RFI - REPORT : PART - IV

SURVEYS OF RADIO FREQUENCY INTERFERENCE (RFI) AT THE GMRT SITE FROM TERRESTIAL TRANSMITTERS

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Keywords : Radio Frequency Interference; RFI at the GMRT site; RFI from Terrestrial Transmitters; RFI - narrow band ; Radio Frequency Spectrum.

SUMMARY

Radio Frequency Interference (RFI) surveys have been carried out periodically at the GMRT site since 1985. Surveys made during the period 1985-88 used a commercial Yagi antenna used for the TV band of 175-230 MHz which was placed at a height of about 6-m above the ground. The Yagi antenna was connected to a low-noise amplifier and a Tektronix Spectrum Analyzer. A bandwidth of about 100 kHz was used generally for the measurements made during 1985-88. The sensitivity obtained i.e. the minimum detectable RFI signal was about -140 to -145 dBW/m^2.

Several surveys have been made during the period 1992-99 by using the primary antenna feeds which are placed at the focus of the 45-m diameter parabolic dish antennas of GMRT. The 45-m antennas and feeds are rotated so that they get pointed towards horizon in various directions, e.g. N, E, S or W for selected frequency bands. The outputs of the antenna feeds in the bands near 152 MHz, 233 MHz, 325 MHz, 611 MHz and 1000-1430 MHz are connected to amplifier system placed near the focus of each dish. The GMRT receiver system brings the signals for the selected feed to the central receiver room and a spectrum analyzer is connected to the IF output of the receiver . Measurements are made over RF bandwidth of 4, 10, 16 or 30 MHz. A resolution bandwidth of spectrum analyser of 10 or 30 kHz is used. Sensitivity reached is about -155 to -160 dBW/m^2. The results described in this report are based mostly on observations made by G. Swarup during 1997-2000. However, RFI surveys made at the GMRT site by various groups during 1985-2000 are briefly summarized in this Report but are presented in more detail in Part-V of this series of reports on Frequency Coordination for GMRT and RFI measurements. During the last two years, M.R. Sankararaman and others have continued to make RFI surveys which are described elsewhere The pulsar group has also made measurements in the 152 MHz

± 4 MHz band.

Surveys have also been made during 1998 using a broad-band log-periodic antenna placed at the GMRT site at NCRA, Pune, Sangamneer, Alephata, Kukdi, Junnar, Lonavala and Khandala which are within 80 km of the GMRT site. Some of the RFI signals seen in the GMRT bands are found to be common at these sites but many of the RFI signals are seen at different frequencies. In particular, it seems that some of the RFI signals seen in the GMRT protected bands arise from transmitters in Lonavala and Pune, some are clearly local around the GMRT site, some are from GMRT electronics, but the source of many other RFI signals is uncertain. These measurements indicate that some of these signals may be unauthorised transmissions in the GMRT bands, or spurious harmonics of transmitters in the vicinity of GMRT or leakages of faulty equipment. More detailed measurements are needed to locate sources of RFI to the GMRT, particularly in the 152-154 MHz and 230-234 MHz bands, which have been given protection for GMRT by the Govt. of India but where considerable RFI is observed. In part-I of these reports are given recommendations for developing practical and low cost direction finding equipment for RFI.

Surveys made over the last few years, show that the level of RFI has increased considerably at the GMRT site, particularly in the GMRT bands 152-154 MHz and 230-234 MHz bands. There is also some increase in the level of RFI in the 310-340 MHz band but RFI is mostly absent in the GMRT band of 322-328.6 MHz. Relative absence of RFI in the 322-328.6 MHz band is also seen from the results of interferometry done recently in four different directions (E, W, N & S) using the GMRT 327 MHz feeds pointed towards the horizon, for four pairs of antennas. The level of RFI is also low in a 32 MHz band centered near the GMRT band of 608-614 MHz. The RFI levels also seem to be relatively low in the band 1000-1427 MHz although there are present RFI signals at several discrete frequencies in this band. However, I would like to stress that more sensitive measurements must be made in the GMRT bands near 325 MHz, 610 MHz and 1400-1427 MHz.

The increase of RFI in the bands 152-154 MHz and 230-234 MHz is quite alarming. Detailed measurements are planned for locating the sources of RFI in the RF bands allocated for GMRT. It may be noted that Government of India has allocated the following bands for operation of GMRT : 37.75-38.25 MHz; 152-154 MHz; 230-234 MHz; 322-328.6 MHz; 608-614 MHz; 1400-1427 MHz; 1610-1613.8 MHz; 1660-1670 MHz (for the last two bands NCRA has recently applied for protection). For adequate protection to GMRT, it is required that no transmitters should operate in the GMRT bands upto distances of about 200 km to 600 km for various RF bands. The required protection zones are discussed in Part-III of these reports.

There is no doubt that we must remain very vigilant. It is important to form a team consisting of a few engineers and astronomers who should pursue sensitive measurements and also ensure coordination with other agencies for minimizing RFI to GMRT. Development of a Direction Finding Equipment is essential. A coordinated group effort is required for adequate protection of the bands allocated by the Govt. of India for GMRT operation.

Brief details of the contents of Parts-I to XI of this series of RFI-Reports are given in Part-I which gives an overview. To summarize, Part-I of this series of Technical Reports discussing RFI, gives an overview of the Frequency Coordination carried out, summary of measurements made of the RFI levels at the GMRT site and Recommendations for future work. Part-II summarizes regulations of the International Telecommunication Union (ITU). Part-III gives coordination made nationally by the Wireless Planning and Coordination Wing, WPC. Part-IV forms this report. In Part-VA are summarised RFI surveys made by various groups. In Part-V-B is described surveys of Radio Frequency Spectrum made in 1998 in the frequency range of about 50-350 MHz using a Log-periodic Antenna and a Spectrum Analyzer; it is concluded that the harmonics of transmitters operating in the frequency range of 76-77 MHz near Pune, Mumbai and beyond are unlikely to be the source of RFI seen in the band 152-154 MHz at the GMRT site. Part-VI describes measurements of spark-induced RFI from automobiles made by Venkatasubramani and Saini. Part-VII describes RFI from 11 kV Power Lines, which produce severe interference to GMRT and also gives recommendations for reducing it. Part VIII gives estimates from the literature of RFI from AC-HT lines (>66 kV) and Part-IX for DC-HT line which passes about 1 to 2 km away from E5 & E6 antennas. In Part X and Part XI are summarized potential threat of RFI from Low Earth Orbiting (LEO), medium-earth orbit (Iridium) and Digital Broadcasting (World Space) satellite networks, and also analysis and coordination done by us for some of the satellite networks. In part XII is given a summary of the propagation losses due to line-of-sight, diffraction and tropo-scatter propagation. In Part-XIII are discussed various mitigation techniques for minimizing harmful effects of RFI.

1. INTRODUCTION

GMRT consists of 30 nos. of fully steerable parabolic dishes located in an array which has an overall extent of about 25 km (Swarup, 1990; Swarup et al. 1991; 1996) Its main objective is to make very sensitive radio astronomy observations. GMRT operates in several radio frequency bands from about 38 MHz to 1670 MHz (Table-1). These bands have been allocated to the radio astronomy service internationally by the ITU and also nationally by the WPC. However, the frequency range of the GMRT antenna feeds and RF front end is much wider (see Table-2). GMRT is the largest radio telescopes in the world operating in the above frequency range. It has been designed and constructed fully in India. GMRT is located near Narayangaon about 65 km north of Pune (latitude 190º 06' N; longitude 74º 03' E).

The sensitivity of a radio telescope is about 50 to 60 dB (about 10^5 to 10^6 times) higher than that of a communication receiver. Hence, it has been recommended by ITU that no transmitters should be located at distances varying from about 500 to 600 km from the site of a radio telescope, depending upon the frequency of operation and terrain. Coordination has not been a problem for the bands 322-328.6 MHz, 608-614 MHz and 1400-1427 MHz. However, the radio frequency bands 152-154 MHz and 230-234 MHz have been specially coordinated by WPC for operation of the GMRT, after a great deal of discussions with other user agencies and for which coordination distances, are only 200 to 400 km as have been mutually agreed to (see part-III of this series of reports). According to the ITU Recommendation ITU-R 769.1, the harmful level of interference to the radio astronomy observations in the band 152-154 MHz is -194 dBW/m^2 and in the band 230-234 MHz is estimated as -192 dBW/m^2 (see Table-3).

RFI measurements have been made at the GMRT site on several occasions during 1985 to end 2000. In Appendix-A are summarized various methods which have been used for RFI surveys and the analysis procedure used. Sensitivity of a radio telescope and required protection levels are summarized in Appendix-B. In RFI-Report, Part-V are given a summary of various measurements made at the GMRT site by various groups during 1985-2000 with suitable references to other reports. In Section 2 are described RFI measurements made at the GMRT site and also near Alephata, Sangamneer, Junnar, Pune and Lonavala/Khandala during April 1998-September 2000 to identify the operating frequencies, power flux density and approximate directions of various radio transmitters producing severe RFI to GMRT, particularly in the bands 152-154 MHz and 230-234 MHz. Results are summarized in Section 3. Discussions are given in Section 4 and Conclusions in Section-5.

2. RFI MEASUREMENTS MADE DURING APRIL 1998-SEPTEMBER 2000

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RFI measurements have been made using the primary antenna feeds of the 45-m diameter parabolic dishes of GMRT. These feeds are located on a turret which can be rotated from the Control Room of GMRT and is placed at the focus of the dishes (Swarup et al. 1991 and Appendix-A). At 150 and 325 MHz, the primary feeds consist of crossed dipoles backed up by plane reflectors. The feeds at 235 MHz and 610 MHz are dual coaxial feeds. A corrugated waveguide feed is used for the 1000-1427 MHz band. The feeds can be remotely rotated from 0^o to 270^o to point either towards the dish or zenith or horizon. The feeds have a gain of about 8 to 10 dB. Parabolic dishes are fully steerable in Azimuth by ± 270^o and in Elevation from about 17^o to 110^o, above the horizon.

Low noise amplifiers are placed after each of the primary antenna feeds. The received RF signals are converted at the base of each antenna to Intermediate frequencies of 130 MHz and 175 MHz, for the two polarizations received by each antenna, using remotely controlled local oscillators. The two RF signals are brought to a Central Receiver Room using optical fibre transmission system.

RFI Measurements have been made at the GMRT site using the primary antenna feeds pointed towards the horizon in four different directions. The 130 MHz IF outputs of the antennas in the Central Electronics Building are connected to a HP 8590 spectrum analyzer. Most of the measurements which were made during April 1998-September 2000 used resolution bandwidth (RBW) of 10 or 30 kHz, video bandwidth (VBW) of 1 kHz, and averaging of 10 or 20 scans. Surveys have been made at the GMRT site mostly in the bands 152-154 MHz, 230-234 MHz and 322-328.6 MHz and also at adjacent frequencies of ± 16 MHz. For measurements described in this report for the period April 1998-September 2000, scans across the frequency bands have been taken only periodically during day and night on several days but more detailed measurements were made in December 1996-January 1997 and recently in 1999 by Venkatasubramani (1996,1997) for several days more or less continuously (RFI-Report, Part-V A). Sensitivity of the present survey at the GMRT site is only about - 155 to - 160 dBW/m^2. Thus only the strong sources of RFI which are likely to be located within about 100 to 150 km distance from the GMRT site have been identified. More sensitive RFI surveys on a 24 Hrs. basis for several days should be made periodically using the GMRT radio interferometric system with likely sensitivity of about -190 dBW/m^2.

