LOCATION OF RADIO FREQUENCY INTERFERENCE USING GMRT

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ABSTRACT

With the increasing level of Radio Frequency Interference (RFI) in the VHF and UHF bands, it has become important to locate sources of harmful spurious emissions of authorized as well as that from malfunctioning and unauthorized transmitters using phased arrays. We have developed a method for the purpose using existing facilities of the Giant Metrewave Radio Telescope (GMRT) that consists of 30 parabolic dishes of 45- meter diameter each. The dishes are spread over a region of about 25 kilometer. For the present, we have used only 12 antennas of the central array located in a region of about 1 km x 1 km in extent. The primary feeds of the GMRT antennas placed near the focus have a 3dB HPFW of about 60 degrees. We rotate these feeds towards the horizon in specified directions. The voltage signals received by the feeds are cross-correlated using the electronic system of GMRT. The instrumental phase errors are calibrated by transmitting a signal from a signal generator located at a known position with respect to the array of GMRT. Procedure for data reduction and search for the location of an unknown transmitter and preliminary results are described in this paper. Our preliminary measurements show that it is possible to locate position of the unknown transmitter to an accuracy of less than 100 meter for distances of about 5 kilometer in a computer search time of about 100 s. It should be possible to extend the size of the array and use parallel processing computer for searching and locating RFI to much larger distances. The method developed may have wider applications in other communication systems.

1. INTRODUCTION

A radio telescope is typically about 50 or 60 db more sensitive than a communication receiver. For satisfactory operation of a radio telescope, several bands have been protected for radio astronomy observations by the national and international authorities. The Government of India has allocated RF bands near 151-153 MHz, 230-234 MHz, 322-328.6, 608-614 MHz and 1400-1427 MHz for radio astronomy observations using GMRT for which bands no transmitters are allowed up to a distance of several hundred km. However, GMRT observations indicate that there takes place considerable RFI from spurious transmitters in some of the GMRT bands by TV boosters, malfunctioning cable transmissions in nearby region of GMRT and also other unauthorized transmitters located far away. Radio direction finding equipment can find direction of some of these transmitters but with the increasing level of Radio Frequency Interference (RFI) in the VHF and UHF bands, it is become important to locate sources of out-of-band spurious emissions of authorized, malfunctioning as well as unauthorized transmitters using phased arrays. A suitable system for location of such unauthorized or mal-functioning transmitters using phased arrays is also likely to be of interest to many other agencies. In Section 2, we describe theoretical aspects of a procedure developed by us for locating the source of a transmitter whose position was unknown. In Sections 3 and 4, GMRT system in brief, preliminary observations, data analysis, search procedure and results are described. Conclusions are given in Section 5.

2. THEORETICAL CONSIDERATIONS

By multiplying voltages received by all the pairs of the GMRT antennas, we get correlated voltages, $V_j V_k^* = V_{jk}\, e^{i\Phi_{jk}} + \varepsilon^*_n$, where $V_{jk} = |V_j|\,|V_k|$, $\phi_{jk} = (\phi_j - \phi_k)$, where $V_j V_k^*$ is the complex products of the voltages received by the jth and kth antennas (j and k runs from 1 to N for the case of N antennas with a total of N(N-1)/2 products, and ε_n is the receiver noise = $|\varepsilon_n|\, e^{i\Phi n}$. Let us first consider the case for which the voltage gains caused by the electronics system, called hereafter the instrumental gains, are calibrated and corrected. Receiver or other sources of noise are also not considered for the present.

In order to locate the position of the source of RFI, we require to calculate path lengths $d_{g\,j}$ and $d_{g\,k}$ from each of the grid points of a search area to all of the jth and kth antennas of the GMRT (Fig.1), the coordinates g being geodetic latitude, longitude and heights of the 3-dimensional grid points of the search area (Fig.2) and similarly for the coordinates of the jth and kth antennas. GMRT scientists have made accurate determination of the geocentric coordinates of the GMRT antennas using astronomical observations. We have converted these to geodetic coordinates of the GPS system. Thereafter, we calculate corresponding phase differences for each of the grid points to the GMRT antennas, $\phi_{g\,j\,k} = (\phi_{g\,j} - \phi_{g\,k}) = [2\pi \{\{(d_{g\,j} - d_{g\,k})/\lambda\} - n\}]$, where n is an integer. We then subtract these calculated phase differences from the *measured phase values* of the voltage signal from the unknown transmitter, as received by the jth and kth antennas. Assuming that the amplitude of the voltages received by each antennas are equal, say $V_{0,}$ we then determine a vector sum, $V^2_{g\ sum}$ of all the correlated voltages, $V_{g\,j}V^*_{g\,k}$, corrected for the corresponding phase differences.

