National Centre for Radio Astrophysics

Internal Technical Report
ITR No. R257
Date: 4.3.2015

Proposed Visitor Centre: Study of RFI environment and site selection.

V.S.Shetty, S.K.Bagde, N.G.Kantharia, B.C.Joshi

vshetty@gmail.com,shailen@ncra.tifr.res.in,ngk@ncra.tifr.res.in,bcj@ncra.tifr.res.in

Objective: Study of theoretical RFI from proposed Visitor Centre and to define criteria towards site selection.

Contents

Abstract

This study addresses the issue of potential interference to GMRT antennas by the proposed visitor center. Theoretical approximations of impact of Radio frequency Interference (RFI) to the antenna array are made. RFI sources relevant to the proposed Visitor Centre are identified and their impacts on the astronomical observations are studied. Shielding and mitigation methods are examined to keep RFI in check under given constraints to keep the RFI close to -200dBw/m^2. The available plots are all assigned scores for RFI, security, plot area ,accessibility ,infrastructure. The plot with the highest score would serve as best plot for a Visitors Center.

1. **Introduction**

Under the 12th plan proposal on the User Community Development (UCD) a visitor center in proximity of GMRT to encourage curiosity in general public in the field of astronomy along with motivating youngsters and general public to pursue astronomy with greater interest has been proposed. The visitor center would act as knowledge hub for people of all ages keen about Radio Astronomy and astronomy in general. The visitor center has to be in close proximity [1] of the GMRT antenna array, and hence a study of possible Radio frequency Interference (RFI) was imperative. The theoretical power from possible noise sources is calculated and later the formula and variables used are modified to accommodate a more practical approach. The different RFI sources that will come with the visitors center are identified and studied to estimate their impact on Astronomical Observation. Architectural and other mitigation methods are studied to regulate the Radio environment. Finally a suitable plot of land for visitor center is selected based on all the required criteria.

2. **Review of Antenna/propagation terms :**

Antennas are characterized by a number of performance measures . To describe the performance of an antenna, definitions of various parameters are necessary. Important among these relate to the directional characteristics, resulting gain and field types. The antenna's power gain also takes into account the antenna's efficiency, and is often the primary figure of merit.
As we are concerned with power transfer we will study a few relevant parameters in brief.

2.1 Directivity

Is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. If the direction is not specified, the direction of maximum radiation is implied.

$$D(\theta,\phi) = \frac{\text{Power emitted into } (\theta,\phi)}{(\text{Total power emitted})/4\pi} \qquad (2.a)$$

2.2 Gain

It is the ratio of the power actually transmitted in the direction θ,φ to that which would be radiated if the entire available transmitter power were radiated isotropically

$$G(\theta,\phi) = \frac{\text{Power emitted into } (\theta,\phi)}{(\text{Total power input})/4\pi} \tag{2.b}$$

Gain parameter measures directivity of an antenna. An antenna with low gain emits radiation with about same power in all directions, whereas a high-gain antenna will preferentially radiate in particular direction. The gain G of the antenna is an actual or realized quantity which is less than the directivity D due to ohmic losses in the antenna. These losses involve power fed to the antenna which is not radiated but heats the antenna structure. A mismatch in feeding the antenna can also reduce the gain. The ratio of gain to directivity is the antenna efficiency factor. Thus,

$G=kD$

Where k=efficiency factor ($0<k<1$) dimensionless.

2.3 Effective aperture

The most important characteristic of an antenna is its ability to absorb radio waves incident upon it. This is usually described in terms of its effective aperture. The effective aperture of an antenna is defined as

$$A_e = \frac{\text{Power density available at the antenna terminals}}{\text{Flux density of the wave incident on the antenna}} \tag{2.c}$$

2.4 Radiation pattern

Are graphical representations of the electromagnetic power distribution in free space . Also, these patterns can be considered to be representative of the relative field strengths of the field radiated by the antenna. The figure below shows all the important parameters

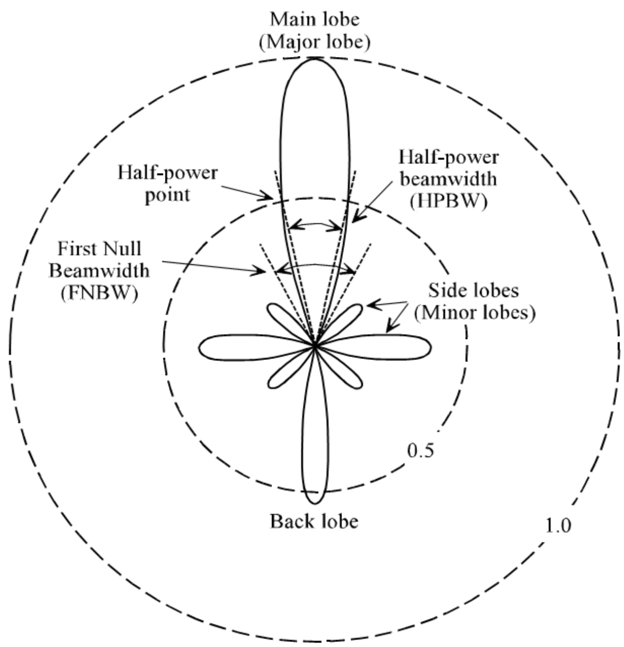

Figure 2.1: Radiation pattern

- Main Lobe (major lobe, main beam) is radiation lobe in the direction of maximum radiation.
- Minor Lobe-is any radiation lobe other than the main lobe.
- Side Lobe is a radiation lobe in any direction other than the direction(s) of intended radiation.
- Back Lobe is the radiation lobe opposite to the main lobe.
- Half-Power Beamwidth (HPBW) is the angular width of the mainbeam at the half-power points. Defined by IEEE as, "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam ".
- When the beamwidth is large the sidelobes are small and vice versa.
- First Null Beamwidth (FNBW) is the angular width between the first nulls on either side of the main beam. Two sources separated by angular distance equal to or greater than FNBW/2 ~ HPBW of an antenna with uniform distribution can be resolved. Hence it determines the antenna resolution

2.5 Antenna Field Types

The antenna field is divided into two types reactive and radiation field

- Reactive field is the portion of the antenna field characterized by standing (stationary) waves which represent stored energy, measuring field or receiving power from field causes changes in voltages/currents in source circuit(antenna). The shape of the field depends completely on source circuit.
- Radiation field is the portion of the antenna field characterized by radiating (propagating) waves which represent transmitted energy. Act of measuring field or receiving power from field has no effect on source. The shape of field is spherical waves; at far distances, field takes shape of plane waves.

2.6 Antenna Field Regions

- Reactive Near Field Region is the region immediately surrounding the antenna where the reactive field (stored energy – standing waves) is dominant.
- Near-Field (Fresnel) Region is the region between the reactive near-field and the far-field where the radiation fields are dominant and the field distribution is dependent on the distance from the antenna.
- Far-Field (Fraunhofer) Region is the region farthest away from the antenna where the field distribution is essentially independent of the distance from the antenna (propagating waves).The plane wave analysis is possible in farfield.

Rayleigh distance is the adopted criteria for plane wave analysis.To obtain perfect plain wave the range would have to be infinitely long, but for practical purposes it is usual to adopt a criterion such that the phase error at the edge of the curved wave front should not exceed π/8 radians.[4]

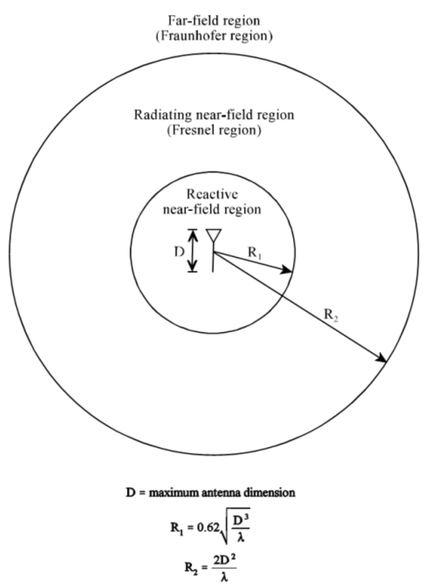

Figure 2.2: Antenna radiation field regions

3. **General formula for power transmission**

To calculate the power transferred between two antennas, generally the Friis transmission formula is used.

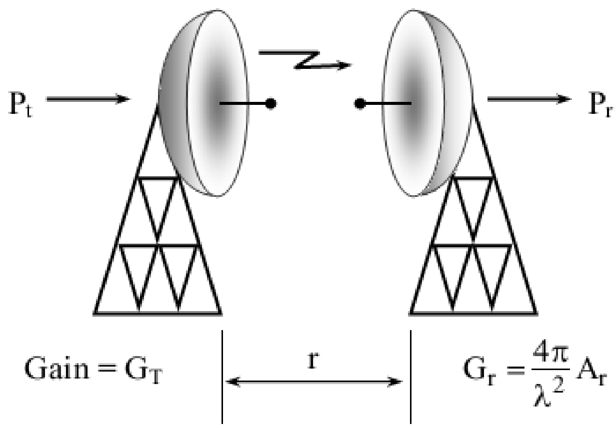

Figure 3.1: Ideally coupled transmitting and receiving antenna separated by distance ' r'.

To begin the derivation of the Friis Equation, consider two antennas in free space (no obstructions nearby) separated by a distance 'r':

Let the transmitter feed a power P_t Watts to the transmitting antenna. For the moment, assume that the transmit antenna is omnidirectional, lossless, and that the receive antenna is in the far field of the transmit antenna.

Then the power density P (in Watts per square meter) of the plane wave incident on the receive antenna a distance 'r' from the transmit antenna is given by:

$$P = \frac{P_t}{4\pi r^2} \qquad (3.a)$$

If the transmit antenna has an antenna gain in the direction of the receive antenna given by G_t, then the power density equation above becomes:

$$P = \frac{P_t}{4\pi r^2} * G_t \qquad (3.b)$$

The gain term factors in the directionality and losses of a real antenna. Assume now that the receive antenna has an effective aperture given by A_{er}. Then the power received by this antenna (P_r) is given by:

$$P_r = \frac{P_t}{4\pi r^2} * G_t * A_{er}$$ (3.c)

Since the effective aperture for any antenna can also be expressed as:

$$A_e = \frac{\lambda^2}{4\pi} * G$$ (3.d)

The resulting received power can be written as:

$$P_r = \frac{P_t\, G_t\, G_r\, \lambda^2}{(4\pi r)^2}$$ (3.e)

The above equation is known as the Friis formula and can be applied assuming the interference source as transmitting antenna if the interference source is in far field of the receiving antenna i.e distance

$$r > \frac{2D^2}{\lambda}$$ (3.f)

Where

r is distance between source and antenna
D is the largest linear dimension of antenna
λ is the wavelength.

4. **Propagation losses in terms of path loss**

We are interested in the frequency range of 50 MHz to 2000 MHz; the propagation of electromagnetic waves in this range is mainly by line of sight (LOS) propagation. There is occasional Sporadic-E propagation but this is severely influenced by environmental conditions.

In telecommunication, free-space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. It does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections.

Total path loss also includes many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas.

The basic path loss is already considered in the Friis formula, the $\left(\frac{\lambda}{4\pi r}\right)^2$ term represents path loss in equation 3.e. To calculate the basic path loss suffered by an electromagnetic wave of given frequency for the required distance, independent of the transmitting and receiving antennas the following formula can be used :

Path loss(dB) =32.45+20 log10 F MHz+20 log10dkm

The above formula is equivalent to $\left(\frac{\lambda}{4\pi r}\right)^2$ and is simplified to calculate path loss in dB.