Surveys of Radio Frequency Spectrum (RFS) in the frequency range of about 50 MHz to 350 MHz have also been made at the GMRT site and at Pune in the GMRT bands using a log-periodic antenna, low-noise amplifiers and a spectrum analyzer (Part-VB). Sensitivity reached is about -145 to -150 dBW/m^2. Preliminary surveys have also been made at Lonavala, (70 km S-W of GMRT), at certain locations overlooking Mumbai and also at Sangamneer (40 km north of GMRT), Kukdi (10 km west of the central array) and Junnar (25 km west of the central array). Several frequencies of RFI have been identified as described in the next section.

Various methods used for RFI surveys and procedure used for data reduction for determining the values of the received power flux density (W/m^2) are described in Appendix-A.

3. RESULTS

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Results of our RFI surveys made in the frequency range of about 151.80-154.43 MHz and 229.70-234.50 MHz are summarized in Tables 4 and 5 respectively for the GMRT site. It may be noted that the estimated values of power flux density (dBW/m^2) at the GMRT antennas are approximate and may have errors upto ± 5 dB (see Appendix-A). In Tables 6 are given a summary of measurements made from about 100 MHz to 350 MHz from 1985 to 2000. Sensitivity of measurements made during 1997-2000 is higher than for the earlier period. Measurements made in the band 150.80 to 154.43 MHz and 229.7 to 234.25 MHz are given in Tables-4 & 5 as well as in Table-6.

Tables 7 to 10 refer to measurements made at Pune, Lonavala, Khandala, Sangamneer and Junnar.

In Tables 4 and 5, date and time of measurements are given in Cols. 1 and 2, frequencies of RFI (MHz) in Col. 3, direction of the GMRT antenna feeds in Column 4, and power flux density (PFD in units of dBW/m^2) in Col. 5. In Tables 7 to 10, PFD values are given for 4 different directions in which the log-periodic antenna was pointed.

Measured values of frequencies of the transmitters have an error of ± 0.02 MHz or larger depending upon the signal strength and also values of the resolution bandwidth and frequency span selected for the spectrum analyzer.

In Figs 1(a) to 1(p) are given typical spectrum analyzer outputs obtained at the GMRT site in the bands 152-154 MHz. In Figs. 2 & 3 are given modulation characteristics of signals observed at 146.6 MHz (Pager transmitter) and for signals near 165 MHz. In Figs. 4(a) to 4(f) and Figs. 5(a) to 5(h) are given outputs for the band 230-234 MHz. RFI in adjacent bands is also seen in many of these plots (Please see Sections 4.1 and 4.2 for discussions concerning these results). The plots show strong sources of RFI superimposed on the IF band of the GMRT receiver system. GMRT receiver system allows observations over a 32 MHz bandwidth but it may be noted that there are filters present in the RF, IF and Base Band systems which can restrict the radio astronomy observations to be made only within the allocated bands.

In May 1998 and in September 2000 detailed measurements for RFI were also made in the frequency range of about 230-234 MHz or wider using GMRT antennas, selected from the Central as well as Y-Array. Antennas were pointed towards each of the South, West, North and East directions. It was found that some of the RFI signals appear only in one of the four directions, (see Figs. 4(a) to 4(f) for typical records). For some signals the frequency was found to vary with time. Thus, it seems that some of the RFI signals could have arisen locally within a km or so of these antennas from GMRT electronics or other equipment such as PCs or Tvs (oscillating TV Booster) Figs. 5(a) to 5(g) shows results of measurements made on 6th September 2000 near 234 ± 2.8 MHz by A. Frezot, A. Sarkar and S. Ananthakrishnan (coordinated by G. Swarup) in which 4 antennas each were pointed towards N, E, S and West and a signal at 234.0 MHz and later at 235.0 MHz was radiated from the Housing Colony at Narayangaon. Scans of either 256 ms only or 10 sec. integration (?) showed some intermittent RFI but averaging over 6 x 10 seconds shows clearer scans except for W05 and C10 antennas for which there may be present instabilities or power-line RFI. A RFI signal near 233.5 MHz was also seen in W04 output and may be a local RFI.

In Fig. 6(a) is given RFI measurements made in the band 300-360 MHz on 26th July 1996. Several signals are seen in the frequency range of about 305-315 MHz and 328-356 MHz but not in the 322-328.6 MHz protected band. In Fig. 6(b) to 6(g) are shown RFI and pass-band measurements made in the 325 ± 8 MHz band. No RFI above the sensitivity level of about -154 dBW/m^2 was observed; the pass-band show appreciable ripples. In Part-V of these series of reports are presented a summary of RFI measurements made by various groups for several frequency bands from about 100 MHz to 1500 MHz. In Figs. 7(a) and 7(b) are shown a summary of RFI measurements made by T.L. Venkatasubramani in January/February 1997 (see Venkatasubramani, 1996 and RFI-Report, Part-V A) in the frequency range of about 100 MHz to 1400 MHz. In Figs. 7(c) and 7(d) are shown measurements made by him in July 1999. The following conclusions can be made from these surveys:

i) There occurs considerable RFI in the band 152-154 MHz, which has increased considerably from January/February 1997 to July 1999.

ii) There also occurs appreciable RFI in the protected band 230-234 MHz, which has also increased in 1999 compared to 1997.

iii) Level of RFI above the sensitivity level of measurements of about -150 to -160 dBW/m^2 is not significant in higher frequency bands.

Some typical measurements made in the 153 MHz band using a log-periodic antenna, 60 dB amplifier and a Spectrum Analyzer (see Appendix-A) near Sangamneer, Alephata, Junnar, Pune, Lonavala and Khandala are shown in Fig.8. Measurements made at the above locations near 233 MHz band are given in Fig. 9 and at Khandala/Lonavala in Figs. 10 and 11. In Figs. 10 & 11 is presented a graph giving summary of RFI seen at the GMRT site and nearby regions (Sangamneer, Alephata, Kukdi, Pune, and Lonavala/Khandala, etc.). Measurements made in the band 300-350 MHz at Pune, Lonavala & Khandala are shown in Fig. 12. Location of these sites are shown in Fig. 18. These measurements were made only for horizontal polarization. It is desirable to make such measurements in future for both horizontal and vertical polarizations. However, for the case of measurements made with GMRT antennas, both polarizations are covered as the feeds are circularly polarized for 150, 235, 325 & 610 MHz and orthogonal linear for 1000-1420 MHz.

Measurements of Radio Frequency Spectrum (RFS) were also made using a log-periodic antenna with a bow-tie (LPA) located (a) above the computer room of the central electronic building, (b) inside the Receiver and Control/Computer room and (c) on a 9-m high tower near the C-4 antenna. A summary of these results is also given in RFI-Report Part-V B. These measurements have been made from about 40 MHz to 350 MHz. In the measurements made above the computer room, lot of RFI was seen at spacings of 1 and 2 MHz which seems to arise from the electronic equipment in the central electronics building. The RFI levels were much lower in the measurements made with the log-periodic array placed near the C-4 antenna, but it could be due to much lower height of the LPA (9 m) compared to that of the primary feeds at the focus of the GMRT antennas (about 40 m). Discussions and Conclusions of these RFS surveys are given in RFI-Report, Part-V-B.

4. DISCUSSIONS

4.1 RFI IN THE GMRT FREQUENCY BAND 152.0 TO 154.0 MHz.

One of the prime purpose of the surveys was to make a preliminary assessment of the directions, power flux-density level and frequencies of narrow-band RFI being observed in the bands allocated by WPC to the GMRT. These surveys were made only occasionally as most of the scientists and engineers were busy in getting the GMRT going.

Surveys made at the GMRT site during 1985-94 did not show much RFI in the band 152-154 MHz. However, surveys made in 1995 and 1996 identified RFI at some discrete frequencies. Surveys made by T.L. Venkatasubramanian (TLV) during December 1996-January 1997 and July 1999 for several days on a 24-hr. basis using the GMRT antenna feeds (RFI-Report, Part-V A; also Fig. 7 of this report Part-IV) show increase in the level of RFI in 1999 compared to earlier period.

Results of surveys made by the Pulsar group during December-January 1998 and those presented in this report show that the degree of RFI seen in the 152-154 MHz band is quite severe and requires urgent coordination with various agencies.

In Figs. 1(a) to 1(o) we have presented only some of the typical records for the surveys made on 28.04.98, 29,04.98 and 26.07.98 but have given all the records obtained on 2.09.98 and 3.09.98. Most of the strong or appreciable RFI observed has been summarised in Table-4, but many of the weak RFI signals are not tabulated. As can be seen from Figs. 1(a), 1(b) and 1(c) that RFI is present in the output of some of the GMRT antennas at harmonics of 922 kHz and is likely to arise from the LO-Synthesizer system as the frequencies of the harmonics are closely the same in different antennas.

It is seen that RFI is seen at a large number of discrete frequencies in the 152-154 MHz band. Most of these vary with time and are therefore not likely to arise from the electronics system of GMRT. Do some of the RFI signals arise from inter-modulation products ? The front end RF amplifiers of GMRT have a bandwidth of about 40 MHz, followed by a mixer, 32 MHz SAW filter at 70 MHz, further selectable IF SAW filters of 16 or 5.6 MHz at 130 and 175 MHz (RH & LH polarization) and finally the IF signal is transmitted on analog optical fibre link. For most of the RFI surveys presented in this report, an IF filter of 5.6 MHz was used. Hence, most of the RFI detected is unlikely to arise from inter-modulation, although further tests on the 150 MHz front-end are required to be done. Besides, a radio frequency survey (RFS) made by G.Swarup and S.Joardar at the GMRT site in February 1998 (Part-V-B) using a log-periodic antenna in the frequency range of about 40 MHz to 360 MHz did not show any strong signals at half or one-third frequency of the 152-154 MHz band and hence the RFI in these bands is unlikely to be due to the 2nd or 3rd harmonics of transmitters located near, Pune, Lonavala, Mumbai and beyond.

RFI arises in the 152-154 MHz band mostly from the Southern direction but there are many cases of RFI from East and West direction. It may be noted that the GMRT feeds have a 10 dB beamwidth of about 120^{o} or 130^{o} and hence weak RFI could be seen when the feed is in East or West direction, even if the source is in the Southern direction.

As noted above RFI is seen in the 152-154 MHz band at many discrete frequencies. However, the RFI signals are more frequent at some of the frequencies and are also higher in strength. These strong and frequent RFI are near 152.10 ± 0.1, 152.25, 152.78 and 153.58 MHz. In Fig. 1(d) are shown records of the RFI near 152.1 MHz with a span of 200 kHz, RF Resolution Bandwidth (RBW) of 10 kHz and VBW of 300 Hz. As shown in Fig. 10, there is some indication that some of the RFI seen in the 152-154 MHz arises from equipment near Pune and Lonavala. This needs to be investigated further.

It is seen from Fig. 1(f) that there seem to be either two FSK transmitters at 152.06/152.08 MHz and 152.110/152.138 MHz or there could be 4 FM transmitters. Further investigations are necessary to locate the source of the RFI near 152.1 MHz which is quite strong and is present most of the time. As also noted in the previous para, strong signals at these frequencies are also present at Lonavala. Perhaps, transmitters at the INS Shivaji at Lonavala are radiating in the protected band of GMRT. We need to investigate this in the near future.

Figure 1(p) shows various transmitters in the frequency range of 140-180 MHz whose signals are being received at the GMRT site. Signals from 4 transmitter sources were quite strong.

a) Paging transmitters at 146 MHz; - there are perhaps two transmitters.

b) Police wireless 158 MHz.

c) Paging or other fixed service transmitters near 165 MHz

d) Pune T.V.

In view of the strong signals, it has been found necessary to put 14 dB “Solar Attenuator” in the front-end electronics for making satisfactory observations at 150 MHz.