$$V^2_{g\ sum} = \sum_{j=k=1}^{j=k=N} V_{gjk}\, V^*_{gjjk} \quad \text{, such that } 1 \le j \le k \le N, \text{ for each value of } g \text{ , such that } 1 \le g \le M, \tag{1}$$

The amplitude of $V^2_{g\ sum}$ is given by,

$$\text{Amp}\,(V^2_{g\ sum}) = \Big[\sum_{j=k=1}^{j=k=N} V_0^2 \cos(\phi_{j\,k} - \phi_{g\,j\,k})\Big]^2 + \Big[\sum_{j=k=1}^{j=k=N} V_0^2 \sin(\phi_{j\,k} - \phi_{g\,j\,k})\Big]^2, \tag{2}$$

The value of the phase of the $V^2_{g\ sum}$ is given by

$$\Phi\,(V^2_{g\ sum}) = \tan^{-1}\Big[\sum_{j=k=1}^{j=k=N} (\sin(\phi_{j\,k} - \phi_{g\,j\,k}) \Big/ \sum_{j=k=1}^{j=k=N} \cos(\phi_{j\,k} - \phi_{j\,k})\Big]. \tag{3}$$

The calculated position of the transmitter producing RFI corresponds to the coordinates of the $g_{t\,h}$ point for which the value of the Amp (V^2_{sum}) is maximum and value of the phase Φ (V^2_{sum}) has relatively a low values.

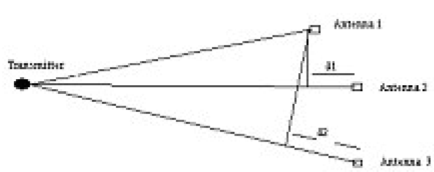

Fig. 1. Determination of path delay between the calibrating transmitter and the GMRT Array.

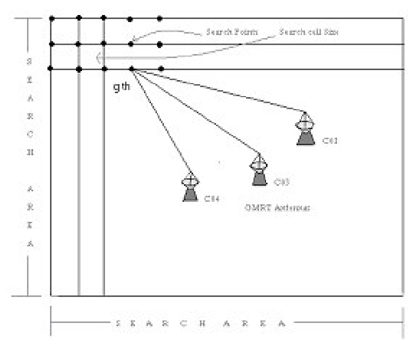

Fig. 2. Three-dimensional search space from g_{th} point to GMRT antennas.

3. COMPUTER SIMULATIONS

In order to test our concepts, computer simulations were carried out using parameters of the GMRT central array, considering a source of RFI located 10 km away and then calculating value of the peak response of the maximum (main lobe) and of secondary maxima with and without phase errors of about +/- 50 degrees. It was shown that the main lobe had appreciably higher value than that of secondary maxima. It's half power width was about 50 m [1].

4. **GMRT OBSERVATIONS AND DATA ANALYSIS**

GMRT consists of 30 fully steerable parabolic dishes, eachof 45 m diameter, located in a region of about 25 km in extent [2]. Twelve antennas are located in a central array of about 1km x 1 km in extent and other 18 antennas are placed in three Y-shaped arms, each 12 km in length. The GMRT operates as an Earth Synthesis Radio Telescope and produces antenna beam of the GMRT array for celestial observations with relatively low side-lobes in a typical observing period of several hours. The signals received by each of the 45 m dishes are amplified, converted to IF signals, transmitted on optical fibers and brought to a central receiver room where all the received voltage signals are cross multiplied using a complex correlator and finally recorded in a computer system.

In order to test the method described in Section 2 and to develop a suitable search procedure, preliminary observations were made at the GMRT site in Feb. 2004, software developed and then again on March 10 2004 as described here. For these observations we used only 12 antennas of the central array of the GMRT located in a region of about 1 km x 1 km in extent. The primary feeds of the GMRT antennas that are placed near the focus of each antenna have a gain of about 8 dB and 3dB HPFW beam-width of about 60 degrees. We rotated these feeds towards the horizon in a western direction. As described above, the voltage signals received by the feeds are cross-correlated using the electronic system of GMRT. The phase errors of the electronics system, called instrumental phase errors, were calibrated by transmitting a signal from a signal generator located at a position about 7 km away from the array of GMRT using a log -periodic antenna facing the GMRT array.

The location of the calibrating signal generator was measured using a GPS receiver. A second signal generator was placed at a distance of about 5 km from the GMRT towards northwest direction from the GMRT central array and whose position was considered as "unknown" during the data reduction. A search procedure was developed as described below and allowed us to determine the position of the unknown transmitter. Its position was later determined using a GPS receiver and differences between the results of search procedure and GPS measurements were tabulated.

The GMRT correlator and computer system provides a 'LTA' file giving sequential complex values of correlation between various antennas typically every 16 seconds. The LTA file also contains various parameters of the GMRT antennas, such as time of observation, elevation and azimuth or hour angle of various antennas.