5. Study of GMRT Parameters

The Giant Metrewave Radio Telescope (GMRT) consists of an array of 30 antennas. Each antenna is 45 m in diameter. The GMRT currently operates at 5 different frequencies ranging from 150 MHz to 1420 MHz. There are five bands altogether, 1000 – 1450 MHz, 610 MHz, 327 MHz, 233 MHz, 150 MHz [7]

For the Friis formula (3.e) to be applicable the condition $r = 2D^2/\lambda$ has to be satisfied i.e. interference sources should be in far field. For GMRT antennas diameter (D) =45m and frequency range of interest is from 150 MHz to 1450 MHz, substituting the value of D and wavelength λ for the 150 MHz in equation (3.f) we get
Distance

$r = 2D^2/\lambda$
$= 2*45^2/1.99$
$= 2.027$ km

Similarly for other feed frequencies:

Frequency (MHz)	Wavelength (m)	Field transition Distance (km)
150	1.9986	2.0
233	1.2866	3.1
327	0.9167	4.4
610	0.4914	8.2
1390	0.2156	18.7
1420	0.2112	19.1

The above results show that when functioning at 150 MHz the antenna near field extends up to 2.02 km while at 1420 MHz near field extends up to 19.1 km. As the antenna array extends to about 25 square km the visitor center plot might fall within the near field range of antennas at required frequencies. Hence we studied the literature to understand and examine a formula that will give good approximation in both near and far field. Below are the papers we examined.

6. **Selection of formula for quantifying RFI from the visitor center**

As already seen in section 2.5 and 2.6 it is clear that electromagnetic waves behave differently in near and far field of an antenna. In far field the ratio of electric and magnetic field intensities is simply wave impedance however, in near field electric and magnetic field can exist independently, and one type of field can dominate other. To obtain the formula applicable in the given case the following papers were studied one of the papers uses the formula giving power of the electromagnetic wave while, the other paper considers both electric and magnetic field separately to calculate output power.

6.1 *Study of Papers*

In the paper "Study of Near to Far Fields of JPL Deep Space Network (DSN) Antennas for RFI" by Vahraz Jamnejad, the author has used the following formula which is Friis formula used in standard link budget calculations.

$$P_r = P_t G_t G_{r\max} \frac{1}{(4\pi r/\lambda)^2} = P_t G_t G_{r\max} / L_s \qquad (5.a)$$

in which space loss is defined as

$$L_s = (4\pi r/\lambda)^2$$

Although the results gave a good approximation of the required values, author suggests further work to produce simple closed-form theoretical pattern models for the middle as well as near field regions is needed.

Another paper "A near Field Propagation Law& a Novel Fundamental Limit to Antenna Gain versus Size" by Hans Gregory Schantz. The author suggests that as electric and magnetic fields behave differently in the near field, they require different link equations. The following equations for separately calculating electric and magnetic field power were given.

Near field equation for electric field signal is:

$$P_E(d,f) = \frac{P_{RX(E)}}{P_{TX}} = \frac{G_{TX}\,G_{RX(E)}}{4}\left(\frac{1}{(kd)^2} - \frac{1}{(kd)^4} + \frac{1}{(kd)^6}\right) \tag{5.b}$$

And for magnetic field signal:

$$P_H(d,f) = \frac{P_{RX(H)}}{P_{TX}} = \frac{G_{TX}\,G_{RX}}{4}\left(\frac{1}{(kd)^2} + \frac{1}{(kd)^4}\right) \tag{5.c}$$

Where G_{RX} and G_{TX} are the receive and transmit antenna gains (respectively), d is the distance between the antennas, λ is wavelength, and k= 2π/λ is the wave number.

The author has derived near field propagation relations analogous to Friis's law and compared theory to experimental data. The above results were derived for comparatively small antennas operating in AM band, for the formula to be applicable "boundary sphere" condition has to be satisfied.

6.2 *Formula applicable*

When the formulas from both the papers were applied for given values the variations in the results were not very prominent. To get approximate value of power in our case the consideration of electric and magnetic field separately is not required. The antennas in paper I are parabolic antennas used in radio science while paper II has whip type antennas used for frequency tracking technology tested for AM band .Hence the formula in the paper I **(**Friis formula) is used, as the case is much similar to our requirement . The formula used is as follows

$$P_r = \frac{G_r G_t P_t}{(4\pi r)^2}\,\lambda^2$$

Where P_r is power received by antenna
P_t is power transmitted by source antenna
G_t is the gain of transmitter antenna
G_r is the gain of receiving antenna
r is the distance between two antennas
λ is the wavelength.

6.3 *Theoretical calculation*

Let us assume the gain of interference source G_t=1.99 (3dB, general cellphone antenna gain),the power transmitted from interference source be P_t=1 watt (worst case condition) and distance between the interference source and antenna r=500m.The gain of receiving antenna was calculated using the formula:

Gain= ή (πD/λ)^2

Where ή = aperture efficiency

D = diameter of the antenna

λ = wavelength

At 153 MHz (λ=1.9594) gain of antenna G_r=3394.1119 (calculated for 150 Mhz)

Substituting the values in Friis formula we get

$$P_r = \frac{3394.1119*1.99*1*1.9594^2}{(4*\pi*500)^2} = 6.5856*10^{-4} = -1.8140 \text{ dBm}$$

Similarly when the distance r = 1000m P_r = -7.8346 dBm

When the formula was similarly applied for required frequencies for distance of 500m and 1000m the received power obtained is as shown in the following table. The gains are estimated assuming the primary beam is directed at the RFI source which is generally not true. Hence these are the worst case scenarios. Generally RFI is picked up by GMRT antennas through sidelobes and hence the gain should be assumed to be 1.Anyway for comparison we included this worst case scenario.

Frequency (MHz)	Gain	Distance (m)	Received Power (dBm)
153	3394.1119	500	-1.8140
		1000	-7.8346
233	7859.9298	500	-1.8206
		1000	-7.8412
327	15792.0456	500	-1.7348
		1000	-7.7554
610	40671.4467	500	-3.0421
		1000	-9.0627
1420	189260.8373	500	-3.7074
		1000	-9.7239

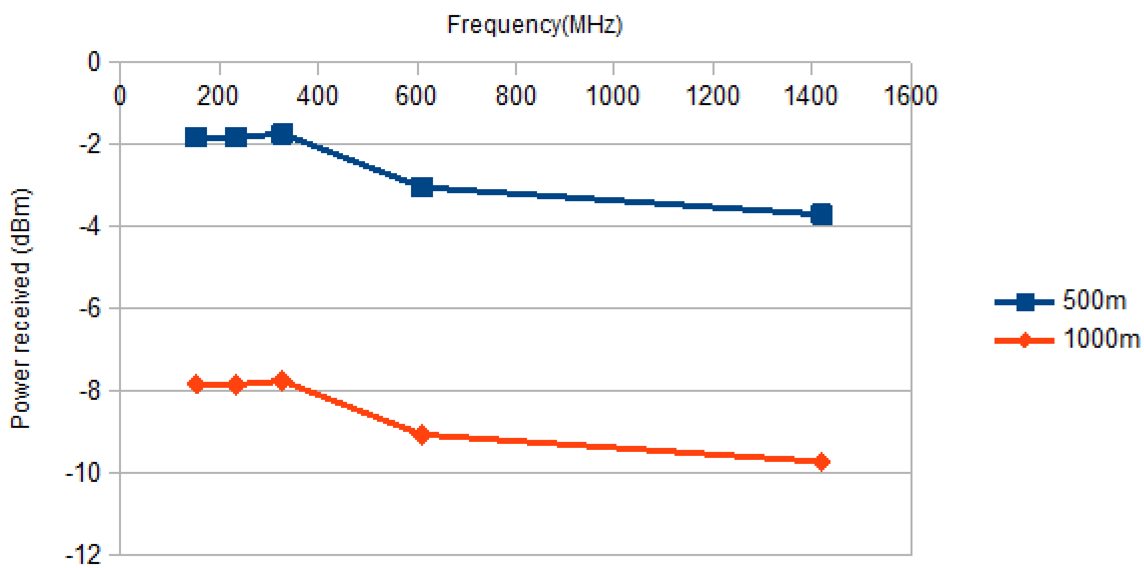

Figure 6.1 : Plot of received power varying with frequency and distance

The above graph plotted for two distance value of 500m and 1000m shows the variation of the received power (dBm) with different frequencies at given distances .However it is important to note that as the frequency changes the gain of the antennas also vary. This is assuming the main lobe is directly pointed at the RFI source.

7. Potential noise sources around the GMRT observatory

In radio astronomy, highly sensitive radio receivers are used to detect and study weak celestial radio emissions. The earth's atmosphere is transparent to electromagnetic radiation from 20MHz to 300GHz; an important limiting factor is manmade RFI. These radio interferences are often much stronger than the weak noise type celestial radio emissions, and therefore may cause serious distortion to the data. So the ground based radio astronomy observatories, co-existing with surrounding radio interfering environment have to monitor the ambient radio environment to ensure reliable observation data.

The proposed visitor center will lead to increase in the number of mobile phone users, electronic equipment and systems. There are various sources of RFI radiating in different frequencies, but for the frequency bands of interest following sources and their estimated severity is to be considered:

- Cellular phones
- Electronic equipment
- Automotive

7.1 *Cellular phones*

The technological advancement and accessibility has led to phenomenal growth in number of cell phone users. When a cell phone is used it radiates signal to the base station in range, the base station responds by assigning it an available radiofrequency channel, once the required connection is established signals carrying the data are then relayed back and forth. In India, mobile phones operate in the frequency range of: [8]

- 824 - 894 MHz (CDMA)
- 890 - 960 MHz (GSM 900)
- 1710 – 1880 MHz (GSM 1800)
- 1920 – 2170 MHz (3G)

Compared to analog mobile phones which were used previously, digital phones (2G and onwards) use less power. The digital phone uses an average of 0.25 watt compared to the 2 watts that was used by analog phones. The amount of power transmitted by digital phones is automatically adjusted to the minimum radio signal level needed for a reasonable call quality and efficient utilization of battery power. SAR (Specific Absorption Rate) is specified to control the power radiated by the mobile device. Modern cell phones also have features like Bluetooth, Wi-Fi, and NFC which may also add to the RFI.

The exposure limit for the radio frequency field (Base station) emissions prescribed by the Department of Telecom, Government of India, is as below:

Type of Exposure	Frequency Range	Power Density (Watt/Sqmtr)
General Public	400-2000 MHz	f/2000
	2-300 GHz	1

f: frequency in MHz

The prescribed safe RF exposure limit is f/2000 (in India), where f is in MHz

Exposure limits in India are:

At 900 MHz, power density is 0.45 watt/m^2 and

At 1800 MHz, power density is 0.9 watt/m^2

A test was conducted at NCRA Pune campus to estimate the activity in the cellular communication bands . A Micronix MSA338 portable spectrum analyzer was used to make measurements. Constant spectral activity was observed in the following bands 869 MHz-894MHz, 927 MHz-968 MHz, 1805 MHz -1880 MHz and bands which are down link bands for CDMA , GSM900, GSM1800 and 3G band respectively. The magnitude of noise in the downlink frequency band was measured with noise floor at -100 dBm,the power peaks reached upto -70 dBm except for GSM 900 where it slightly exceeded -70 dBm but stayed below -60 dBm . When a mobile phone was active the peak power radiated in narrow bands within uplink range of 824 to 849 MHz(CDMA), 890 to 915 MHz (GSM900), 1710 to 1780 Mhz (GSM1800) and 1920 – 1980 MHz (3G) which reached well above- 60dBm. When multiple phones were active radiations upto -10 dBm were observed in uplink band. It is important to note that the power of the devices was observed at about 30cm hence there were minimum propagation losses and the radiation from the internal electronics circuit could not be isolated. Thus mobile signals were found to severely affect frequencies between 820 to 1000MHz making this band unusable. Similar results were observed by the RFI group in GMRT premises as documented in the report “Study of RFI ambience in and around GMRT” by Vaibhav Savant, ShrikantBhujbal.