The 150 MHz GMRT feeds has a bandwidth of (SWR < 2) of about 120-210 MHz. However, there is installed in the Front-end Box a filter with a 3 dB bandwidth of 130-170 and 10 dB bandwidth of about 125-180 MHz. We should install narrow band selectable filters of 4, 10, 40 MHz and also no filter in the 150 MHz front end box so that we can make observations at various frequencies in the band for observations such as recombination line or for solar observations. Also, over the next few years, we should plan to increase the dynamic range of the 150 MHz front-end electronics.

After the mixer at the base of the antenna, there arises a signal at IF with a frequency of 70 MHz which is applied to a 32 MHz SAW filter. In the second IF at 130 and 175 MHz there are switches which provide either direct path to 32 MHz or SAW filters of 16 MHz or 5.6 MHz. Since the frequency band 140-180 MHz is heavily occupied, it desirable to use a second 5.6 MHz filter in the 2nd IF stage to provide high selectivity and to use only a 2 MHz baseband filter for sensitive observations in the frequency band 152-154 MHz.

4.2 RFI in the Frequency band of 230-234 MHz

Fig. 4(a) show RFI measurements in the band 235 ± 8 MHz made at the GMRT site in May & June 1998. These Figures show plots of HP spectrum analyzer (SpA) scans obtained for the 130 MHz IF channel, at the output of the optical fibre in the Receiver Room of the GMRT. The following conclusions can be made

i) RFI at 229.75 MHz is stronger towards South (-124 dBW/m^2) and was seen on both May 27th & May 29th 1998.

ii) A strong signal was seen near 231.0 MHz towards North, on 29th May 1998 but at 231.35 MHz on 27th May 1998.

iii) Signal at 237.10 MHz was observed on 29th May 1998 around $22^h\ 10^m$ 1998 as well as on 27th May 1998 around $15^h\ 39^m$. Similarly signal near 233.10 MHz was present on both days for W3-N (and not seen for W2-5 and S6-E).

iv) In S6-E was present a signal near 233.80 MHz whose frequency varied by 0.3 MHz from about 233.65 to 233.95 MHz over minutes (see Fig. 4(e))

v) A strong signal was observed for W3-N on 27th May 1998 around $16^h\ 03^m$ whose frequency was seen to vary by about 0.7 MHz from about 241.575 MHz to 242.255 MHz over minutes (Fig. 4f).

vi) Signal at 243.9 MHz had on an average same p.f.d. for W3-N and S6-E may have occurred in the north-east direction.

FIG. 5(a) to 5 (d) : show signals received at (W01, E03, C00, C09), (W02, E04, C02 and C10); (W04, E05, C03 and C12) and (W05, E06, C04 and C13) antennas pointed towards N, E, S & W respectively and show several sources of RFI in addition to 234.0 MHz signal transmitted by us from the GMRT housing colony near Kukdi before 1556 hours and 235 MHz after 1556 hours. The following conclusions may be made from Figs. 5(a) to 5(d).

i) RFI signals are seen at discrete frequencies (in addition to 234.0 and 235.0 MHz) which are present at more than one antenna pointed in the same direction and in a few cases even adjacent directions

* 231.29 MHz at W01-N; C00-N and W02-E
* 232.6 MHz at E05-S and C12-S
* 233.3 MHz at C04-W and W02-E
* 236.9 MHz at W01-N; C00-N; C02-E, W02-E, C10-E

However, the above are not seen at all the antennas pointed in the same direction, perhaps due to propagation effects.

ii) Several RFI signals are seen at only one of the antennas out of a group of 3 or 4 working antennas pointed in the same direction. It is not clear whether these arise due to any local or nearby sources.

4.3 RFI surveys in the GMRT bands of 322-328.6 MHz, 608-614 MHz and 1000-1427 MHz

As shown in Figs. 6 and 7, the level of RFI in the above bands is relatively weak. However, more sensitive and continuous measurements need to be made as discussed in RFI-reports Part-I.

4.4 Path Loss

Calculations for expected path loss between GMRT site to Mumbai and GMRT site to Pune were done by the National Physical Laboratory, New Delhi (NPL) in 1986 on our request. In Fig. 13 is shown the path height profile between Mumbai and the GMRT site. Based on this data, NPL calculated the probability function for the path loss which depends on the refractive index of the atmosphere that depends on the season and time of the day. In Fig. 14 is shown the probability function for Mumbai-GMRT, for which case it was calculated that the path loss is expected to be more than 170 dB for 50% of time and more than 150 dB, 65% of time. Similar calculations by N.P.L. predicted loss of 150 dB or more 83% of time between Pune and GMRT site (Fig. 15). In Fig. 16 is given estimates made by T.L. Venkatasubramani (RFI-Report Part XII) using N.B.S. Tech. Note 101, Vol.II. However, according to N.P.L. these may not be applicable for India. It would be useful to monitor the Power level of signals from strong transmitters, say paging Tx receiver at GMRT as well as that of TV transmitters located near Pune and Mumbai.

According to ITU report 329-6 the spurious emission (including harmonics) from a transmitting equipment should not exceed above 50 microwatts (depends on the national standards and power of the transmitter but the above value is for transmitters of less than 100 W or so). For a path loss of about 150 dB, we should therefore not suffer from weak RFI at a level of about -190 dBW/m^2. Further, an interferometric system will give us a protection of another 8 or 10 dB. Please see Part-V-B for further discussions.

4.5 Probable sources of RFI in the GMRT bands of 152-154 MHz and 230-234 MHz.

It is seen from Tables 4 and 5 and Figures 1, 4 and 5 that the power flux density of most of the strong sources of RFI at the GMRT site in the GMRT bands lies in the range of about -137 to -150 dBW/m^2. The estimated propagation loss between the GMRT site and Pune is about -150 dB and about -165 dB between the GMRT site and Mumbai. These losses can vary by about ± 10 dB depending upon the troposcatter conditions which is dependent on the atmospheric refractive gradient. Most Fixed (FX) transmitters used for radio communications radiate power in the range 15 W to 40 W. For a 25 W transmitter (+ 13 dBW), the estimated value of pfd at the GMRT site for a transmitter at Pune is given by pfd = -150 dB/m^2 + 13 dBW = -137 dBW/m^2.

It is therefore seen that our measurements are consistent with the assumption that some of the transmitters giving strong RFI are likely to be located near Lonavala, Mumbai, Pune, Ahmednagar or Nasik. For the required protection of -190 dBW/m^2, as agreed by the WPC (RFI Report - Part-III no transmitters should be located in the GMRT bands upto a distance of at least 400 km for 152-154 MHz, 200 km for 230-234 MHz bands and 600 km for 322-328.6 MHz and 608-614 MHz bands (Fig. 17). All transmissions are prohibited by the ITU for the band 1400-1427 MHz which is used for spectral line radio astronomy observations and also passive sensing of earth’s resources and earth’s atmosphere by Remote Sensing.

The RF band 150.05-153 MHz is allocated to MAR - Rural Communication System but the MAR authorities have agreed not to use the band 152-153 MHz upto 400 km distance from the GMRT site (RFI-Report Part-III) and also confirmed the same when myself, Prof. S.H. Damle and Shri M.R. Sankararaman visited their office in mid-1998. The band 153-156 MHz is allocated to Defence but they have agreed to protect GMRT in the band 153-154 (RFI Report - Part-III).

It may be noted that if there are present several RFI signals with pfd values greater than about -158 dBW/m^2, there is likely to take place serious loss of the sensitivity of continuum observations with GMRT. For the 4-bit GMRT correlator, the intermodulation products are expected to be about - 35 dB (needs to be tested - this estimate is based on estimates which I got made during 1988 both theoretically and simulation tests made by NRAO on our request). Therefore, if there are present two RFI signals with power received by the antenna which is greater than 35 dB compared to the rms noise, the non-linearity imposed by the 4-bit correlator will produce a third spurious signal at $(2f_2-f_1)$ or $(2f_1-f_2)$ frequency. Let us consider a case when the baseband filter used has a 2 MHz bandwidth and the correlator provides 128 frequency channels so that each channel has a width (Df) of about 15.8 kHz. The rms sensitivity at input of front-end amplifier for t = 2000 s integration is given by

$$Dp = kDT, \; Df/ (Df \times t)^{1/2}$$

$$= k T_s (Df/T)^{1/2} \; k T_s (Df \times t)^{1/2}$$

Where T_s = system temperature, (500 k at 150 MHz) so that

$$Dp = 1.38 \times 10^{-23} \times 500 \times (15,800/2000)^{1/2}$$

$$= - 198 \text{ dBW}$$

Since the gain of distant sidelobes of the GMRT antenna is about 1 (i.e. G=1), the corresponding collecting area, A= $(l^2 G/4p)$ = - 5 dB for l = 2m (150 MHz).

Hence, it is required that the level of RFI for avoiding intermodulation in the Correlator should be weaker than, S,

$$S = -198-(-5-35) \text{ dB}$$

$$= - 158 \text{ dBW/m}^2$$

This is a rough estimate and needs to be tested. Hence it is very important that we locate the sources of RFI in the protected bands of GMRT which are greater than about -158 dBW/m^2 and get these transmitters or faulty equipment to stop radiation in the GMRT bands.

4.5 Radio Frequency Spectrum

In the VHF bands of about 40 MHz to 235 MHz there exist a large number of active transmitters in India. Band 61-68 MHz is allocated to one of the three TV transmitter at Mumbai with 62.25 MHz for picture carrier and 67.75 MHz for sound carrier. The band 68 to 85 MHz is allocated to fixed mobile transmitters; the band 85-110 for FM transmitters at Pune, FM station transmits at 102 MHz), 108-130 MHz to civil aviation. The band 130 to 171 MHz is allocated to fixed mobile transmitters, but 136-137 MHz is allocated to space-to-Earth transmitters. The band 175 to 230 MHz is allocated for TV transmission with 175 to 181 MHz for Pune, T.V. The band 230 MHz to 400 MHz (except 322-328.6 MHz) is allocated to the Fixed and aeronautical mobile services, mostly to Defence but there are new civil allocations in the offing. The band 322-328.6 MHz has primary allocation for Radioastronomy service.

It is also clear that there exist several sources of RFI closer to various antennas of GMRT. It is recommended that measurements be made with feeds of all the antennas pointed towards N, E, S, W sequentially for all the available antennas for a few hours every month. We should also carry out periodically interferometric measurements using all the available antennas of GMRT, which will give better sensitivity. In order not to be flooded with data, one may take scalar average for each frequency channel for each 16 sec. sampling time and make greyscale plot by plotting frequency (channels) versus time.

In RFI-Report Part-III are presented measurements made in 1998 at the output of a TV cable at NCRA-Pune in the frequency range of about 48 MHz to 258 MHz providing 30 TV channels. Some of the T.V. cable operators are also using bands upto about 350 MHz. Many of these cable TV operators are using very poorly shielded coaxial cables and for which the wires are also not properly silvered as per specifications. It is quite probable that many of these cable networks are radiating strong spurious emissions in the above frequency range. Suitable protections need to be provided by WPC in this connection. The RFI to the GMRT from the TV cable operations was brought to the attention of WPC in a meeting held at Delhi in July 1998. WPC requested us to identify the actual sources of RFI from TV cable operations in GMRT area. If this is pointed to them, they would try to provide protection to GMRT by requesting cable TV operators not to make TV transmissions in the GMRT bands and also adjacent channels. Any case, we should note that many of the sources of strong RFI seen at the GMRT site are not likely to be from Cable TV because the received power varies over several minutes (on and off) typical of a communication signal. This can be checked easily with a VHF communication receiver with a voice which has been purchased recently.