Using the Astronomical Image Processing System (AIPS) software that has been developed by the National Radio Astronomy Observatory (NRAO), USA, the data was converted to a standard FITS format. The data was flagged using the VPLOT task. Accurate frequency of signals received from the calibrating and unknown transmitter was determined using the task POSSM. Amplitude and phases of the calibrating transmitter were then determined using the CALIB task, with respect to a selected reference antenna. Path lengths between the measured positions of the calibrating transmitter and GMRT antennas were calculated. The corresponding phase values for these path lengths were then subtracted from the output of the SN table created by the CALIB task, which provided us values of the *instrumental error* ϕe of the electronic system of each antenna of GMRT. From these values we then constructed a *matrix table* giving $\phi e_{j\,k}$ for all the antennas.

The phase matrix $\phi u_{j\,k}$ for the unknown transmitter was obtained using the LISTR task. From these phase values we subtracted the matrix $\phi e_{j\,k}$, which provided phase matrix $\phi u'_{j\,k}$ of the voltage received from the unknown transmitter and corrected for instrumental errors. In order to determine the location of unknown transmitter, a search procedure was developed in which we divided a selected search area in to 3-dimensional grid points, g (Fig. 2). We then calculate phase values, $\phi_{g\,j\,k}$ as described in Section 2 and finally amplitude and phase responses using Eqs. (2) and (3) for each of the $g_{\,t\,h}$ grid points. The maximum value of the amplitude and minimum value of phase of $V^2{}_{g\ sum}$ for a particular grid point determines the location of the unknown transmitter.

We have so far not discussed various parameters such as phase errors due to receiver noise and multi-path propagation. We also expect to get secondary maxima due to the expected 'side lobes' of the GMRT array towards relatively nearby locations in the search area. We therefore made contour plots of Amp ($V^2_{g\ sum}$) (Fig. 3) and also of Φ ($V^2_{g\ sum}$). For observations made on 10th March 2004, 12 antennas were used and hence we expect a maximum value of N x (N-1)/2 = 12 x 11 / 2 = 66. Our search routine give us a maximum value of 40 in a search period of 73 sec over a region of about 1.5km x 1.5km and height variations of about 150m. The position of the peak value of the amplitude of $V^2_{g\ sum}$ provided us coordinates of the unknown transmitter. The differences between these coordinates and GPS positions, (which may be considered errors in determination of location of the unknown transmitter), were found to be as follows: Δ latitude = 64 m, Δ longitude = 2 m, Δ height = 89 m . There were several 'side-lobes' as seen in Fig. 3 but their phases had large values.

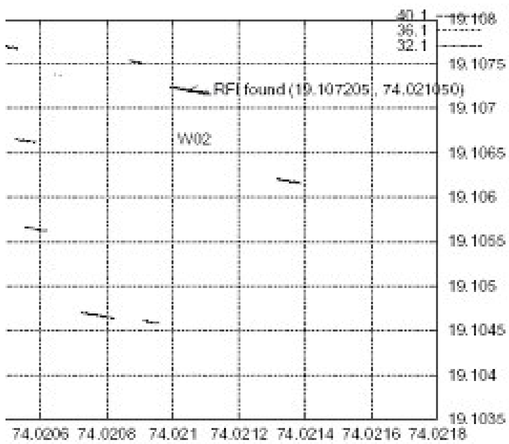

Fig. 3. RFI Search plot giving location of the unknown transmitter at W02.

4. DISCUSSIONS AND CONCLUSION

Our preliminary observation and search procedure developed show that a 2-dimensional array of limited number of antennas distributed over an area of about 1 km x 1 km can locate sources of RFI up to several km away from the GMRT array, by using only the primary feeds of the GMRT 45m dishes which have a gain of only about 8 dB. One of our motivations for the above work was to locate the source of RFI observed at GMRT at 229.4 MHz during a search for the expected neutral hydrogen absorption from the farthest known radio galaxy in the Universe at a redshift of 5.1. Our observations indicated that the source of RFI could be from the city of Pune that is about 60 km away from the GMRT. Considerable more work needs to be done by using more antennas of the GMRT for locating sources of RFI up to tens of km away. For search over a large region, one may use better algorithms including parallel processing algorithms. Since GMRT antennas can be rotated only from 17 degrees to 90 degrees from the horizon, it is not possible to use the full 45 m dishes for detecting and locating the sources of RFI. For finding sources of RFI in the region of about 15 to 20 km around the central array of GMRT other methods are being tried by the GMRT group and need to be further explored. The method developed is likely to be useful for locating sources of RFI much further away. It may also be applicable for the general problem of locating malfunctioning or unauthorized transmissions affecting other communication systems near cities by setting up special phased arrays.

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6. REFERENCES

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