7.2 *Electronic equipment*

Electronic devices can cause interference to radio observation as they generate electromagnetic radiation. Numerous electronic devices are used in the GMRT premises, to avoid RFI due to this device they are selected only after they pass the required RFI tests. Electronic equipment is generally placed in a shielded enclosure but this may not possible at all times. Here we note some electronic devices which generate RFI so that their use in the visitor centre is optimized and, appropriate shielding as recommended by GMRT RFI group are implemented.

Lab instruments:

Any signal generators or lab instruments that contain (micro) processors or high speed digital electronics potentially generate RFI. It is therefore mandatory that instruments are switched off at the end of the day or when not actually in use. An example is a Power Analyzer, appears to generate particularly much RFI ~800 MHz[13]

LAN Switch:

Usually in switches a plastic housing with not much shielding metal inside is unable to prevent the high speed digital backplane from radiating. Having a lot of UTP (Unshielded twisted pair) cables connected to the device also leads to problems. As the number of switches used increases the background noise level also increases. A report from RFI team shows that switches may change the noise floor level up to 7 dB. The noise from the switches is more prominent in 0 – 500 MHz range .The report recommends use of Shielded CAT5 cables to regulate the RFI.[15]

LAN UTP/Fiber converter:

Although optical fiber is intended to reduce RFI, fiber LAN converters can be a source of RFI. Several discrete peaks were observed by RFI group at GMRT in 0 – 2 GHz and broadband disturbance was observed in 150- 850MHz. The interference was found to be prominent in 1-2 GHz .The radiations peak of about -50dBm were observed. Suitable shielding decreased the radiations to acceptable levels as per the test carried out by RFI team at GMRT.

Computing Equipment:

Personal computers, desktops, workstations, notebooks, can be found everywhere. Even though they cause interference they are necessary. It is the aggregate of computers of differing brands, speeds and quality standards that raise the level of the background noise. Computer speeds are ever increasing. Internal CPU speeds reach clock frequencies of several GHz. From these chips not much EMI emanates because of the very small radiating structures and relatively small internal voltage swings (dV/dt). Front side bus (FSB) speeds of 400 MHz and above are more damaging, because of the longer leads on the PC's motherboard that carry this frequency. Internal connections to storage devices will also contribute significantly to the overall EMI.[10]

Test on laptop by the GMRT RFI team showed radiations in 100 – 300 MHz most of which are broadband fluctuations of the noise floor. Some high level radiations changed the noisefloor level by 15 dB.[16]

Computer monitors:

CRT screens have been known to be radiating interference signals. LCD screens were assumed to be less of a problem. Sometimes even LCD screens are found to be radiating due improperly shielding of internal microprocessors or digital logic. The radiation from monitors is broadband and is prominent in 100 - 380 MHz .The magnitude of such noise signals can be about 10dbm above the noisefloor .

Uninterruptible power supply(UPS) ,Power supply :

Switch mode power supplies (SMPS) generate noise as a direct consequence of the switching process. An ideal switch provides infinite resistance when open, when closed it provides a zero resistance path for current to flow without any voltage drop. An ideal switch would control conduction of high speed pulsed waveform without adding any transients events or voltage spikes. But, real switches don't change states instantaneously and require some interval called as rise time and fall time. These transitions can lead to distortion in harmonic components of the high frequency switching waveforms. The switching process produces voltage spikes resulting in RFI which is above 100 MHz. The spikes are caused by short duration charging and discharging of parasitic components in the power supply circuit.

A study of SMPS based power supplies by GMRT RFI team notes that it can radiate causing changes in noise floor level by about 17 dB in the 30-300 MHz frequency ,while in the 500 – 2000 MHz band discrete peaks were observed with magnitude upto -60dBm.[17]

A DC power supply tested for RFI by RFI team found that it had radiation within permissible limits.[18]

An Uninterruptible power supply (UPS) uses inverters to convert DC to AC .There are also different circuits , processors, relays etc. in the system, which can lead to RFI. UPS tested by RFI team were found radiating in frequency range of 30 – 300 MHz, some were also found to increase noise floor level by 16 dB.[19]

7.3 *Automotive*

Vehicles have ignition systems, alternators, motors and electronic equipment that radiate in various ranges of frequencies .Some are broadband while others are narrow band noise signals. The noise from ignition system, pulse type and brush type motors are broadband while others like microprocessors come under narrowband. The problem of automotive RFI can be solved by using correct wiring methods, split beads and proper shielding. Few of the major causes of RFI are mentioned in brief below:

Ignition and fuel injection systems:

The ignition system uses high voltage pulse applied through spark plugs to start the engine. As ignition signals are pulses which practically they have a finite rise time so the spectral energy envelope decreases above some frequency. This type of RFI typically extends from 30 MHz to 1 GHz.

Fuel injectors used in vehicles utilize an electromagnet (solenoid)and when their field collapses that is power is shut down to them they emit electrical pulses .These pulses are similar to ignition pulses but are slightly narrower in bandwidth.

The ignition spark generated noise and fuel injector noise manifest themselves as “ticking” in radio receiver audio outputs also their frequency varies with engine RPM.

Electronic Control Unit (ECU):

ECU is a generic term for any embedded system that controls one or more of the electrical system or subsystems in a motor vehicle. The ECU consists of microprocessors, as already discussed above microprocessors need clock signals in the form of square waves to function. The clock frequency may be further divided which leads to harmonics above or below the clock frequency. This emission can be observed in time domain in the form of distorted sine wave.

Data Bus are used to communicate between various sensors and processors used in the system. The various sensors and controllers use ISO-defined networking to transfer data between them. These data buses use various frequency for communication which may lead to generation interference signals.

Other devices including sound systems, navigation systems, data recorders, pulse width modulation controlled devices etc can also cause RFI.

Hybrid/Electric vehicles produce more EMI comparatively, experiments found peak 40 dBµV/m in the frequency range 30-85MHz.

A test was conducted in GMRT to check RFI from automobiles. The bikes which were tested radiated throughout the 100 MHz to 2 GHz band with peaks upto -50dBm. A diesel car tested radiated in 450-550 MHz band but the magnitude of the highest peak stayed within 10 dBm from the noise floor. A diesel bus tested had very negligible radiation from the engine but when the internal devices like lights and fans were switched on, the noise floor rise of upto -40 dBm was observed, this could be because of the DC motors used in the fans installed in the bus. A petrol car used radiated in 200-400 MHz, a few discrete peaks were observed around 950 MHz and 1700 –1800 MHz band the highest magnitude of peak was about -60 dBm. Only one petrol car was used for measurements hence the encouraging result cannot be generalized as petrol vehicles are known sources of RFI caused by spark plug in ignition systems [22].

8. Experimental studies of RFI from the visitor centre location

After study of the possible RFI sources that could come up with the visitor center, a practical approximation of the effects of radiation from RFI sources to antennas was required hence an experiment was devised. The aim was to study the minimum magnitude of power required to be radiated from any noise source in order to be detected by spectrum analyzer recording the output of a GMRT antenna. . The experiment is detailed in the report "Effect of RFI on GMRT frequency bands" by S.Sureshkumar,Pravin Raybole,Shrikant Bhujbal .A signal was transmitted using an antenna connected to a signal generator and the GMRT antenna was used as a receiver. The signals were transmitted at feed frequencies and the power was lowered from 13dBm (maximum) in steps till signal was no longer visible above the noise floor at the receiver. The lowest amount of power which could be detected at receiver for the given frequency was noted as the least power required to affect any astronomical observations. The following graph shows the results obtained.

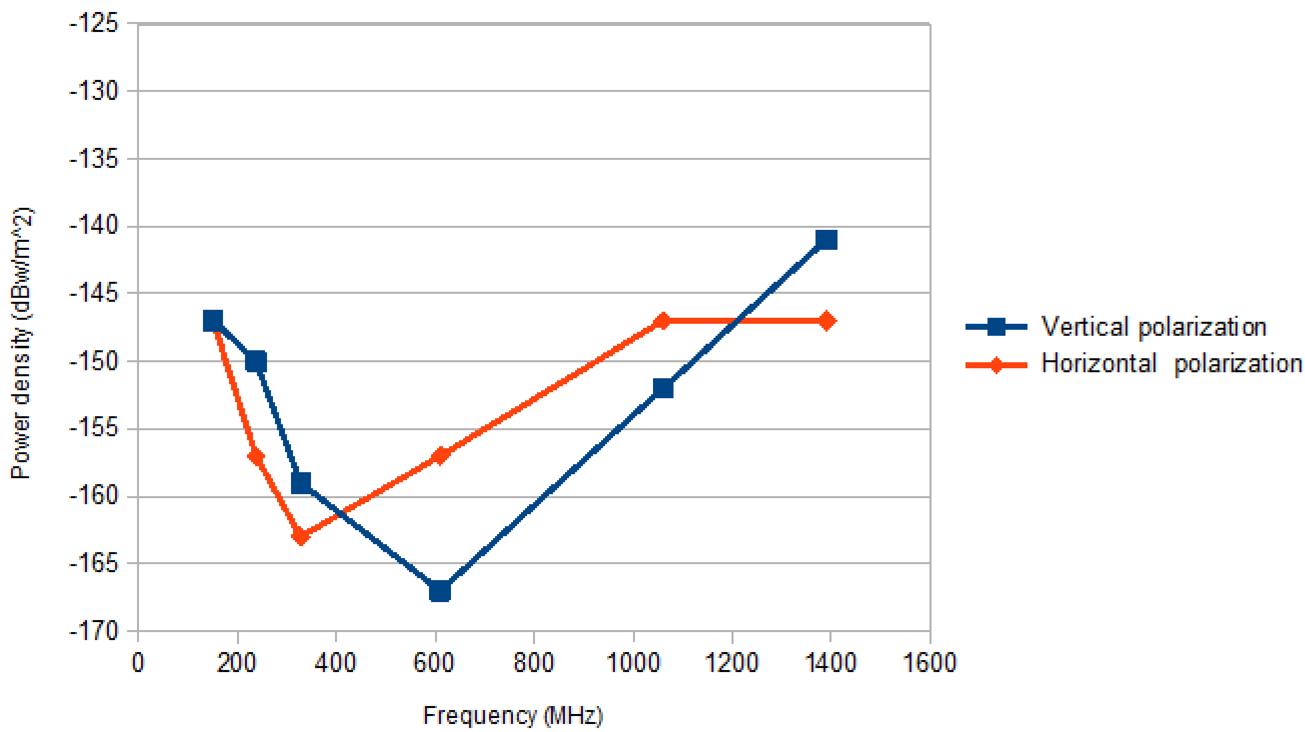

Figure 8.1:Power received for each feed frequency with different polarization

As seen from the graph the lowest transmitted power that can cause disturbance is about -167dBw/m^2 (-60 dBm) for the 610 MHz band .So it can be assumed that the radiation from all noise sources at any frequency below this power level from the given radiation should be harmless to Radio observations . It is to be noted that the experiment was performed for the astronomical bands where RFI filters are not installed and using a single GMRT antenna practice, interferometers which are sensitive to this common signals will help reduce the detected RFI.

We also note that a 40dB shielding around the building and shielded enclosures for electronic items will be able to ensure a RFI –quiet zone.

To further study the effects on RFI environment of GMRT when many visitor are allowed at GMRT, a test was performed during the Science day program in February 2014 . Few of the GMRT antennas(C01,C02,C06,C09) were pointed with minimum elevation in the direction of exhibition ground and the data was recorded. Three feeds 150, 325 and 1060 were used to collect the data. There was a general rise in power of about 5 to 10 dBm in 150 and 325 MHz bands while it is higher in the 1060 MHz band likely due to proximity of cellular communication bands. The most significant RFI observed during science day was in the 1060 MHz band. For details of experiment please refer Appendix B.