5. CONCLUSIONS

GMRT is world’s largest radio telescope operating at metre wavelengths. Hence, it is important to provide adequate protection in its band of operation. Careful coordination is required between TIFR, WPC, monitoring Agency of WPC/DOT at Mumbai and various concerned radio communication agencies at in the Pune-Mumbai region.

signals may be spurious measurements from local sources, such as GMRT electronics, PCs, etc. and others may be arising due to transmitters operating in the GMRT bands in the coordinated area (!) or due to spurious emission of electronic equipment such as PCs, etc. A few of the RFI signals could be due to intermodulation products. Several conclusions are given in Sections 4.1, 4.2 and 4.5.

Following steps are recommended

a) RFI arising from GMRT electronics should be identified urgently and steps taken to suppress the same, as discussed in detail in RFI-Report, Part-I.

b) WPC to identify agencies which may be operating in the GMRT bands.

c) TIFR to undertake more sensitive measurements including use of a mobile test van with direction finding equipment, spectrum analyzer and vhf/vhf AM/FM receiver; also to listen to the received signals to identify whether the RFI signals e.g. at 152.11/152.13; 152.78/80 and 153.58 are AM/FM or voice or data streams or of spurious origin. Any faulty oscillating equipment, such as TV Booster or spurious emission from P.C. is likely to have a very narrow bandwidth. Hence, modulation as well as time-behaviour of RFI is likely to give a clue about its source.

d) Regional Monitoring Stations at Mumbai or the Wireless Monitoring Agency at Delhi to undertake a survey to identify locations of transmitters producing RFI to the GMRT.

In RFI-Report Part-I are given more detailed recommendations for RFI protection to the GMRT.

6. ACKNOWLEDGMENTS

Many colleagues at TIFR have contributed to the RFI measurements described in this report. Contributions made by T.L. Venkatasubramani, S. Ananthakrishnan and M. Srinivasan at the GMRT site during 1985-1997 and by S. Joardar at the GMRT site

Pune, Lonavala and Khandala during early 1998 are specially acknowledged. Further measurements of RFI have also been made at the GMRT site since September 1998 by M.R. Sankararaman and colleagues. The required RF amplifiers and filters for measurements made at Pune, Lonavala, etc. using the Log Periodic Antenna were made by Shri Shiralkar, who also helped in making various measurements. A software programme for reducing the data obtained with the LPA was written by S. Joardar. A.V. Atre helped in some of the measurements made during October 1998 to March 1999.

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LIST OF TABLES

TABLE - 1

FREQUENCIES ALLOCATED FOR GMRT BY WPC, MINISTRY OF COMMUNICATIONS, GOVT. OF INDIA *

	Frequency Bands	Allocation Status (ITU)	
1.	37.75 - 38.25 MHz	Secondary	Internationally
2.	152 - 154 MHz	Primary	Several countries including India
3.	230 -234 MHz	Coordination	(Nationally)
4.	322 - 328.6 MHz	Primary	Internationally
5.	608 - 614 MHz	Primary	Several countries including India
6.	1400 - 1427 MHz	Exclusive	Internationally
7.	1610 - 1613.8 MHz	Primary	Internationally
8.	1660 - 1670 MHz	Primary	Internationally

* For further details, please see Part-II and Part-III of this series of reports on RFI.

TABLE-2 FREQUENCY RANGE AND BANDWIDTH OF GMRT RECEIVERS

Sr. No.	GMRT Protected Bands	Redshift for HI Observation	Frequency Range of GMRT Front End	Probable Usable Bandwidth for which RFI level is low
	MHz		MHz	MHz
1.	37.5 - 38.25	-	40 - 60 *	~ 1 MHz
2.	152-154	8	153 ± 16	2.0 (4)
3.	230-234	5	233 ± 16	4 (8)
4.	322-328.6	3	325 ± 16	32
5.	608 - 614	1.3	611 ± 16	32
6.	1330 -1400	0.1	1000-1400	32
7.	1400 - 1427	~ 0		32
8.	1610 - 1613.8		**	3
9.	1660 -1670		**	10

* To be installed during 1999-2001

** RRI has modified the frequency range of the 21-cm feed to 1150-1700 MHz by optimizing the ortho-mode polarizer. They will try to make it to operate from 1000-1700 MHz. Another possibility is to make a small horn and an amplifier to cover only from 1600-1700 MHz only and use the present 50 MHz port of the Common Box for the 1.6 GHz band and to bring down signal of the 50 MHz ± 10 MHz from the focus to the ground through separate cables.

TABLE - 3

Sensitivities and harmful interference levels for radio astronomy continuum observations with 2000s integration time

(extracted from Table 1. Rec. 769 page 22 of ITU-R Recommendations, 1994 RA Series Volume)

Centre Frequency (1) fc (MHz)	Assumed Bandwidth Δf MHz	Antenna & Receiver Noise temperature T_R (K)	Harmful Interference Levels	
			Power flux-density $\Delta P_H = S_H \Delta f$ (dB(W/m²))	Spectral Power flux-density ΔS_H (dB(W/m² Hz))
151.5	2.95	300	-194	-259
325.3	6.6	140	- 189	-258
611	6.0	115	- 185	-253
1413.5	27	30	- 180	-255
1665	10	30	- 181	-251

Calculated values for other bands (headings see above)

38	0.5	7000	-195	- 252
50	1	5000	- 193	- 253
233	4	200	- 190	- 256

TABLE 4

RFI MEASUREMENTS AT GMRT SITE GIVING A LIST OF FREQUENCIES AND POWER FLUX DENSITY OF THE RECEIVED SIGNALS IN THE FREQUENCY BAND 151.5-154.4 MHz. THE DIRECTION OF THE ANTENNA FEEDS IS SHOWN BY N, E, W OR S FOR NORTH, , EAST, WEST & SOUTH RESPECTIVELY (FREQUENCIES AND AVERAGE PFD ARE APPROXIMATE : SEE TEXT)

Date	Time IST	f(MHz)	ANTENNA	PFD dBW/m^2	Remarks (Perhaps Same Tx)	Av. PED dBW/m^2
98 07 29	1801	151.30	S02-SW	-142	)	-142
98 09 02	1620	151.45	CO9-E	-152	)	-152
98 09 02	16131	151.538	CO9-E	-153	)	-153
98 29 07	1801	151.67	SO2-SW	-129	)	
98 09 02	1625	151.68	C09-E	-148	)	
98 09 02	1631	151.70	C09-E	-157	) 151.70	-146
98 07 29	1759	151.7	E02-SW	-150	)	
98 09 02	1620	151.76	C09-E	-154	)	
97 03 07	2210	151.8	COO-S	-147	) 151.78	-151.00
98 04 28	1811	151.83	C00-S	-138	)	
98 09 02	1631	151.875	C09-E	-151	) 151.83	-145
98 09 02	1632	151.900	C09-E	-155	) 151.90	-155
98 09 03	1640	152.057	C04-S	-139	)152.06	-141
98 09 03	1725	152.065	C04-S	-143	)	
98 09 02	1635	152.07	C04-S	-153	)	
98 09 03	1629	152.075	C04-S	-137	) 152.075	-143
98 09 03	1640	152.08	C04-S	-139	)	
98 09 02	1631	152.088	C09-E	-154	)152.09	-153
98 07 29	1759	152.09	E02-SW	-151	)	
98 09 03	1640	152.095	CO4-S	-139	)	
98 07 29	1802	152.1	E02-SW	-152	)	
98 07 29	1801	152.100	S02-SW	-149	)	
97 03 07	1731	152.11	C04-S	-134	)	
98 09 03	1725	152.110	C04-S	-137	) 152.11	-141
98 09 02	2327	152.10	C04-S	-140	)	
98 09 03	1641	152.112	C04-S	-138	)	

98 09 03	1729	152.115	C04-S	-138	)	
99 09 23	1305	152.113	C13-5	-141	)	
98 09 02	1635	152.120	C04-S	-141	)	
98 09 02	1628	152.125	C04-S	-137	) 152.12*	
97 03 07	1455	152.13	C04-S	-135	)	
98 04 28	1811	152.13	C00-S	-146	)	
98 04 28	1838	152.13	C05-W	-145	)	
98 07 29	1759	152.13	E02-SW	-152	) 152.13 *	-145
98 07 29	1759	152.13	E02-SW	-152	)	
98 09 03	1640	152.138	C04-S	-139	)	
96-07 26	1742	152.15	W03-S	-156	)	
99 09 28	2008	152.13	C10-S	-136	)	
99 09 28	2009	152.13	C13-S	-144	)	
99 09 28	2011	152.13	S2-S	-147	)	
98 04 28	1825	152.30	C05-W	-145	)	
98 09 02	1629	152.375	C04-S	-151	) 152.35	-149
98 09 02	1628	152.375	C04-S	-153	)	
98 09 02	1620	152.370	C09-E	-148	)	-148
98 09 02	1630	152.45	C09-E	-152	)	
98 09 02	1625	152.5	C09-E	-157	)	-152
98 03 09	1725	152.55	C04-S	-156	) 152.55	
98 04 28	1825	152.60	C05-W	-143	) 152.7	
98 09 02	1632	152.725	C09-E	-147	)	-147
97 03 07	1731	152.74	C04-S	-134	)	
97 03 07	1455	152.78	C04-S	-137	)	
98 07 29	1802	152.76	E02-SW	-153	)	
98 07 29	1759	152.76	E02-SW	-151	) 152.78 *	
98 09 03	1725	152.76	C04-S	-155	)	
98 09 03	1725	152.78	C04-S	-152	)	-148
98 09 02	1455	152.78	C04-S	-143	)	
98 09 02	1635	152.78	C04-S	-155	) 152.78	
98 09 03	1729	152.785	C04-S	-154	)	
98 09 02	1629	152.795	C09-E	-141	)	
99 09 23	1305	152.80	C13-SX	-155	)	
98 09 02	1630	152.795	C09-E	-143	)	
98 09 02	1628	152.795	C04-S	-150	)	
98 09 02	1629	152.795	C04-S	-150	) 152.80 *	-146
95 08 11	2210	152.80	YAGI-S	-134	)	
98 04 28	1846	152.80	C00-S	-149	)	
98 07 29	1801	152.80		-148	)	
98 09 02	1635	152.825	C04-S	-156	) 152.83 *	
99 09 28	2008	152.83	C10-S	-156	)	
99 09 28	2009	152.83	C13-S	-155	)	-156

99 09 28	2011	152.83	S2-S	-158	)	
98 09 02	1629	152.876	C04-S	-151	)	
98 09 02	1636	152.900	C04-S	-151	)	
98 09 02	1635	152.905	C04-S	-151	) 152.90	-151
98 09 02	2327	152.93	C04-S	-148	)	
98 09 02	1629	152.92	C04-S	-155	)	
98 09 02	1625	153.0	C09-E	-155	)	
98 04 28	1825	153.0	C00-S	-142	) 153.0	-152
98 07 29	1802	153.03	E02-SW	-158	)	
97 03 07	1455	153.13	C04-S	-142	)	-142
98 09 02	1620	153.24	C09-E	-154	)	
98 04 28	1825	153.28	C05-W	-145	)	
98 09 03	1725	153.44	C04-S	-155	)153.44	-149
97 07 03	1731	153.44	C04-S	-140		
98 07 29	1759	153.53	E02-SN	-136	)	
98 04 28	1846	153.55	C00-S	-145	)	
98 09 02	1622	153.56	C09-E	-154	)	
98 04 28	1818	153.58	C00-S	-146	)153.58 *	-143
98 07 29	1802	153.580	E02-SW	-133	)	
98 07 29	1801	153.580	S02-SW	-122	)	
98 09 02	1625	153.59	C09-E	-153	)	
98 09 02	1630	153.595	C09-E	-148	)	
98 09 02	1629	153.610	C04-S	-152	)	
98 09 03	1725	153.88	C04-S	-149	)	-149
98 07 29	1759	154.0	E02-SW	-148	)	
98 07 29	1802	154.00	E02-SW	-152	)154	-147
98 07 29	1801	154.01	S02-SW	-142	)	
		154.03	E02			
98 09 02	1620	154.22	C09-E	-153	) 154.20	-153
98 04 28	1811	155.18	C00-S	-143	)	
98 04 28	1818	155.18	C05-S	-143	)	-146
98 04 28	1811	154.43	C00	-145		
98 04 28	1817	154.43	C00-S	-153	)	
98 04 28	1811	155.45	C00-S	-134	)	
98 09 02	2327	155.58	C04-S	-156	)	
98 09 02	2327	156.20	C04-S	-148		

