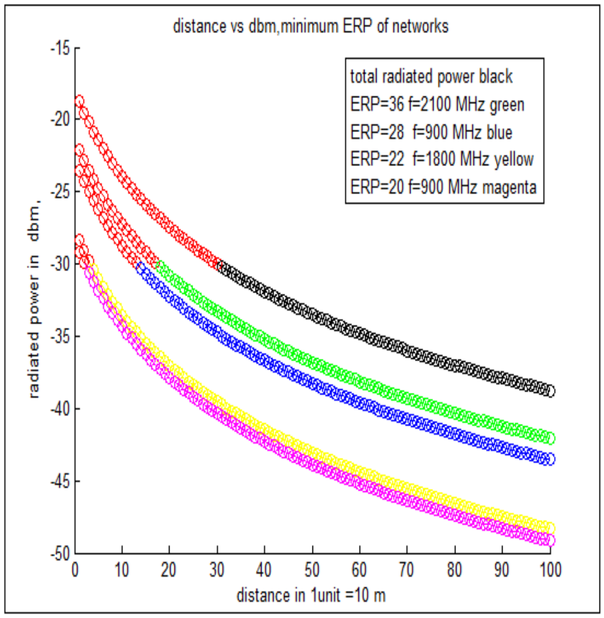

Figure 1 (e) Computed Radiation Power (dBm) of different cellular base stations with 36 W, 28 W, 22 W and 20 W of ERPs (Minimum Possible ERP values) operating at different frequencies

The Figure 1 (e) shows the the graph plotted between the calculated radiation power values and the distances upto 1 km, for the different cellular base stations with the minimum possible ERP values of with 36 W, 28 W, 22 W and 20 W. From this figure, it is clear that, greater the ERP of the cellular base station, the more is radiated power from it. Also, the radii of the zones affected by hazardous electromagnetic radiation, of the different cellular base stations are 180 m, 120 m, 70 m and 50 m respectively. The total radiated power for these four base stations (assumed that they are colocated in a place) is hazardous with in the distance of 280 m from the base stations.

From the figures 1 (a) – (e), the following observations are made.

1. The greater the ERP of the cellular base station, the more is the radius of the zone affected with hazardous level of radiation.
2. The total radiation of the co_located cellular base stations is more than that of the individual base station.
3. The total radiation of the base stations excited with high ERPs affects the wide area.

A cell tower ensures that mobile phones should receive adequate signal for its proper operation. A mobile phone shows, full strength at -69 dBm input power and works satisfactorily in the received power range of -80 to -100 dBm. The measured power level at R = 50 m is at least 50 to 60 dB higher, which translates to 100,000 to 1,000,000 times stronger signal than a mobile phone requires. There are millions of people who live within 50 m distance from cell towers and absorbing this radiation 24x7.

So far, the theoretical analysis of radiated power from a cellular base station is limited to distance of 2 km only. But, the communicating device like mobile phone can be operated even -90 dBm received signal power level, at which the range may be beyond 2 km. Hence, there is a need to study the radiation powers of the cellular base station with different configuration for the distances more than 2 km. Figure 3.3 represent the graphs plotted (using MATLAB 7.6) between the radiation power of cellular base station and the distance up to 10 km.

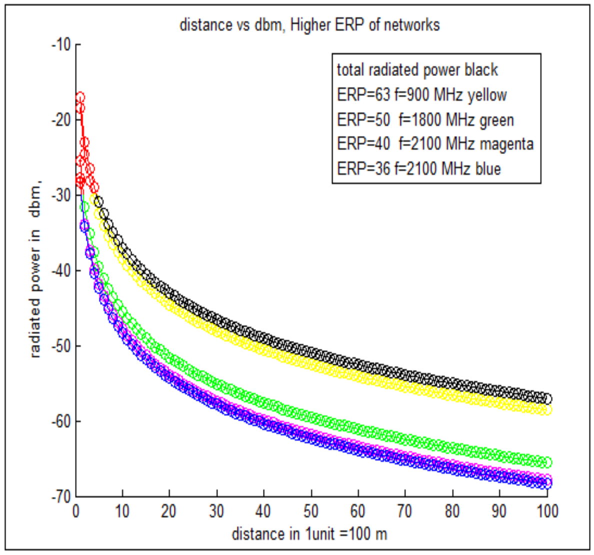

Figure 2 Computed Radiation Power (dBm) of different cellular base stations with 63 W, 50 W, 40 W and 36 W of ERPs operating at different frequencies for the distance upto 10 km.

Figure 2 shows the computed radiation power values of different cellular base stations with excited ERPs 63 W, 50 W, 40 W and 36 W for the distance upto 10 km. From this figure, it can be observed that the received powers from the different cellular base stations at 10 km distance are -56 dBm, -63 dBm, -65 dBm and -66 dBm and these powers are sufficient to be received by a mobile unit to perform communication satisfactorily.

V. **CONCLUSION AND FUTURE SCOPE**

CONCLUSION

The Mathematical estimation of the electromagnetic radiation level is done in the premises of a cellular base station. From the theoretical derivation of the received power from an RF source, the received power is computed for various distances from the cellular base station operating with different excited Effective Radiated Powers (ERP) at a particular frequency. The computed radiation values are interpreted as both tabular and graphical representation. The graphical representation of the received power is carried out for four cellular base stations by considering the distance up to 10 km; this specifies the radius of the zone affected with hazardous level of radiation. From the graphical interpretation of computed radiation power values with distance, it can be observed that the total radiation of co-located four base stations is more than that of the individual base station and hence, the radius of the zone affected with danger level for radiation of co-located four base stations is more than that of the individual base station.

FUTURE SCOPE

The theoretical analysis of electromagnetic radiation from the cellular base stations is carried out in this paper work is limited to the Cellular Network frequencies. The theoretical calculations of field intensities (E & H), power density and effective radiated power are carried out without considering the terrestrial configurations. If the terrestrial configuration is also taken into account, the degree of similarity between the theoretical computations and practical measurements.

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