9. Revised formula for quantifying RFI from the visitor centre

The formula used in section 5.4 was modified to accommodate the practical aspects as per the note by Professor G.Swarup. For practical calculation the gain of the antenna can be assumed to be 1 as the RFI will be picked up by the side lobes and not the main lobe. The amplitude of the RFI sources was derived from the FCC regulation which is 6.28x 10^{-8} dB for a FCC certified electronic device. The equation is same as equation 3.c used in section 3 of the report which is as follows

$$P_r = \frac{P_t \times G_t \times A_e}{4\pi r^2} \text{ dB}$$

The above equation gives the power, to find the power density the following formula can be used

$$P_d = \frac{P_t \times G_t}{4\pi r^2} \text{ dBw/m}^2$$

where

P_r is power received by antenna
P_t is power transmitted by source antenna
P_d is power density
G_t is the gain of transmitter antenna
A_e is the effective aperture
r is the distance between two antennas

If we consider 30 FCC certified electronic devices each with unity gain kept in the visitor center. If the visitor center is at distance of 850m from nearest antenna power received will be
P_r= -131 dB and power density P_d= -126 dBw/m^2.If shielding of 40 dB is achieved the power density will further decrease to -156 dBw/m^2.

10. Study of architectural methods for RFI control

As many electromagnetic wave emitting devices will be used in the center a few architectural shielding measures are necessary to reduce their impact on radio observation.

The attenuation provided by an RFI shield depends on the following mechanisms

Incident energy is reflected by the surface of the shield because of the impedance discontinuity of the air-metal boundary. This method does not require particular material thickness, but simply material discontinuity.

Energy that does cross the shield instead of getting reflected is attenuated as it is converted into heat while passing through the shield.

The energy that passes through the shield encounters another air metal boundary hence some of it is reflected back.

The relationship for shielding effectiveness of a conductive material is typically expressed as follows:

$SE = [R + A + C]$ dB

Where

R = reflection loss

A = absorption loss

C = correction term for re-reflection within the metal surfaces

The correction term (C) is usually of small magnitude and ignored when the absorption loss (A) is greater than about 10 dB.

The following are the important parts of a RFI shielded structure:

10.1 *Doors*

The door is the most important opening in the shielded enclosure, it is generally the weakest link in the enclosure and most difficult to maintain due its high usage. It is precision device and should be designed and manufactured in such a way that it maintains its electrical and mechanical function under most demanding circumstances that it might encounter. The important features of RF door are that a metal to metal seal must be obtained around the perimeter of the door opening. The seal must be maintained for thousands of door operation with minimum maintenance. When shielding above 60 dB is expected there must be two rows of contacts. We shall consider a few types of doors as follows:

The Recessed contact mechanism (RCM) or knife-edge door

These doors can give shielding up to 120 dB when double knife edge is used .The advantage is the RF seal is recessed hence protected from wear and tear. But the construction tolerances are very tight to keep the doors aligned properly. Periodic maintenance is required.

The Compression Door

A variety of this type of door is commercially available. The door frame is designed to be very flat, and two rows of finger stock are mounted on face of door leaf. The door is mounted on three or four heavy hinges 'and the door is closed using a very heavy rack and pinion closing mechanism that clams the door leaf against the door frame. The advantage of this type is the ease of use .Its disadvantages are the height of the door sill, the exposed fingerstock that may get caught in clothes and break off, and the weight of the door. Places where high traffic is expected a vestibule with two doors provides better results.[25]

10.2 *Heating and Air conditioning*

One major penetration that must be considered is how to handle the need for air conditioning within shielded enclosures. Honeycomb vents, with an inch of thickness are used for shielding against this type of penetrations. Over 100 dB attenuation is achieved upto 30 GHz with 3/16in. Cell size. For very high performance installations (120dB) a composite of brass and steel is used.[25]

10.3 *Piping*

Pipe penetration in shielded enclosure must be designed in such a way that metal to metal contact is achieved at the point of penetration. The size of the piping and the method of its termination inside the enclosure is very important in maintaining overall shielding effectiveness.

Electromagnetic energy will pass through the pipe that is large in terms of wavelength and will provide leakage path into the enclosure unless proper design procedure is followed. If the piping is continuous and completely sealed, such as gas or water pipe inside the enclosure, then it only requires metal to metal seal at the wall entrance to the shielded enclosure, regardless of the pipe size. In very high performance enclosures, it may require that all the pipe joints be welded or soldered rather than using plumber's dope or Teflon tapes in pipe joints since normal method of sealing fail to provide high performance RF seal.[25]

10.4 *Shielded windows*

The use of shielded windows must be limited as they are expensive. Generally they are limited to low frequency low performance application .Two types of shielded windows are commercially available. The most common form is the sandwich design made of copper screen and glass or plastic. The screen must be well attached to the window frame and the frame should be bonded with surrounding shield. Two layer of copper screening are best with different threads per inch. The second type is conductive vapor-deposit metal type which reflects the electromagnetic energy.

Copper screening provides a higher degree of shielding effectiveness than does the continuous film system. For same degree of optical transmission at the lower frequencies it goes down in performance in plane wave region. The disadvantage of mesh is that it forms a Moiré pattern which can be objectionable to the viewer. The following graphs help to understand the performance of film material [25]

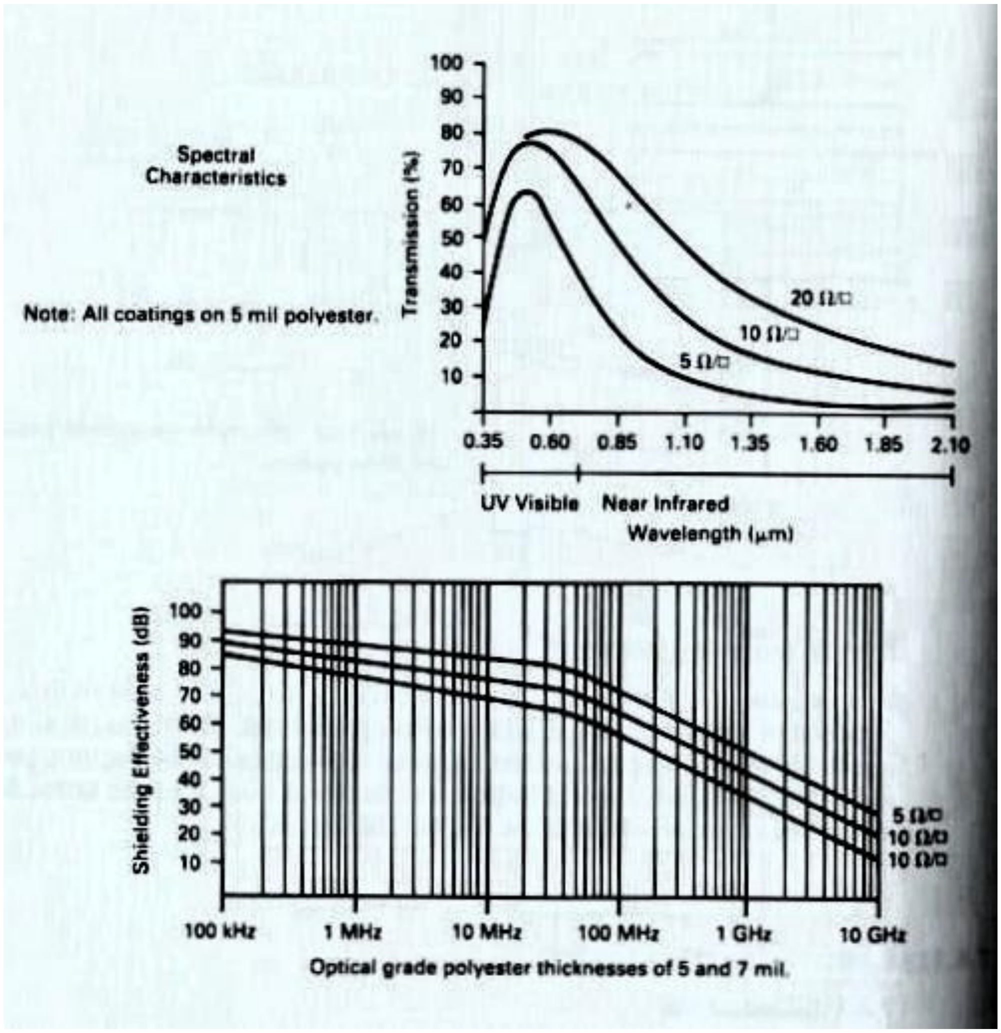

Figure 10.1:Shielding effectiveness of continuous film window material. [25]

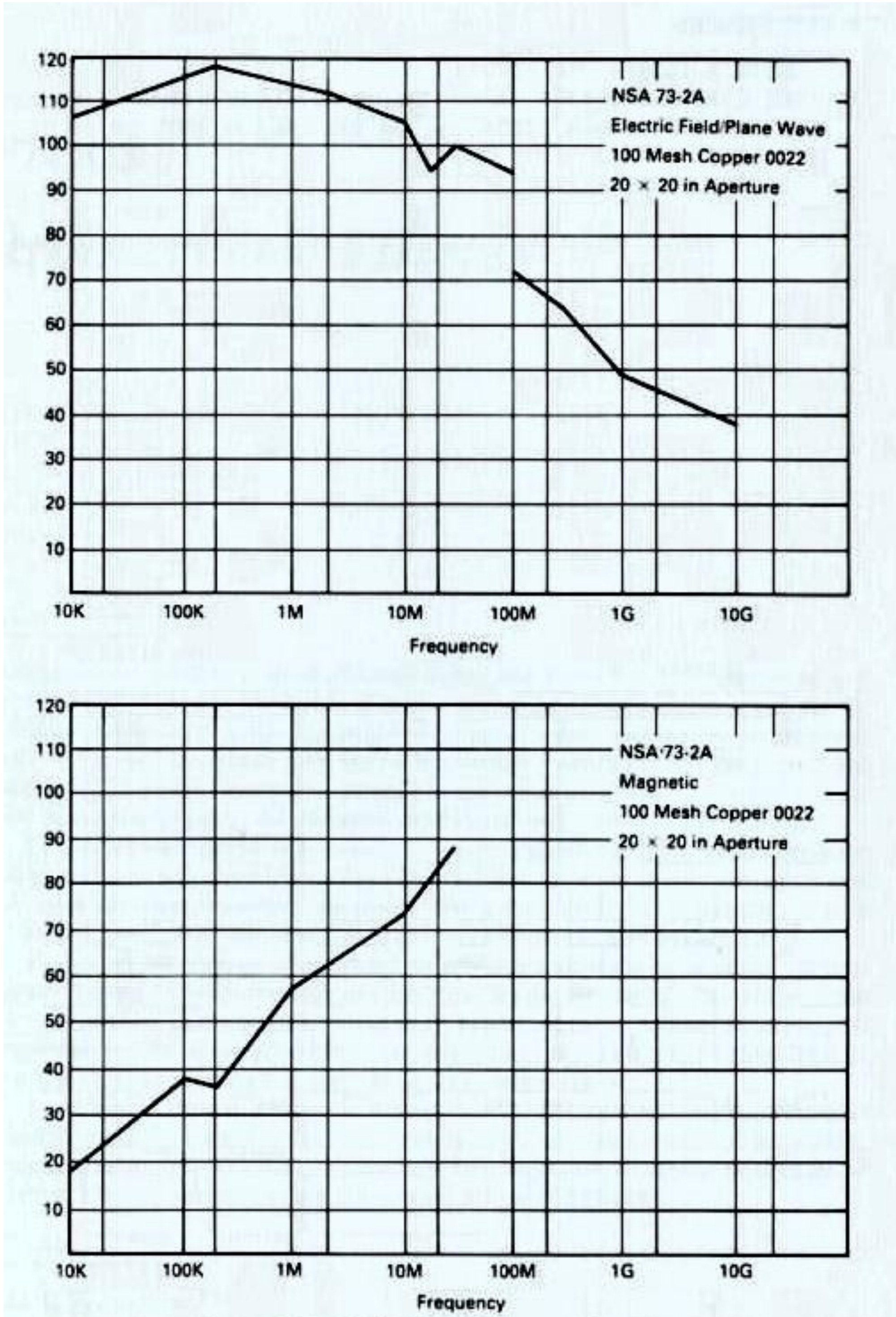

Figure 10.2: Shielding effectiveness of continuous film window material. [25]

Radio frequency shielding of about 45 dB (average) has been achieved at GMRT structures with proper shielding measures.[23]An alternative to shielding embedded within the structure's wall is a shielding structure like a geodesic dome with mesh enclosing the whole structure which can also be considered.