TABLE-~~2~~ 5

RFI MEASUREMENTS AT GMRT SITE GIVING A LIST OF FREQUENCIES AND POWER FLUX DENSITY OF THE RECEIVED SIGNALS IN THE FREQUENCY BAND 229.0-235.0 MHz. THE DIRECTION OF THE ANTENNA FEEDS IS SHOWN BY N, E, W OR S FOR NORTH, EAST, WEST & SOUTH RESPECTIVELY

Date	Time	f (MHz)	Ant	PFD dBW/m^2	REMARKS
98 26 05	2303	229.70	W03-N	-144	) Same
98 26 05	2308	229.70	W03-N	-141	) Tx
98 26 05	2325	229.75	W03-N	-145	)
98 12 05	2216	230.65	E03-S	-138	) Same
98 12 05	2251	230.69	E03-S	-124	) Tx
98 12 05	1756	231.00	E03-S	-140	) Same
98 12 05	1816	231.06	E03-S	-144	) Tx
98 26 05	2258	231.35	W03-N	-127	
98 12 05	1807	232.31	S4-W	-149	) Same
98 12 05	1806	232.75	S4-W	-152	) Tx
98 26 05	2325	233.05	W03-N	-147	)
98 26 05	2303	233.10	W03-N	-148	) Same
98 26 05	2306	233.10	W03-N	-145	) Tx
98 26 05	2310	233.80	S06-E	-150	
98 12 05	1808	234.25	S4-W	-148	

chart5.xls

TABLE- 6

RFI MEASUREMEN TS AT LONAVALA IN THE BAND 151.5 TO 154.5 MHZ

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m²) S	E	N	W	NE	Remarks
Lonavala	98 06 2~~6~~0	1752	151.96	-	-	-	-131		
Lonavala	98 06 2~~6~~0	17.52	152.06	-	-	-	-124		
Lonavala	98 06 12	1602	152.23	-141	-142	-118	-120	-116	
Lonavala	98 06 2~~6~~0	17.50	152.25	-139	-132	-135	-126	-	
Lonavala	98 06 2~~6~~0	17.52	-152.62	-	-	-145	-142		
Lonavala	98 06 2~~6~~0	17.50	153.52	-132	-137	-139	-124	-	
Lonavala	98 06 12	1602	153.53	-138	-140	-132	-126	-139	
Lonavala	98 06 2~~6~~0	17.50	154.81	-138	-133	-139	-133	-	
Lonavala	98 06 2~~6~~0	1752	155.40	-	-144	-	-131		

lona.xls

TABLE - 6(a)

RFI MEASUREMENTS MADE AT KHANDALA IN THE BAND 151.5 TO 154.5 MHZ

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m²)					Remarks
				S	E	N	W	NW	
Khandala	98 06 26	15.30	151.56	-139	-147	-153	-140	-	
Khandala	98 06 26	15.37	152.41	-	-151	-	-154		
Khandala	98 06 12	14.21	152.25	-149	-142	-145	-142	-147	
Khandala	98 06 26	15.37	152.60	-	-148	-	-153		
Khandala	98 06 26	15.30	152.70	-149	-151	-139	-151	-	
Khandala	98 06 12	14.21	152.78	-147	-148	-138	-142	-137	
Khandala	98 06 12	14.21	153.53	-150	-147	-147	-139	-140	
Khandala	98 06 26	15.31	153.53	-	-138	-	-		
Khandala	98 06 26	15.31	154.10	-	-133	-	-		

Khan.xls

TABLE - 6 (b).

RFI MEASUREMENTS MADE AT SANGAMNEER IN THE BAND 151.5 TO 154.5 MHZ

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					Remarks
				S	E	N	W		
S-NER	98 06 24	12.28	152.88	-152.86	-	-	-	-	
S-NER	98 06 24	12.28	154.36	-143.77	-	-	-	-	
S-NER	98 06 24	12.29	152.88	-			-149.86		
S-NER	98 06 24	12.29	154.35	-	-	-	-143.77		
S-NER	98 06 24	12.33	152.06	-	-	-146.90	-	-	
S-NER	98 06 24	12.33	154.36	-	-	-137.77	-	-	
S-NER	98 06 24	12.33	152.03	-	-141.91	-	-	-	
S-NER	98 06 24	12.33	154.36	-	129.77	-	-		
S-NER	98 06 24	12.33	151.33	-	-148.95	-	-	-	

sner-150.xls

TABLE - 6(c)

RFI MEASUREMENTS MADE AT KUKDI IN THE BAND 151.5 TO 154.5 MHz.

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					Remarks
				S	E	N	W		
Kukdi	98 06 25	11.07	153.13	-139.84	-	-	-	-	
Kukdi	98 06 25	11.07	150.75	-146.98	-	-	-	-	
Kukdi	98 06 25	11.07	154.19	151.78	-	-	-		
Kukdi	98 06 25	11.09	151.52	-	-	-	-149.93		
Kukdi	98 06 25	11.09	153.12	-	-	-	-145.64	-	
Kukdi	98 06 25	11.10	151.75	-	-	-154.92	-	-	
Kukdi	98 06 25	11.11	151.75	-	-151.92	-	-	-	

kuk-150.xls

TABLE - 6(d)

RFI MEASUREMENTS MADE AT JUNNAR IN THE BAND 151.5 TO 154.5 MHz

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					Remarks
				S	E	N	W		
Junnar	98 06 23	18.06	151.01	-119.96	-	-	-		
Junnar	98 06 23	18.07	151.01	-	-	-	-123.96		
Junnar	98 06 23	18.08	151.01	-	-	-113.96	-		
Junnar	98 06 23	18.09	151.01	-	-120.96	-	-	-	
Junnar	98 06 23	18.08	154.01	-	-	-146.79	-		

Jun-150.xls

TABLE 6 (e)

RFI MEASUREMENTS AT NCRA, PUNE IN THE BAND 151.5-154.5 MHz

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m^2)					Estimated Direction
				S	E	N	W	NW	
Pune	98 05 22	1205	151.86	-135	-127	-125	-		
Pune	98 05 22	1205	152.00	-122	-136	-125	-126		
Pune	98 05 22	1205	152.26	-	-	-138	-139		
Pune	98 05 22	1205	152.76	-137	-	-141	-144		S, NW
Pune	98 05 22	1205	153.26	-139	-	-	-		
Pune	98 05 22	1205	153.86	-	-	-134	-		
Pune	*98 05 22*	*1205*	*153.50*	-	-	-	*-145*		
Pune	98 05 22	1205	154.01	-140	-	-	-139		
Pune	98 05 22	1205	154.04	-	-147	-141	-		
Pune	98 05 22	1205	154.26	-	-146	-	-		

chart4.xls

TABLE- 7

RFI MEASUREMENTS MADE AT ALEPHATA IN THE BANI D 230 MHZ

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					Remarks
				S	E	N	W		
Alephata	98 06 24	16.54	230.98	-	-152.27	-	-		
Alephata	98 06 24	16.42	231.15	-	-143.27	-	-		
Alephata	98 06 24	16.39	231.31	-143.26	-	-	-		
Alephata	98 06 24	16.41	231.91	-	-	-137.24	-		
Alephata	98 06 24	16.51	231.98	-149.23	-	-	-		
Alephata	98 06 24	16.55	232.11	-	-151.23	-	-		
Alephata	98 06 24	16.52	232.88	-	-	-	-130.20		
Alephata	98 06 24	16.54	232.90		-149.20	-	-		
Alephata	98 06 24	16.51	232.91	-141.20	-	-	-		
Alephata	98 06 24	16.42	232.92	-	-138.20	-	-		
Alephata	98 06 24	16.54	232.95	-	-150.20	-	-		
Alephata	98 06 24	16.55	232.95	-	-144.20	-	-		
Alephata	98 06 24	16.39	232.94	-121.20	-	-	-		
Alephata	98 06 12	16.40	233.87	-	-	-	-116.18		

Ale.xls

7

TABLE- 7(a)

RFI MEASUREMENTS MADE AT JUNNAR IN THE BAND 230 MHZ

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					Remarks
				S	E	N	W		
Junnar	98 06 23	18.32	231.33	-147.26	-	-	-		
Junnar	98 06 23	18.33	231.33	-	-	-	-148.26		
Junnar	98 06 23	18.33	231.33	-	-	-149.26	-		
Junnar	98 06 23	18.35	231.38	-	-136.26	-	-		

lona.xls

TABLE-7(b)

RFI MEASUREMENTS AT NCRA, PUNE IN THE BAND 229-234.5 MHz

Location	Date	Time	Freq. (MHz)	Power Flux Density(dBW/m2)*					Estimated Direction
				S	E	N	W	N W	
Pune	98 05 22		229.15	-139	-	-141	141	-	S, W, N
Pune	98 05 22	1212	229.60	-141	-	-150	-144	-	S
Pune	98 05 22	1257	231.25	-	-	-143	-141	-	NW
Pune	98 05 22	1251	231.66	-141	-	-	-		S
Pune	98 05 22	1257	231.80	-	-	-137	-	-140	N
Pune	98 05 22	1211	232.05	-145	-	-135	-130	-126	NW
Pune	98 05 22	1244	232.70	-144	-	-	-134	-134	NW
Pune	98 05 22	1244	232.98	-	-	-	-141	-139	NW
Pune	98 05 22	1244	233.04	-	-	-	-142	-	W
Pune	98 05 22	1211	233.35	-133	-145	-	-140	-137	NW
Pune	98 05 22	1244	233.48	-	-	-	-139	-135	NW
Pune	98 05 22	1211	233.70	-144	-	-	-	-139	S, NW(233.76)
Pune	98 05 22	1257	233.83	-	-	-134	-	-	N
Pune	98 05 22	1244	233.94	-	-	-	-140	-139	NW
Pune	98 05 22	1244	234.04	-141	-	-143	-145	-136	NW

* Blank (-) indicates values which are near or below the Base Level of about -150 dBW/m

TABLE- 7(c)

RFI MEASUREMENTS MADE AT LONAVALA IN THE BAND 230 MHz

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					
				S	E	N	W	NW	NE
Lonavala	98 06 26	15.41	230.98	-136	-137	-139	-142	-	-
Lonavala	98 06 12	15.54	231.00	-142	-145	-139	-149		-134
Lonavala	98 06 26	15.41	231.78	-148	-	145	-	-	-
Lonavala	98 06 26	15.41	232.19	-148	-146	-145	-147	-	-
Lonavala	98 06 26	15.41	232.51	-122	-121	-131	-137	-	-
Lonavala	98 06 12	15.54	232.53	-134	-138	-134	-144		-130
Lonavala	98 06 26	15.41	233.62	-146	-144.00	-145	-	-	-

lo-230.xls

TABLE- 7(d)