11. Site selection

Visitors center site has to developed with focus on visitors while making sure that the Radio Astronomical studies stay largely unaffected . A few plots were evaluated based on criteria like ease of access to visitors, accessibility to GMRT staff for consultation, infrastructure and effects of probable radio frequency noise, explained in detail in Appendix C . It is also observed that the proximity of antennas to the Visitor Center adds crucial elements of context and relevance to visits.[1] The following sites were considered:

- HT yard outside GMRT main gate.
- Proposed E1 antenna plot.
- Plot adjacent W04 antenna.
- VSNL Arvi plot.
- Proposed S05 antenna plot.

The table below assigns score to every plot depending on the following parameters RFI, distance of plot from GMRT and Narayangaon town, area of the plot, central array view available infrastructure,security,etc.

	RFI		Accessibility		Infrastructure		Area	Central array view	Security	Total (max 45)
	Nearest antenna	Central Array	Staff	Visitor	Water	Power				
H T yard	3	3	5	3	3	3	5	5	5	35
Plot at E01	3	3	4	3	2	2	3	5	1	26
Plot at W04	1	4	3	4	2	2	2	2	1	21
Plot at VSNL Arvi	4	4	2	5	4	4	1*	2	1	27
Plot at S05	4	4	1	1	2	2	3	1	1	19

*Although the estimated area of ARVI is the highest it has been scored low as it is not owned by GMRT .

Considering the mentioned criteria among the available plots the HT yard plot was found most suitable for a visitor center.

12. Summary

A detailed study of the radio frequency interference environment of the proposed Visitor Centre was undertaken and has subsequently led to a site selection for the Visitor Centre after considering several parameters. Here is the summary of this study:

1. An examination of the near and far field scenarios were undertaken by studying a few research papers. From the study, we concluded that Friis's law which is applicable to far field scenarios can be a reasonable approximation for the near field also. To recall, a source is in the near field if placed at a distance < $2D^2/\lambda$ .Using the Friis formula i.e.

$P_r = P_t*G_t*G_r*\lambda^2 / (4*\pi*r)^2$, we estimated the received power at different distances from its location using GMRT antenna gains >> 1 i.e. if the main lobe of the antenna was observing the interference.

2. In the next part of the study, we made an extensive study of the potential RFI-producing sources. These were mainly cellular phones, electronic equipment in the labs and automobiles.

2.a. Cellular phones:

In the NCRA Pune campus, an experiment was conducted wherein a mobile was operated near a spectrum analyzer and the RFI generated as a result of that was recorded by the spectrum analyzer. We found that even in the absence of any mobile in the vicinity, the cellular bands always showed strong signals which make the bands 824-894 MHz, 890-960 MHz, 1710-1880 MHz and 1920-2170 MHz astronomically unusable. A separate study by the RFI group at GMRT had found a similar effect.

2.b. Electronic equipment:

Several different types of these equipment which are used in the labs at GMRT were examined from existing reports on such devices. For example, we studied LAN switches, LAN UTP/Fibre converter, computers, computer monitors, UPS etc. Different GMRT bands were affected by different components and additionally some components resulted in spiky RFI. Most reports suggested that many components radiated at frequencies lower than 300 MHz.

2.c. Automobiles:

These generate wide-band RFI. We conducted simple experiments in the GMRT campus to check the RFI generated by two-wheeler and four-wheelers. We find that bikes radiated through the 100 MHz to 2 GHz band. A diesel-run car radiated in the 450-550 MHz band with the highest peak within 10 dbm of the noise floor. A diesel-run bus radiated negligibly but enhanced RFI was observed when internal devices such as lights and fans were switched on. Petrol-run car was found to radiate in the 200-400 MHz .

3. We conducted an experiment of radiating from the plot located outside the main GMRT gate and recording the received power by the antenna C04. This experiment was done in collaboration with the RFI group. The recorded power density which is mainly picked up by the sidelobes was between -140 to -170 dbm/m^2 for all the bands.

4. We also made a preliminary study of the architectural design for the proposed Visitor Centre which would be useful for controlling the RFI environment. This included doors, windows, air-conditioning, piping etc.

5. We also suggest that a possible way to provide enhanced shielding for the Visitor Centre building would be to use two layers of Faraday cage, thus increasing the attenuation of unwanted signals.

6. Finally, we have studied several possible sites for the Visitor Centre and a detailed comprehensive listing is presented in the report. After weighing several factors such as RFI environment, accessibility, infrastructure, security, plot areas etc, we conclude that the lot located opposite the main GMRT entrance is the best choice for the proposed Visitor Centre.

Acknowledgement

We express our gratitude to Mr. Suresh Kumar,Mr. Pravin Raybole and the entire RFI team for helping in experimentation and acquisition of substantial data on RFI sources. Their contribution was vital in completion of the project.

We are also thankful to Prof. G. Swarup for his extensive inputs on power density calculation and electromagnetic shielding. His advice helped greatly in shaping the practical aspects of the project. We are also thankful to Dr. Subhashis Roy and Dr. Niruj Mohan Ramanujam for the discussions which helped us explore multiple perspectives for research.

We are grateful to Mr. R. V. Swami for bringing to notice several unoccupied proposed antenna sites, visits to C13 and E01 and useful discussions. A special thanks to Mr. S .D. Patil and entire civil engineering team for providing us required data on various plots.

We also take this opportunity to thank Mr. N. J. Shinde, Mr. S. S. Sherkar and the entire Control room team for helping us in performing experiments and acquiring required data. We are also thankful to Mr. Jesu Raja .P and Mr. Shrikant Bhujbal for helping in execution of required experiments concerning radio frequency interference.

References:

1. Kimberly Burtnyk ,"Impact of Observatory Visitor Centres on the Public's Understanding of Astronomy", Publications of the Astronomical Society of Australia / Volume 17 / Issue 03 / 2000, pp 275-281

2. Constatine.A. Balanis, "Antenna theory analysis and design",Wiley, 2nd edition

3. Max Born and Emil Wolf ,"Principles of optics",Cambridge,7th edition.

4. S. Drabowitch,A. Papiernik,H. D. Griffiths,J. Encinas,B. L. Smith "Modern Antennas" , Springer, p 18

5. Blake and Long ,"Antenna fundamentals, Design and Measurement", Scitech,3rd edition,p 13,96

6. John D Kraus, Ronald J Marhefka, Ahmad S Khan, "Antenna and wave propagation", Tata McGraw-Hill,4th edition

7. Chengalur, Jayaram N, Gupta Yashwant,Dwarkanath K. S. ,"Low frequency radio astronomy", 3rd edition

8. Technical Advisory Committee,S.K.Guha,S.Neogi,G.Kumar," Cell phone tower radiation hazards", OCT 2011

9. Joseph.J.Carr, "The Technicians EMI Handbook", Newness

10. DoT, Government of India, "Mobile communication Radio waves and safety report".

11. I.M.Rao ,"Prediction and measurement of EMI pollution generated by the personal computers", Proceedings of the International Conference on Electromagnetic Interference and Compatibility, 2001/02

12. PranasKanapeckas,StasysMaciulevičius,AlfredasOtas,VytautasPetrauskas, AlgisValys ,"Electromagnetic Radiation at Computerized Workplaces "INFORMATION TECHNOLOGY AND CONTROL, 2007, Vol.36, No.4,p 348 - 352

13. R.P. Millenaar ,H.J. Stiepel," On Self-generated RFI at Radio Astronomy Sites",WSRT,27 February 2004

14. Analysys mason," Study of long-term RFI environment for the SKA radio telescope",Ref:20100-442,10 November 2011

15. S.Suresh kumar,Pravin Raybole,Shrikant Bhujbal ,"Ethernet Switch and Shielded CAT 5 cable RFI measurement Report"

16. S.Sureshkumar,P.Raybole,S.Bhujbal ,"Dell N5110 Laptop RFI Report"

17. S.Sureshkumar,PravinRaybole,S.Bhujbal, "SMPS based power supply - RFI measurement Report "

18. S. Sureshkumar,Pravin Raybole,Shrikant Bhujbal,"Sairush make power supply RFI measurement Report"

19. S.Sureshkumar,PravinRaybole,ShrikantBhujbal,AbhijeetGahlot,Ankur,Sanjeetkumar Roy, "UPS RFI Comparison Report"

20. S. Guttowski, S. Weber, E. Hoene, W. John,H. Reichl, "EMI in Electric Vehicles"

21. Mike Gruber , "RFI book " ,2nd Edition,ARRL

22. Mark Steffka,Vipul Patel ,"Vehicular spark ignition systems radiated emissions and reception performance", International Symposium on Electromagnetic Compatibility, 2005

23. Christopher Haslett ,"Essentials of Radio Wave Propagation",Cambridge,2008

24. S. Sureshkumar , Pravin Raybole,Shrikant Bhujbal ,"Review of RFI ambience around New Servo Lab located in central square near Jog shed"

25. Leland.H.Hemming ,"Architectural electromagnetic shielding handbook", IEEE press

Appendix A

Study of RFI caused by cellular devices

Introduction

Cellular devices are serious cause of concern in radio astronomy. The radiation from cellular devices in various frequencies close to the observation band can corrupt astronomical signals. When a cell phone is used, it radiates signal to the base station in range, the base station responds by assigning it an available radio frequency channel. Once the required connection is established signals carrying the data are relayed back and forth. The signal transmitted from the phone is called uplink while the signal transmitted by tower to establish connection is called downlink. These two links require separate frequency bands to communicate. The study of radiation from cellular device is necessary to approximate the magnitude of interference and mitigation methods to control the damage.

Methodology

To measure the ambient RFI of surroundings with active cellphones the study was performed at the NCRA campus in Pune. A handheld spectrum analyzer Micronix MSA338 available in Radio Physics Lab (RPL) was used with the manufacturer-provided dipole antennas M301 and M303 for 0.8 to 1 GHz and 1.7 to 2.2 GHz frequency bands respectively. The observations were made in the following bands:

- 824 - 894 MHz (CDMA)
- 890 - 960 MHz (P-GSM900)
- 1710 – 1880 MHz (GSM1800)
- 1920 – 2170 MHz (3G)

The frequency band in which a cellphone transmits is called uplink band and the frequency band in which the cell tower transmits is called downlink band. The uplink and downlink for respective protocol are tabulated below:

Protocol	Uplink band(MHz)	Downlink band (MHz)
CDMA	824 - 849	869 - 890
P-GSM 900	890 - 915	935 - 960
GSM 1800	1710 - 1780	1810 - 1880
3G	1920 - 1980	2110 - 2170

All the settings made on the spectrum analyzer for corresponding reading can be seen in the images on the right side of the plot. The spectra were examined for two cases

1. Ambient radio frequency activity was measured with no cellular device active in the immediate vicinity.

2. When cellular devices were active in the vicinity of spectrum analyzer

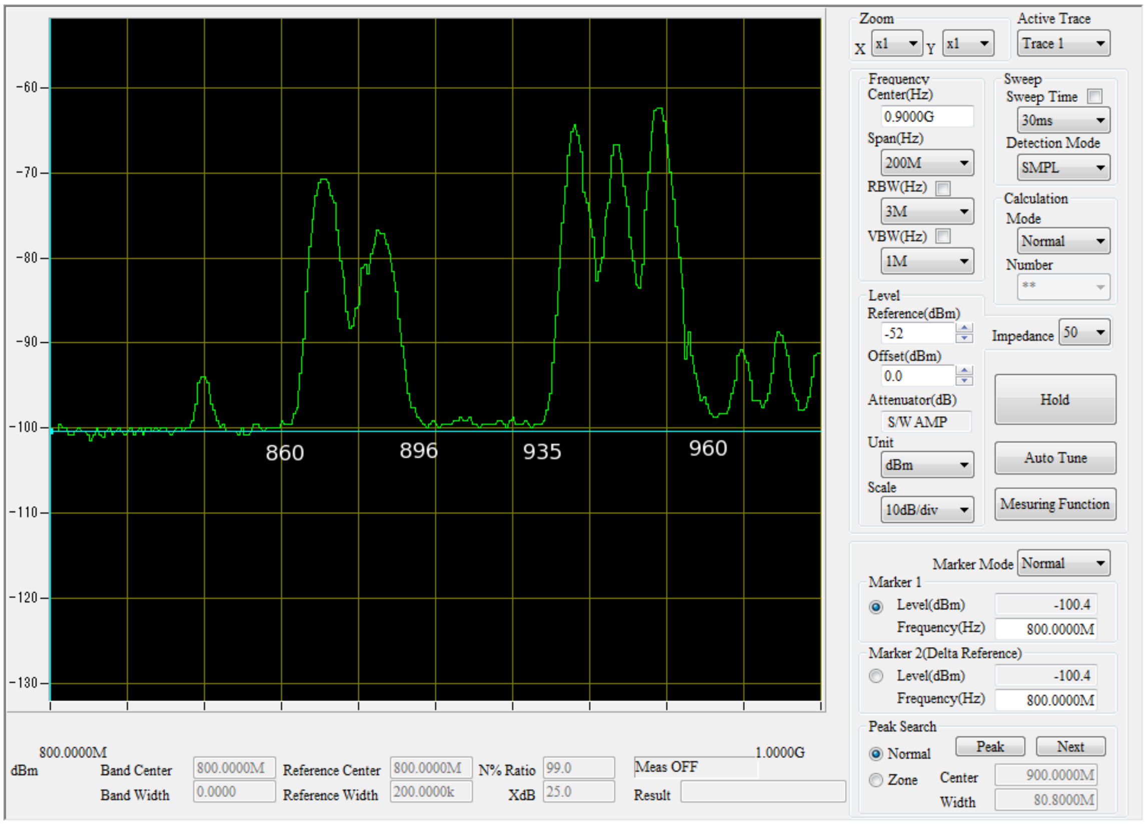

Figure 1: Graph of 0.8 to 1GHz band, activity seen in 860-896 MHz and 935-960MHz is due to cell phone tower radiations for GSM 850 and GSM 900 downlinks respectively

The noise floor is at -100 dBm.

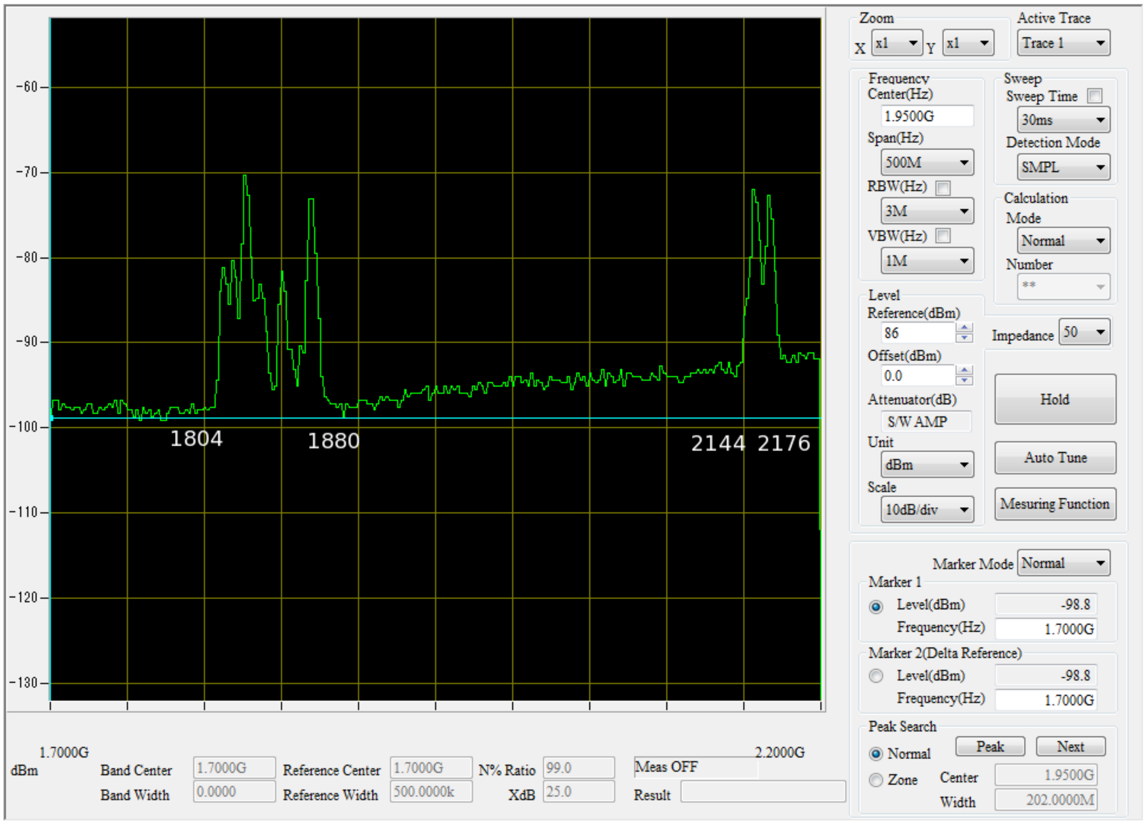

Figure 2: Graph of 1.7 to 2.2 GHz band activity in 1804-1880 MHz and 2144-2176 MHz is due to cell phone tower radiations for GSM 1800 and 3G downlink respectively.

As can be seen from figure1 and 2 the disturbance in the downlink frequencies is always present even with no cell phone active in the vicinity. This is because there signals are used by operators to detect and assign network to user cell phones. The radiations found in the above frequencies are also present around GMRT as noted in the report "Study of RFI ambience in and Around GMRT" by Vaibhav Savant, Shrikant Bhujbal.

To check contribution of cell phone radiation a cell phone was operated at a distance of 30 cm from the spectrum analyzer and measurements were made. The cell phones used operated in the GSM1800 frequency band, and when a call was made with the cell phone the observed band is shown in figure 3.

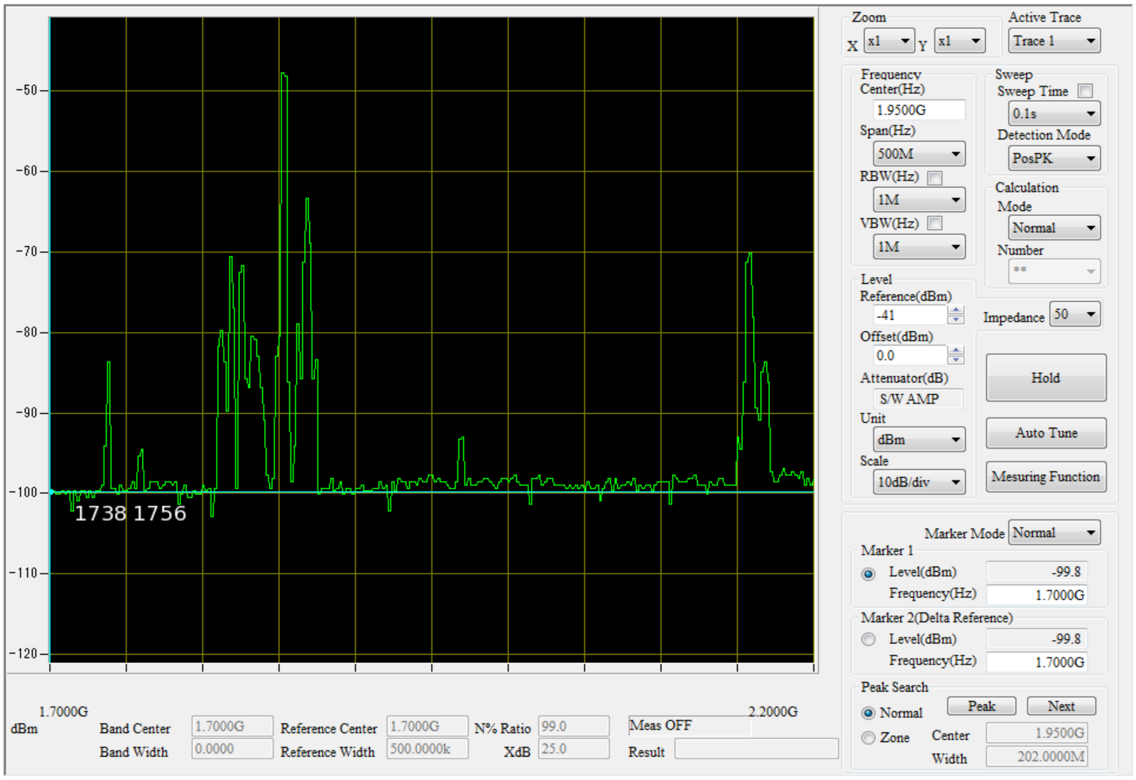

Figure 3: Readings for 1700-2200MHz band activity seen from 1738-1756 MHz due to active cellphone

Discrete peaks were observed at uplink band for GSM 1800 (1710 to1780 MHz).In Figure 3, peaks are observed at 1738 MHz and 1756 MHz and the magnitude of uplink frequency radiation increased from a peak of -70 dBm to -50dBm.

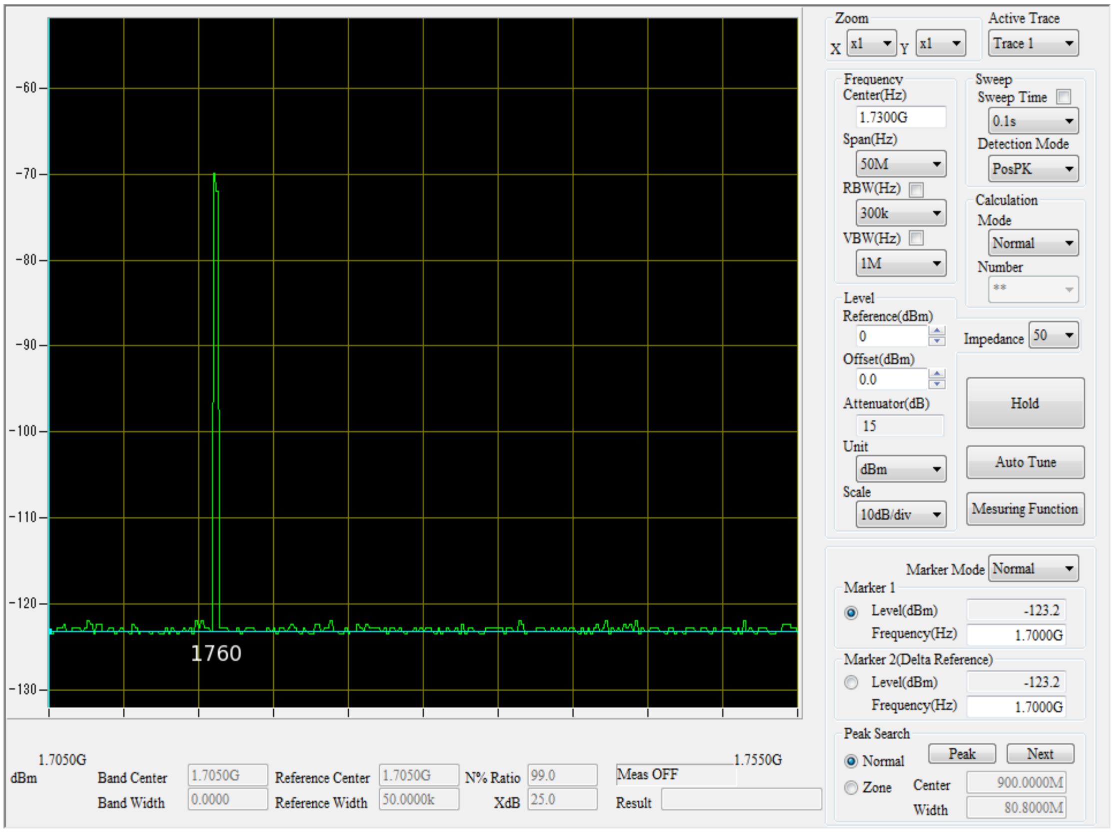

Figure 4: Detailed view of spike occurring at 1760 MHz in uplink band of GSM 1800MHz with cellphone active

In figure 4 a discrete peak can be seen with magnitude up to -70dBm in the GSM 1800 uplink (1710-1780 MHz) frequency. Some disturbance may also be observed in the 3G band (not seen in the picture).