RFI MEASUREMENTS MADE AT KHANDALA IN THE BAND 230 MHz

Location	Date	Time	Frequency MHz	Power Flux Density (dBW/m)					
				S	E	N	W	NW	NE
Khandala	98 06 12	14.21	230.98	-146	-141	-131	-142	-132	-
Khandala	98 06 26	15.51	230.98	-	-140	-	-	-	-
Khandala	98 06 26	15.51	231.42	-	-147	-	-	-	-
Khandala	98 06 26	232.5	232.50	-145	-138	-129	-139	-129	
Khandala	98 06 26	15.51	232.50	-148	-133	-	-	-	-
Khandala	98 06 26	15.51	233.62	-	-147	-	-	-	-

KH-230.XLS

Table-8

RFI measurements in the frequency ranges of 100 to 183 Mhz at the GMRT site during 1985-2000 (see txt)

Date	Time	f (MHz)	Ant	OBS					PFD dBw/M2	Remark
96 05 01	1528	101	C9-S	TLV/SAK						
95 06 06		104							-105	
		110							-102	
		115							-99	Aero
		119							-92	Aero
		124							-87	Aero
		125							-73	Aero
96 05 01	1628	131	C9-S	TLV/SAK					-119	Aero
96 30 04	1700	133	C9-N	TLV/SAK					-128	
95 11 08	2210	140.4	Y(S)+A	GS/APK					-135	
96 30 04	1700	142.3	C9-N	TLV/SAK					-140	
		144.08								
96 30 04	1700	146	C9-N	TLV/SAK					-138	
97 03 07	1455	146.63	C4-S/I	GS/MS/PH				-106	~~-107~~	Pager-1
97 03 07										
97 03 07	1508	146.65	C4-S/1	GS/MS/PH				-123	~~-108~~	Pager-1
98 09 03	1731	146.65	C04-S	GS		10 kHz		-112	~~-125~~	✓
97 03 07	1505	146.63	C4/S/1	GS/MS/PH				-108	✓ -113	Pager-1
Do	1505	146.57	C4-S/1	GS/MS/PH				-105	~~-111~~	Pager-2
97 03 07	1446	146.8	C4-S/I	GS/MS/PH				-107	~~-107~~	
97 03 07	1755	146.63	C4-S	Do		100 kHz		-120		
Date	Time	f (MHz)	Ant	OBS					PFD dBw/M2	Remark
98 28 04	1737	146.8	C5-W/1	GS					-120	

96 05 01	1528	147	C9-S-R						-126	
98 09 03	1731	147.70	C04-S	GS					-158	
97 03 07	1455	147.7	C4-S/1	GS/MS/PH					-136	
98 09 03	1731	147.68	C04-S	GS					-143	
97 03 07	1455	148.73	C4-S/1	GS/MS/PH					-139	
98 09 03	1731	148.35	C04-S	GS					-153	
97 03 07	1455	148.83	C4-S/1	GS/MS/PH					141	
98 09 03	1731	148.85	C04-S	GS					-159	
85 06 06		149.9	Yagi						-103	Satellite
		150							-115	
98 09 03	1731	150.0							-143	
95 11 08	2210	150.08	Yagi(S)+Amp	GS/APK					-114	
95 11 08	2210	150.36	Y(S)+A(16dB)	GS/APK					-156	
98 09 02	2327	150.7	C04-S	GS					-158	
97 03 07	2210	151.8	G C0-S ✓	GS					-149.5	
98 04 28	1811	151.83	CO-S ✓	GS					-141	
		152.08							-158.5	
97 03 07	1455	152.13	C4-S	GS/MS/PH					-138	
98 04 28	1811	152.13	CO-S	GS					-149	
98 04 28	1838	152.13	C5-W	GS					-148	
98 04 28	1825	152.6	C5-W	GS					-146	
97 03 07	1455	152.78	C4-S	GS/MS/PJ					-140	
95 11 08	2210	152.8	Y+Amp 16dB	GS/APK					-137	
98 04 28	1846	152.8	C0-S	GS					-152	
98 04 28	1825	152.3	C5-W	GS					-148	
98 04 28	1825	152.6	C5-W	GS					-145	
98 04 28	1825	153	C0-S	GS					-145	
97 03 07	1455	153.13	C4-S	GS/MS/PH					-149	
97 04 28	1825	153.28	C5-W	GS					-148	
98 04 29		153.58							-152.5	
98 04 28	1818	153.58	C5-W	GS					-149	
98 04 28	1846	153.55	C0-S	GS					-148	
97 03 07	1455	154.18	C4-S	GS/MS/PH					-148	
	1527	154.23	C4-S	GS/MS/PH						
85 06 06	1230	154	Yagi						-85	
		154	W3						-115	
96 04 30	1700	154.5	C9-N						-131	
96 05 01	1523	154	C9-S						-140	
		154.59								
		155								
98 09 02	2327	155.58	C04-S	GS					-157	

95 11 08	2210	156.12	Y(S)+A	GS/APK					-132	
950902		156.20	C04-S	CS					-153	
95 11 08	2210	159.16	Y(S)+A	GS/APK					-151	
960430		158.45	C9-N	CS/SAK					-104	Police
										Wireless
95 11 08	2210	158.63	Y(S)+A	GS/APK					-122	
		159							-122	
96 04 30	1700	158.45 ~~159~~	C9-N					-104	~~-102~~	Police
95 11 08	2210	159.68	Y(S)+A	GS/APK					-113	
97 03 07	1740	159.7	C4-S	GS/MS					-139	
		160.6	Y(S)+A	GS						
		163.08	Y(S)+A	GS/APK						
		+-.04								
		163.64	Y(S)+A	GS/APK	)					
		163.72	Y(S)+A	GS/APK	)				-129	
		163.82	Y(S)+A	GS/APK	)					
85 06 06	1230	163	Yagi						-199	Police
96 25 06	2154	163.5	W2	TLV/SAK					-137	
96 05 01	1628	163.5	C9-S	TLV/SAK					-102	High
97 03 07	1740	163.8	C4-S	GS/MS					-139	
96 07 25	2153	164.3	W2	TLV/SAK					-129	
97 03 07	1740	164.4	C4-S	GS/MS					-142	
97 03 07	1740	166.17	C4-S	GS/MS					-141	

97 03 07	1740	166.24	C4-S	GS/MS					-145	
97 03 07	1740	166.38	C4-S	GS/MS					-146	
97 03 07	1740	166.45	C4-S	GS/MS					-138	
95 11 08	2210	166.6	Y(S)+A	GS/APK					-120	
97 03 07	1740	166.65	C4-S	GS/MS					-135	
96 06 25	2153	167	W2	TLV/SAK					-139	
96 06 25	2210	168.12	Y(S)+A	GS/APK					-131	
95 11 08	2210	169	Y(S)+A	GS/APK					-133	
95 11 08	2210	170.36	Y(S)+A	GS/APK					-129	
96 05 01	1628	170.3	C9-S						-131	
		171								
		172.8							-138	
		173								
		174								
85 06 06	1230	175	Yagi						-88	TLV-Pune
									-105	Carrier
96 05 01	1040	175.5	C9-~~E~~ S						-96	TV-Car
96 04 30	1700	175.8	C9-N						-104	TV-Car

(175-25)

(As per Alloc) TV Car

Correct values of Pune TV are 175.25 MHz for Picture Carrier and 180.75 MHz for Sound Carrier (see Table 9)

05 01	1628	176	C9-S							-83	TV-Car
07 25	2154	175.8	W2 Z	TLV/SAK						-109	TV-Car
		*									
		178									
06 06	1230	182								-90	TV-Aud
		180.75	? (TV	AUDIO	as per Allocation)						Pune
05 01	1040	181	C9-F							-104	
04 30	1700	181.3	C9-N							-115	TV Aud
05 01	1628	181.5	C9-S							-105	TV-Aud
		181.5	WS-Z								
04 30	1700	182.8	C9-N							-123	TV
		184									
		186									

Average pfd meas for Pune TV picture carrier ~ −98 dBW/m² for during 1996. Assume power transmitted was 6 kW (to check). Hence path loss from the ~300 m (to check) high tower at Singhgad (to check) to the GMRT site is about 98 + 38 = 136 dB.
(10 log 6000)

Table-9

RFI measurements in the frequency ranges of 230 to 244 Mhz at the GMRT site

Date	Time	f (MHz)	Ant	OBS					PFD dBw/M2
98 12 05	2216	230.65	E03-S	GS					-138.4
98 12 05	2251	230.69	E03-S	GS					-124
98 12 05	1756	231	E03-S	GS					-140
98 12 05	1816	231.06	E03-S	GS					-144
98 12 05	1806	232.75	S4-W	GS					
98 12 05	1807	232.31	S4-W	GS					-149
98 12 05	1808	234.25	S4-W	GS					-147.6
98 12 05	1806	235.25	S4-W	GS					-146.75

98 12 05	1807	235.38	S4-W	GS						-143.5
98 12 05	1808	236.75	S4-W	GS						-145
98 12 05	1806	237.56		GS						-146.67
98 12 05	1807	238.5	S4-W	GS						-148.8
98 12 05	1806	239.9	S4-W	GS						-147.7
98 12 05	1808	239.38	S4-W	GS						-147.8
98 12 05	1808	241.9	S4-W	GS						150.3
98 05 12	1806	242.13	S4-W	GS						-149.76

Cable TV ?

Sheet1

98 12 05	1807	243.9	S4-W	GS					-147.5
98 12 05	1806	244	S4-W	GS					142.9
98 12 05	1808	244	S4-W	GS					-142

TABLE 10: TV Channel Allocation for PAL System in India

RAS bands. · 152–154 MHz · 230–234 MHz · 322–328.6 MHz · 608–614 MHz

operators don't come into the picture in DTH. The channels are beamed in high frequency Ku-band transponders, are digitally compressed and provide LD quality video and CD quality stereo at your homes. What is DTH really? What is digital broadcast? What are these transponders? What is Ku- band and what is frequency? To appreciate the advantages of DTH better, and to get answers to all the above questions, it is necessary that the technology behind satellite television broadcast be understood.

Earth to space and back to Earth

Satellite communication is a perfect example of how the technological developments in multidisciplinary areas are fast combining. Modern satellite communication is the outcome of a combination of path breaking developments in space technology and microelectronics. If putting artificial satellites in their designated space orbits and ensuring that they perform at their optimum level constitutes the first part of satellite communication, deriving the best from the satellites in space for the benefit of humanity is the second part. The former is the job of space technologists and the latter that of electronics and communication experts.

Mirror in the sky

The simplest way to understand satellite communication is to treat the satellite as a mirror in the sky. When light rays fall on a mirror they get reflected and manifest themselves at a different location based on the angle of incidence of light. A satellite acts as a mirror in space 'reflecting' signals from an earth station to a large geographical area in the line of 'vision' of the satellite. A single satellite is capable of covering up to 40% of Earth's geographical area.