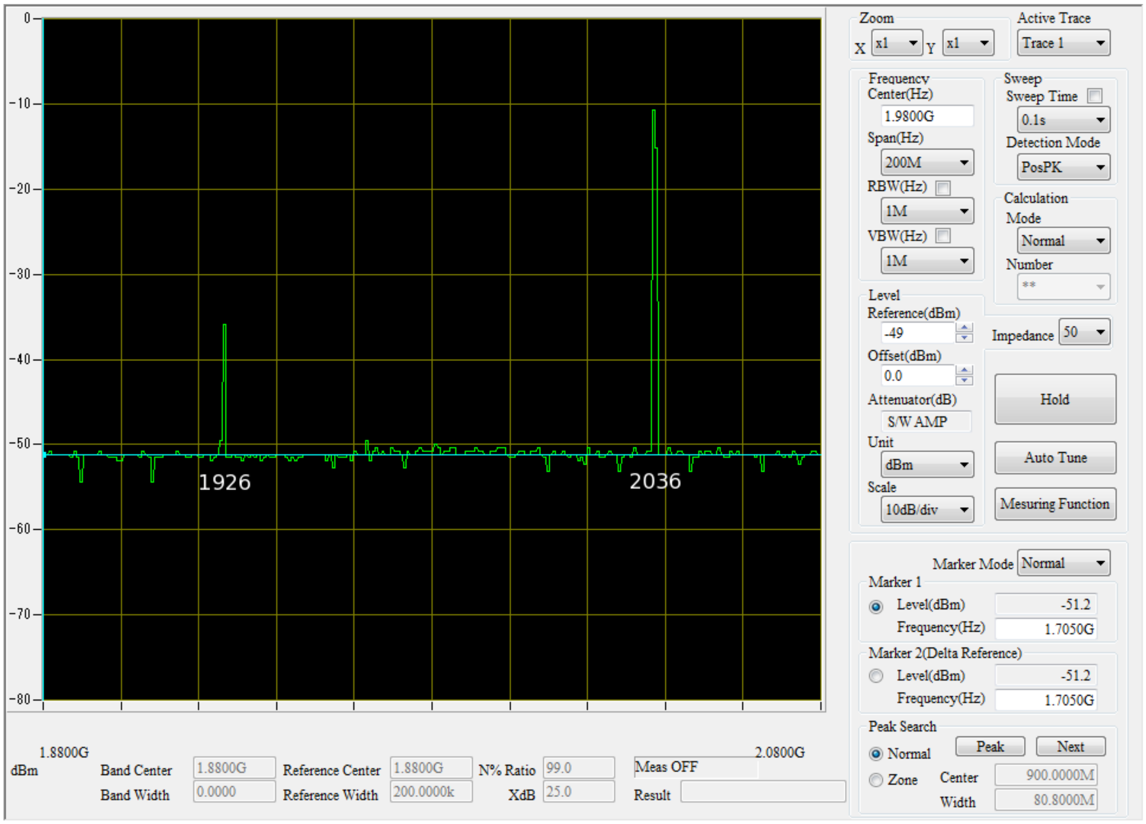

Figure 5: Spikes occurring in the 1880-2080 MHz band due to active cellphones

When multiple cell phones were used the activity in the band (the number of prominent peaks) increases. The magnitude of peaks may reach upto -10 dBm when two phones were used as seen in Figure 5. The frequency at which the peak occurs varies with the cell phone operators.

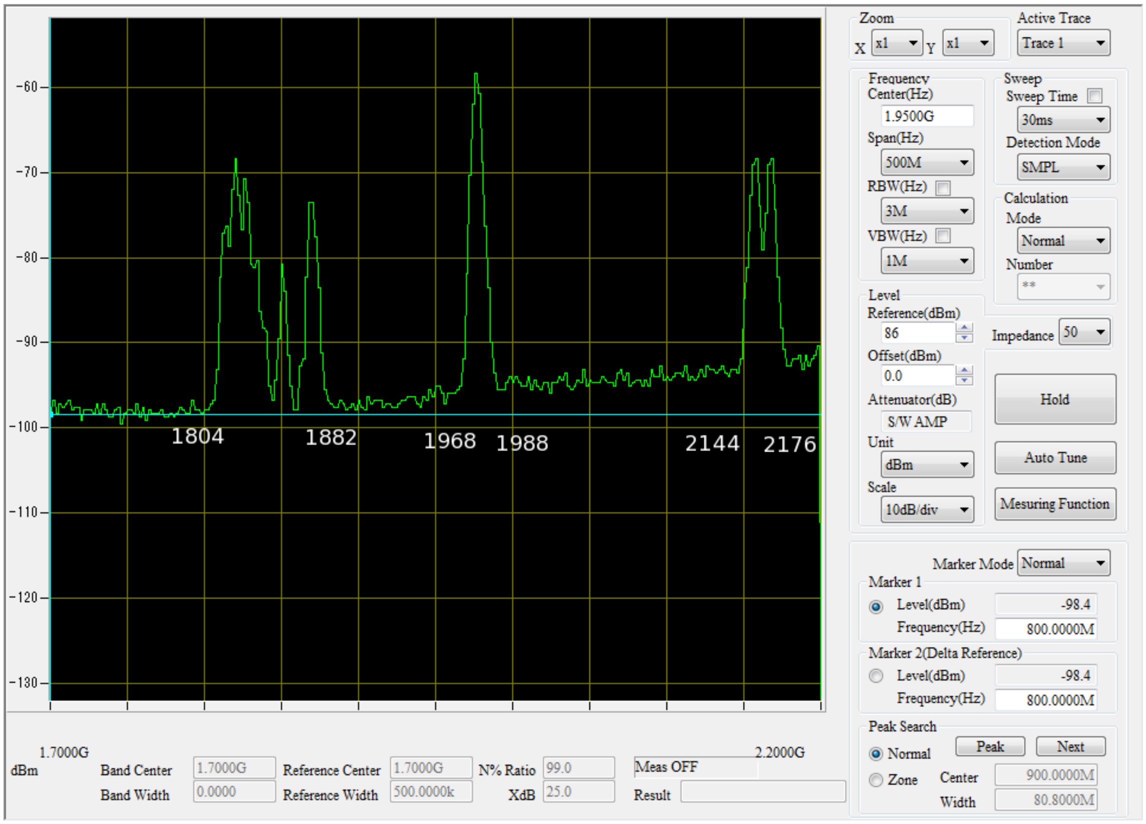

Figure 6: Readings for 1700-2200 MHz band with cellphone using data transfer

When internet is used on cell phone under test, a peak can be seen in the 3G uplink band from 1968-1988 MHz with magnitude upto -60 dBm(see figure 6). The magnitude of adjacent downlink bands also increases.

Conclusion

Downlink band radiation is always present independent of the cell phone device usage. The activity in uplink bands is observed when a cellphone is in use the peaks may occur at different frequencies as per the service provider.

Appendix B

Note on RFI recorded by the 30-to-1 utility at GMRT

To examine RFI due to visitors coming to GMRT on the National Science Day an experiment was conducted. Few GMRT Antennas (C01,C02,C03,C06,C09) in the central square were pointed in the direction of the ground where the science day program was held .The gray plots from the 30-to-1 utility were studied in comparison with gray plot observations on other days at GMRT in the same bands. The comparison was done at frequency band 150MHz, 325MHz and1060 MHz. The maximum and minimum power levels of the gray plots were compared to get an estimate of difference in RFI power levels on science day (28 February 2014) with RFI levels on other days.

All the Gray plots are available online on the GMRT website under GDDP (GMRT Data Diagnostic package) section.(http://www.gmrt.ncra.tifr.res.in/~gtaclog/)The following table compares the maximum and minimum power obtained on Science day with power obtained on other days for required frequency bands :

Frequency band (MHz)	**Observation Time & date**	**Antenna received power (dBm)**									
		C01		C02		C03		C06		C09	
		Low	**High**	Low	**High**	Low	**High**	Low	**High**	Low	**High**
150 (135 -165)	08:51:55 – 16:43:23 14 July 2013	-80	**-20**	-80	**-30**	-80	**-45**	-85	**-30**	-85	**-35**
	17:45:25 - 22:07:44 6 August 2013	-80	**-25**	-80	**-35**	-80	**-35**	-80	**-20**	-80	**-30**
	00:52:06 – 03:56:261 March 2014	-90	**-20**	-80	**-30**	-90	**-20**	-85	**-35**	-85	**-35**
	14:00:21- 14:29:4328 February 2014	-80	**-35**	-75	**-25**	-80	**-68**	-85	**-30**	-80	**-30**
325 (310-340)	04:40:15 – 06:53:2811 July 2013	-52	**-43**	-53	**-44**	-58	**-44**	-63	**-50**	-59	**-51**
	02:08:37-08:50:5222 September 2013	-90	**-20**	-80	**-30**	-85	**-30**	-85	**-40**	-85	**-35**
	19:13:27- 00:50:5830 March 2014	-62	**-48**	-54	**-38**	-54	**-42**	-62	**-48**	-62	**-44**
	12:11:03- 12:29:0328 February 2014	-70	**-35**	-70	**-40**	-80	**-35**	-80	**-10**	-70	**-40**

1060 (1046 - 1075)	22:08:11-00:13:55 14 - 15 November 2013	-85	**-40**	-85	**-35**	-85	**-35**	-85	**-50**	-85	**-40**
	01:33:23 - 03:47:25 23 May 2014	-66	**-56**	-62	**-44**	-56	**-44**	-66	**-54**	-60	**-48**
	06:34:53-07:56:43 22 June 2014	-65	**-25**	-65	**-35**	-55	**-25**	-75	**-45**	-65	**-40**
	12:30:11-13:49:05 28 February 2014	-80	**-20**	-80	**0**	-80	**-20**	-90	**-10**	-80	**-10**

The results in table were plotted to study any obvious increase in RFI on science day compared to other days. These are shown in figure 1 to 3.