The idea of satellite communication was mooted first by the revolutionary thinker and science fiction writer Arthur C. Clarke as early as October 1945. In the 1945 edition of Wireless World, Clarke had proposed the establishment of a global communication system using three satellites placed in geo-

Channel Allocation

TV bands	Ch	Picture Carrier MHz	Sound carrier MHz
Band I	2	48.25	53.75
	3	55.25	60.75
	4	62.25	67.75
	X	69.25	74.75
	Y	76.25	81.75
	Z	83.25	88.75
	Z+1	90.25	95.75
	Z+2	97.25	102.75
VHF Midband	S1	105.25	110.75
	S2	112.25	117.75
	S3	119.25	124.75
	S4	126.25	131.75
	S5	133.25	138.75
	S6	140.25	145.75
	S7	147.25	152.75
	S8	154.25	159.75
	S9	161.25	166.75
	S10	168.25	173.75
Band III (PUNE TV)	5	175.25	180.75
	6	182.25	187.75
	7	189.25	194.75
	8	196.25	201.75
	9	203.25	208.75
	10	210.25	215.75
	11	217.25	222.75
	12	224.25	229.75
VHF Superband	S11	231.25	236.75
	S12	238.25	243.75
	S13	245.25	250.75
	S14	252.25	257.75
	S15	259.25	264.75
	S16	266.25	271.75
	S17	73.25	278.75
	S18	280.25	285.75
	S19	287.25	292.75
	S20	294.25	299.75
VHF Hyperband	S21	303.25	308.75
	S22	311.25	316.75
	S23	319.25	324.75
	S24	327.25	332.75
	S25	335.25	340.75
	S26	343.25	348.75
	S27	351.25	356.75
	S28	359.25	364.75
	S29	367.25	372.75
	S30	375.25	380.75
	S31	383.25	388.75
	S32	391.25	396.75
	S33	399.25	404.75
	S34	407.25	412.75
	S35	415.25	420.75
	S36	423.25	428.75
	S37	431.25	436.75
	S38	439.25	444.75
	S39	447.25	452.75
	S40	455.25	460.75
	S41	463.25	468.75
UHF	21	471.25	476.75
	22	479.25	484.75
	23	487.25	492.75
	24	495.25	500.75
	25	503.25	508.75
	26	511.25	516.75
	27	519.25	524.75
	28	527.25	532.75
	29	535.25	540.75
	30	543.25	548.75
	31	551.25	556.75
	32	559.25	564.75
	33	567.25	572.75
	34	575.25	580.75
	35	583.25	588.75
	36	591.25	596.75
	37	599.25	604.75
Band V	38	607.25	612.75
	39	615.25	620.75
	40	623.25	628.75
	41	631.25	636.75
	42	639.25	644.75
	43	647.25	652.75
	44	655.25	660.75
	45	663.25	668.75
	46	671.25	676.75
	47	679.25	684.75
	48	687.25	692.75
	49	695.25	700.75
	50	703.25	708.75
	51	711.25	716.75
	52	719.25	724.75
	53	727.25	732.75
	54	735.25	740.75
	55	743.25	748.75
	56	751.25	756.75
	57	759.25	764.75
	58	767.25	772.75
	59	775.25	780.75
	60	783.25	788.75
	61	791.25	796.75
	62	799.25	804.75
	63	807.25	812.75
	64	815.25	820.75
	65	823.25	828.75
	66	831.25	836.75
	67	839.25	844.75
	68	847.25	852.75
	69	855.25	860.75

An overview of the frequency levels (operating bands) of signals received by your Television.

Band specifications	Operating frequency
Midband channel	111 - 174 MHz
S-band channels	230 – 399 MHz
Very high Frequency (VHF) band	302 – 446 MHz
Ultra High Frequency	HF > 470 MHz

BRIEF LEGEND OF FIGURES

(for detailed legends, see the coloured sheet placed before each of Figures 1 to 9 and also captions at the bottom of Figures)

Fig. 1(a) to 1(p) : RFI in the band 152-154 MHz observed during 1998-2000.

Fig. 2 : Modulation Characteristics of radio signal at 146.6 MHz due to a paging transmitter near Pune

Fig. 3 : Modulation Characteristics of radio signal near 165 MHz

Fig. 4(a) to 4(f) : RFI in the band 230-234 MHz observed in May 1998.

Fig. 5(a) to 5h) : RFI in the band 230-234 MHz seen in September 2000.

Fig. 6(a) to 6(f) : RFI in the band near 325 MHz.

Fig. 7 : Summary of RFI surveys made by T.L. Venkatasubramani in mid 1996, early 1997 and July 1999 (see RFI Report Part-V).

Fig. 8(a) to 8(j) : RFI surveys in the band 151-155 MHz made near Sangamneer, Kandali, Kukdi, Junnar, Pune, Lonavala and Khandala (see Fig. 12 for location of the above sites).

Fig. 9(a)to 9(j): RFI Surveys in the band 229.5-234.5 MHz near Alephata, Jamburphata, Kandali, Junnar, NCRA-Pune, Lonavala and Khandala.

Fig. 10 : A summary plot of RFI measurements in the GMRT Band of 152-154 MHz based on observations made at Sangamneer, Kukdi, GMRT site, (Pulsar Rx : see text), Pune, Lonavala and Khandala Ticks are marked on the GMRT site data for those frequencies for which there seems to be some correlation between RFI at (a) the GMRT site and (b) Pune, Lonavala and Khandala.

Fig. 11 : RFI measurements in the GMRT Band of 230-234 MHz at (a) Alephata (b) the GMRT site, (c) Junnar, (d) NCRA-Pune, (e) Lonavala and (f) Khandala.

Fig. 12 : Radio Frequency Spectrum (RFS) at Pune, Lonavala and Khandala

Fig. 12(a), 12(b) and 12(c) show RFI measurements made in the frequency band of 300-350 MHz at Lonavala, Khandala and Pune respectively. It is seen that the signals received are much larger at Khandala compared to Lonavala or Pune. In Fig. 12(d) is shown measurements made at NCRA-Pune in the bands 315-335 MHz, 140-160 MHz and 225-245 MHz. All measurements were made using method 2 of Appendix-B. It is clear that the Radio Frequency Spectrum is much quieter near the 325 MHz band than near the bands 150 and 233 MHz.

Fig. 12 (a) : RFI measurements in the band 300-350 MHz near Lonavala.

Fig. 12 (b) : RFS measurements in the band 300-350 MHz near Khandala.

Fig. 12 (c) : RFS measurements in the band 300-350 MHz at NCRA-Pune.

Fig. 12(d) RFS measurements in bands 315-335 MHz, 140-160 MHz and 225-245 MHz at NCRA-Pune.

FIG. 13 : Height path profile between Bombay and GMRT site.
The plots were made using survey of India maps along the line of site from the GMRT site to the central part of Bombay.

FIG. 14: The calculations of Tropo-Scatter path as shown in Fig. 13 show transmission loss by NPL. The absissa percent of time ordinate exceeded at different values of losses. For e.g. it may be noted that 65% of the time will be lost at the 150 dB between Bombay and GMRT site.

FIG. 15 : The percentage probability at Pune and GMRT site will lost at 150 dB for 17% of time.

FIG. 16 : Tropscatter loss estimated by T.L. Venkatasubramani from NBS Tech. Note 101, Vol. II (see RFI Report-Part XII)

FIG. 17 : Circles given Protection Zones for GMRT on a map of Western India.

FIG. 18 : Shows locations of sites where RFI measurements were made as given in Figs. 8 and 9.

Fig. 18 (a) Shows locations where RFI measurements were made :

Fig. 18 (b) Shows a sketch showing locations of the site near the Kandali Industrial Estate where RFI measurements were made.

Fig. 18 (c) Shows location near Jambul-phata where RFI measurements were made.

FIG.1 RFI IN THE ~ 150 MHz Band

FIG. 1 :Shows plots of narrow-band RFI measurements made in the frequency band of about 152-154 MHz during 1996 to 1999. The GMRT 150 MHz antenna feeds were pointed towards the horizon in various directions. Fig. 1(a) to 1(p) show Spectrum Analyzer scans obtained for the 130 MHz IF channel at the output of the optical fibre in the Receiver room of the GMRT. Selected SpA outputs are presented in order to illustrate and summarize the nature of RFI present from terrestrial transmitters and perhaps also from GMRT electronics.

FIGS. 1 (a) : shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards East (E) and another 4 towards South (S) on 28th September 1999 (Fig. 1(b) shows the same for feeds towards W & N). Antennas used are noted in the Figures. It is seen that strong RFI is observed mainly when the feeds are pointed to the South. Further, it may be noted that RFI is observed every 922 kHz apart. For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N and is likely to arise from the GMRT electronics. In particular see W3-N and C8-W scans.

FIG. 1 (b) : [Fig. 1(b) is continuation of Fig. 1(a)] shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards West (W) and North (N) on 28th September 1999. Antennas used are noted in the Figures. It is seen that strong RFI near 152.13 MHz is observed when the feeds are pointed to the South. For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N RFI is observed every 920 kHz apart and is likely to arise from the GMRT electronics.

FIG. 1(c) : [continuation of Fig. 1(a)] shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards South on 28th September 1999 (same as right band side of Fig. 1(a) but the Figure is somewhat enlarged). Antennas used are noted in the Figures. It is seen that strong RFI is observed mainly when the feeds are pointed to the South. For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N RFI is observed every 920 kHz apart and is likely to arise from the GMRT electronics. In this Figure 1(c), the Right hand side plots of Fig 1(a) for antenna feeds to the South are enlarged for better display.

FIG.1 (d) : [Also Fig. 1(e) & Fig. 1(f) and particularly Fig. 1 (f)] detailed characteristics of RFI (FM or FSK modulation) observed in the frequency range of about 152.000 to 152.200 MHz. It seems that there may be present 3 different transmitters centered at 152.06, 152.10 and 152.116 MHz (see also Table-4).

FIG. 1(e) : see caption of Fig. 1(d)

FIG. 1(f) : see caption of Fig. 1(e)

FIG. 1(g) : RFI observed in the 150 MHz-156 MHz band on 28th April 1998 with the 150 MHz dipole feed of C5 antenna pointed towards West. Strong RFI is observed in the 152 MHz-154 MHz band which is protected for GMRT ! The bandwidth of the IF Saw filter was 5.6 MHz.

FIG. 1(h) : Same caption as for Fig. 1(g) for C0 antenna feed towards South and C5 towards West.

FIG. 1(i) : Same caption as for Fig. 1(g) for C0-S and C5-W.

FIG. 1(j) : Same caption as for Fig. 1(g) for C5-W, C0-S and C0-8 antennas.

FIG. 1(k) : Same caption as for Fig. 1(g) for C0-S and C5-W antennas.