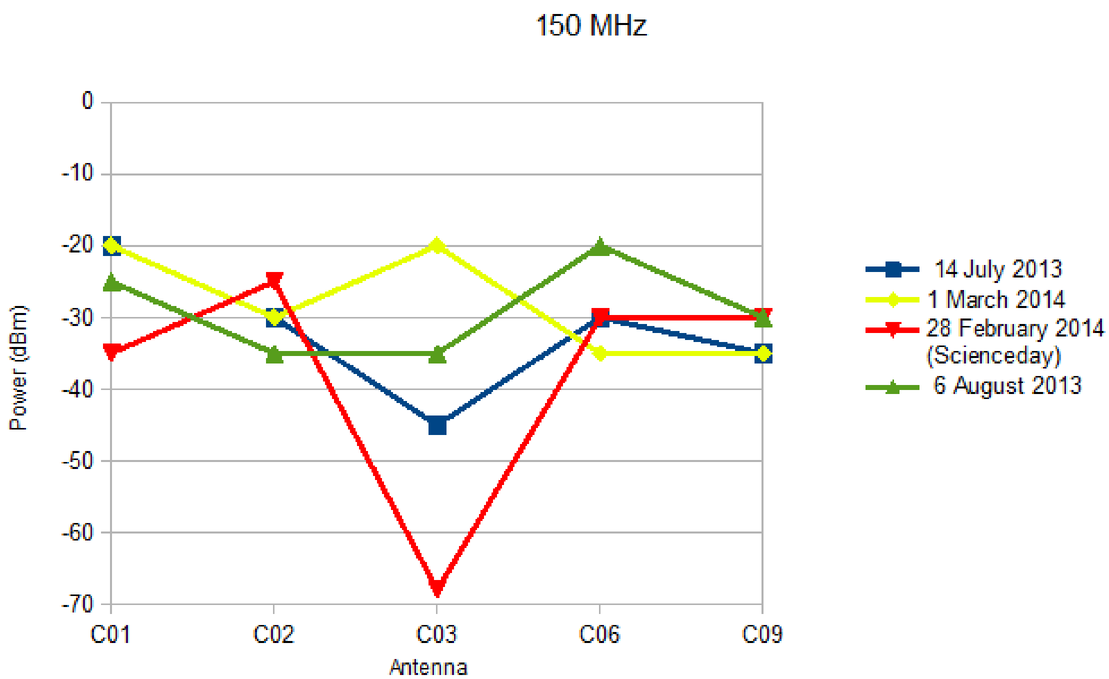

Figure 1: Maximum power recorded in the 150 MHz Band

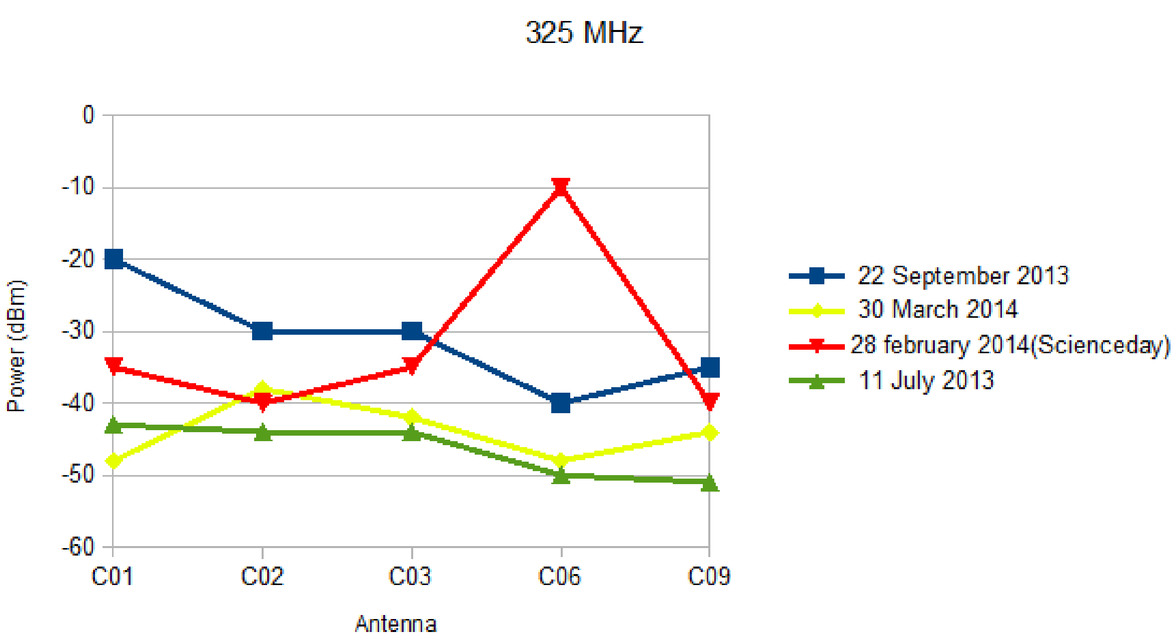

Figure 2:Maximum power recorded in the 325 MHz Band

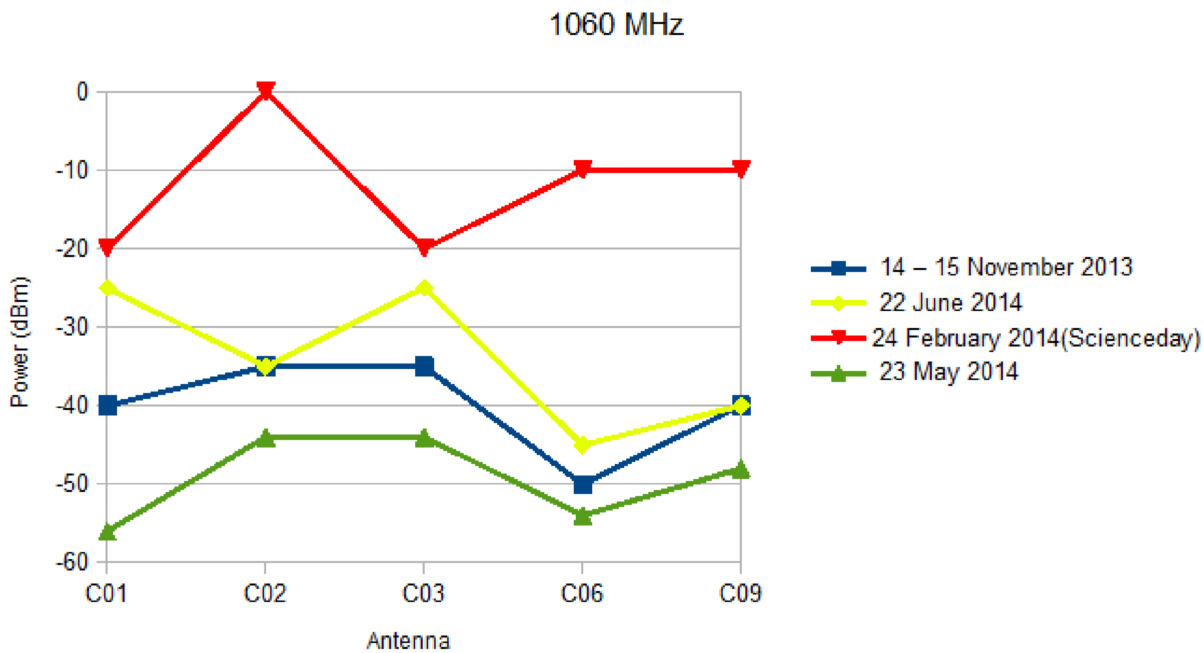

Figure 3Maximum power recorded in the 1060 MHz Band

Results:

150 MHz band

No significant difference is noticeable in this band between science day and other days.

325 MHz band

No significant difference is noted in the maximum power recorded in case of C01,C02,C03 and C09.Only C06 appears to show peak power of ~ 30 to 40 dBm higher than noticed on other days .

1060 MHz band

This was the most affected band. It showed 40 to 50 dBm power increase on Science Day as compared to other day. The most affected antenna was C02 which showed maximum of 0 dBm compared to the normal -40 dBm. The increase in power appeared to be wideband in nature instead of being regulated to narrow bands. The above is likely a result of the proximity of cellular communication bands to this frequency.

We note that this experiment was done to obtain a zeroth order result on the increase in RFI due to increased number of visitors on Science Day. It is encouraging to that no significant change in the 150 and 325 MHz bands was observed. The increase in the 1060 MHz band needs to be further investigated.

Appendix C

Note on site selection for the visitor centre

To select an appropriate site for the visitor center the following criteria were taken into account and a weightage factor for each criterion was given between 1 &5:

Radio frequency environment

The visitor center will house multiple electronic gadgets and exhibits .This will contribute in increasing the RFI activity in the vicinity. To approximate the RFI the following formulas were used for estimating power and power density received by antennas:

Power received (dB) = $$\frac{A_e \times P_t \times G_t}{4 \times \pi \times R^2}$$

Power density (dBw/m^2) = $$\frac{P_t \times G_t}{4 \times \pi \times R^2}$$

Where

A_e is the effective aperture
P_t is transmitted power
G_t transmitter gain
R is distance

It was assumed that each electronic device radiates P = 6.28 X 10^{-8} w/m^2 which is derived from FCC specification for electronic devices. It is assumed that 30 such devices will be required in the visitor center and each has Gain(Gt)= 1 .The calculated power density for each site is noted in Table 1.

- Distance from GMRT antennas

The distance of the plot from the central array is important to give a glimpse of multiple large GMRT antennas to the curious visitor and also put in place RFI shielding if required. The plot distance from central array and the closest antenna are noted in Table 1 for respective sites.

- Accessibility to staff for consultation

The visitor center will house different exhibits and devices which may require technical assistance from GMRT staff from time to time, hence the plot must be close to GMRT for easy approach by staff.

- Accessibility to the visitors

Accessibility for visitors is an important factor and hence the directions to the site should be well known to general public.

- Visitors management

The planning and management of expected visitors is essential to properly handling the influx of people. The area of the site plays an important role as larger area will allow bigger buildings, garden, parking, etc. Hence a site with larger area and better symmetry are preferred. Most of the plots considered are already owned by GMRT with exception of VSNL Arvi plot. This factor also influences the weightage.

- Security

Security is indispensable, hence the ease with which security personnel can be deployed is an important factor.

- Infrastructure

Factors like water,power,network and access roads is important while considering the plot as it will simplify the process of establishing and maintaining the visitor center eventually.

The following sites were considered for the visitor center :

1. HT yard (plot outside GMRT gate)
2. Site at E01
3. Site at w04
4. Site at VSNL Arvi
5. Site at S05

Table 1 below indicate the distance of the site from nearest antenna ,central array, GMRT and Narayangaon town; it also displays the power density values calculated with respect to each plot for the closest antenna and the central array. It is important to note that distance indicated for GMRT and Narayangaon are by road distances while the distance for central array and the nearest antennas are point-to-point distances.

Table 1

	RFI (dBw/m2)		Distance (km)		
	Nearest antenna	Central Array	Nearest antenna	Central Array	GMRT
H T yard	-126	-130	0.85	1.3	0.1
Plot at E01	-128	-133	1	1.9	3
Plot at W04	-108	-147	0.1	9	13
Plot at VSNL Arvi	-136	-149	2.5	11.8	17
Plot at S05	-135	-149	2.2	11	18.5

With the data from table above all the plots are rated with scores out of five for each parameter considered. The following table shows the result

Table 2

	RFI		Accessibility		Infrastructure		Area	Central array view	Security	Total (max 45)
	Nearest antenna	Central Array	Staff	Visitor	Water	Power				
H T yard	3	3	5	3	3	3	5	5	5	35
Plot at E01	3	3	4	3	2	2	3	5	1	26
Plot at W04	1	4	3	4	2	2	2	2	1	21
Plot at VSNL Arvi	4	4	2	5	4	4	1*	2	1	27
Plot at S05	4	4	1	1	2	2	3	1	1	19

*Although the estimated area of ARVI is the highest it has been scored low as it is not owned by GMRT .

From study of the above data the HT yard plot would be most suitable for hosting a visitor center near GMRT.