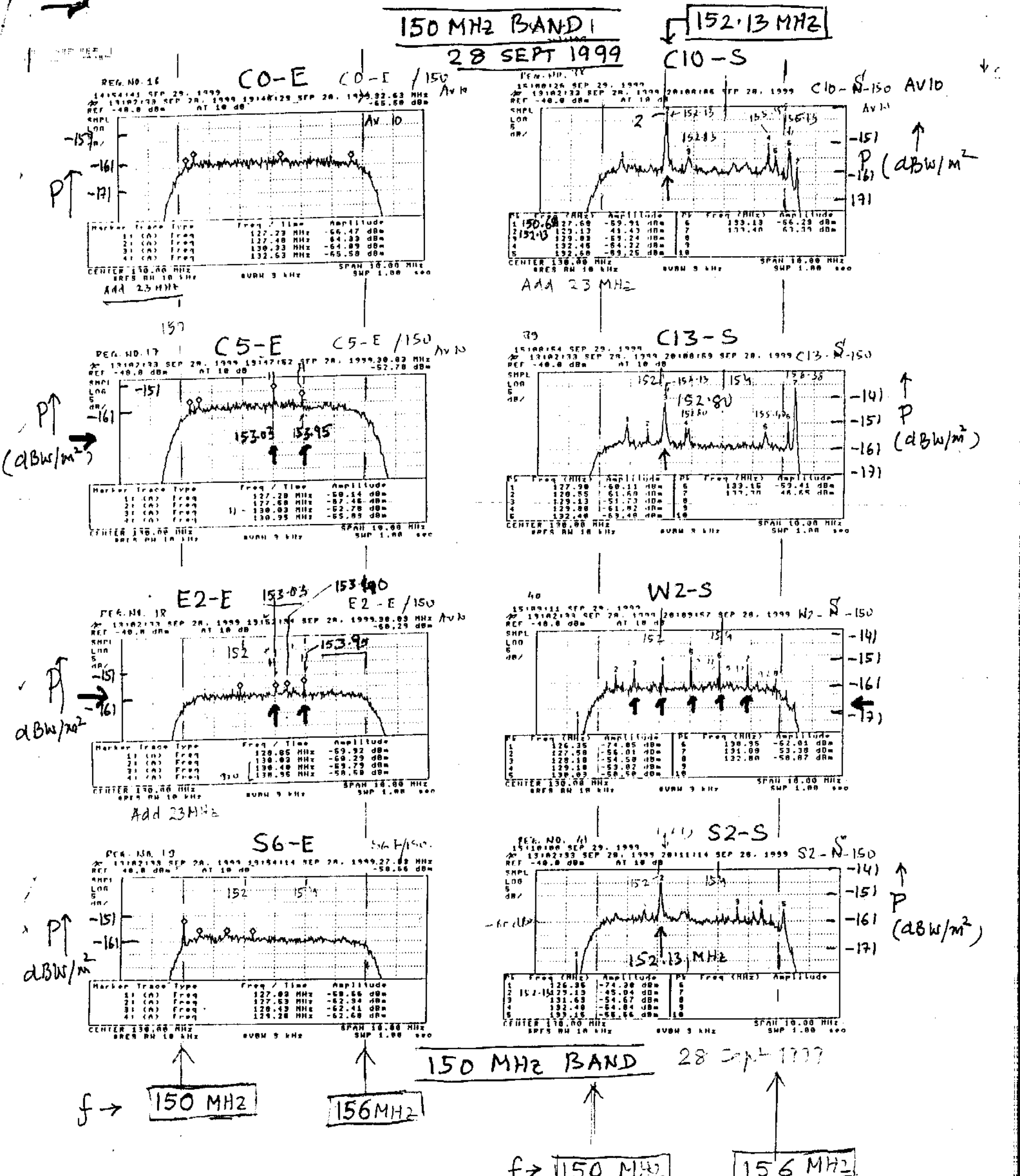
FIG. 1(l) : Same caption as for Fig. 1(g) for C5-W at 3 different times showing that RFI varies rapidly with time.

FIG. 1(m) : Same caption as for Fig. 1(g) for scans obtained on July 30, 1998. Strong RFI signals are seen at S2 antennas with feed pointed towards S-W near 152.10 MHz, 152.80 MHz and 153.58 MHz. These signals are also seen on 28th April 1998 for different antennas (see Table 4).

FIG. 1(n) : Caption as for Fig. 1(g) for scans obtained on September 2, 1998 showing presence of RFI at 152.12 MHz, near 152.8 MHz and 152.9 MHz.

FIG. 1(o) : Same caption as for Fig. 1(n).

FIG. 1(p) : Spectrum of RF signals received at the output of the 150 MHz front end at the base of C-9 with feed pointed towards N (see Appendix-C for more scans).



FIGS. 1 (a) : shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards East (E) and another 4 towards South (S) on 28th September 1999 (Fig. 1(b) shows the same for feeds towards W & N). Antennas used are noted in the Figures. It is seen that strong RFI is observed mainly when the feeds are pointed to the South. Further, it may be noted that RFI is observed every 920 kHz apart, For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N and is likely to arise from the GMRT electronics. In particular see W3-N and C8-W scans. (see arrows

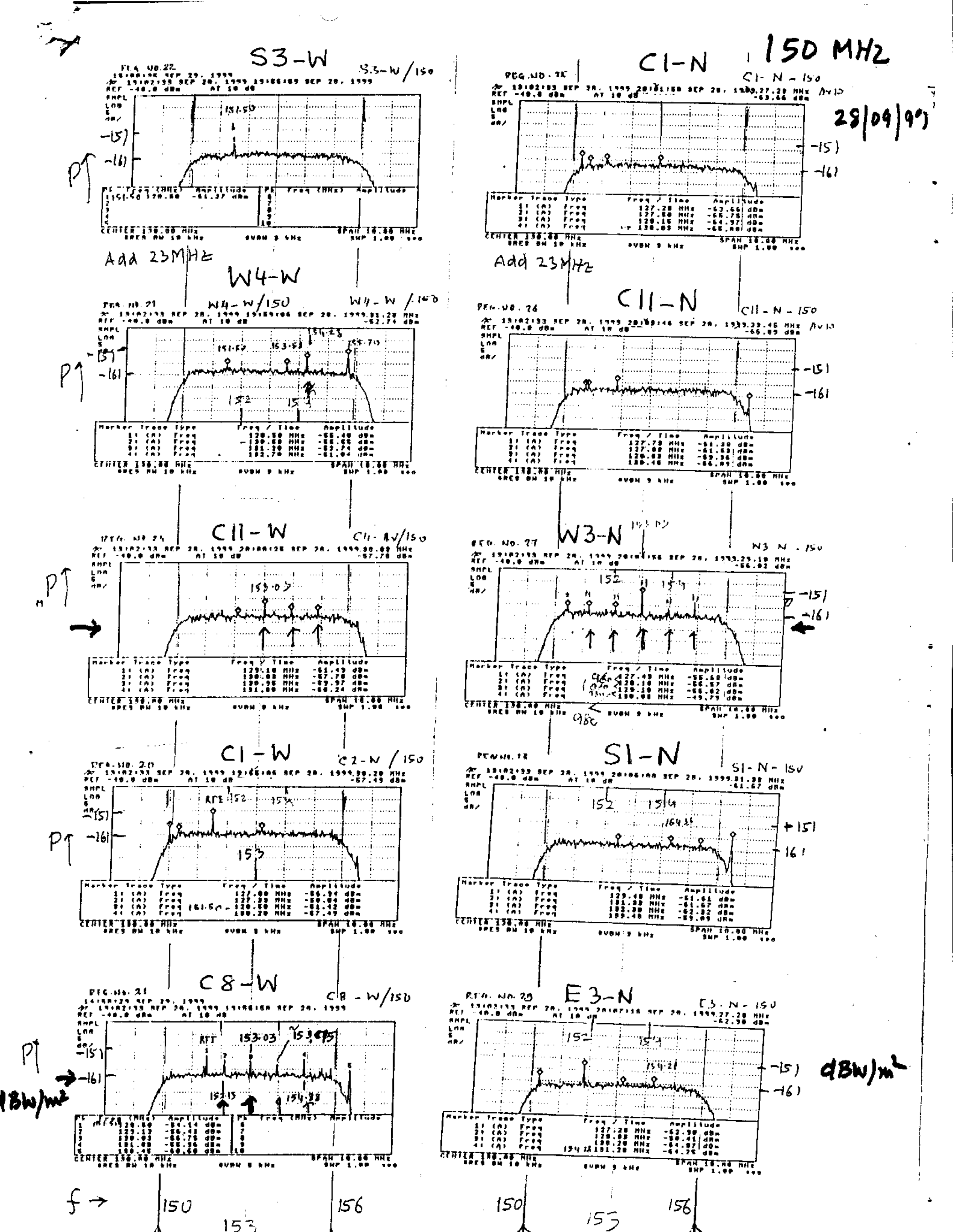


FIG. 1 (b) : [Fig. 1(b) is continuation of Fig. 1(a)] shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards West (W) and North (N) on 28th September 1999. Antennas used are noted in the Figures. It is seen that strong RFI near 152.13 MHz is observed when the feeds are pointed to the South. For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N RFI is observed every 920 kHz apart and is likely to arise from the GMRT electronics.

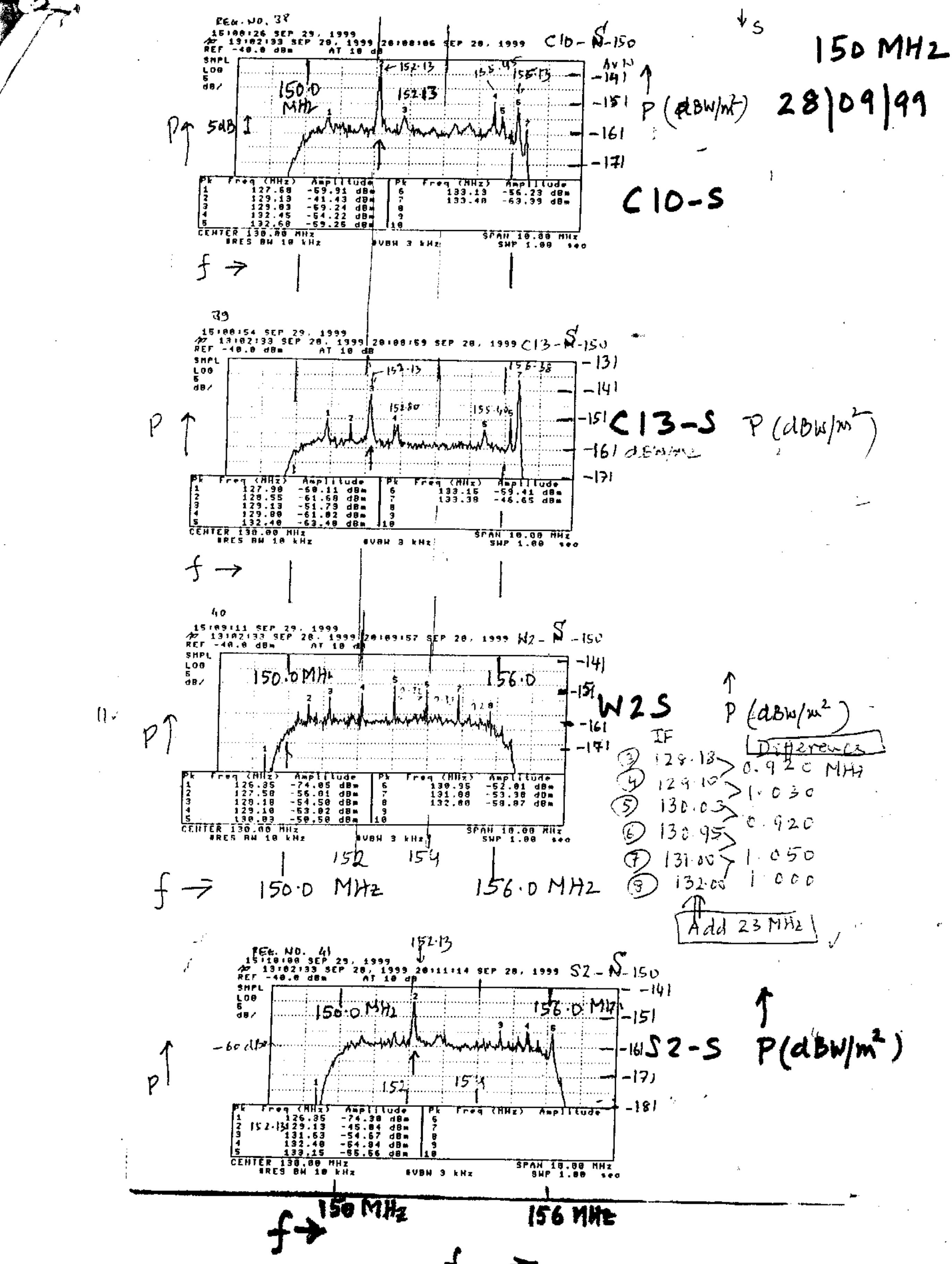


FIG. 1(c) : [continuation of Fig. 1(a)] shows results of RFI observations made when 4 of the GMRT 150 MHz antenna feeds were pointed towards South on 28th September 1999 (same as right band side of Fig. 1(a) but the Figure is somewhat enlarged). Antennas used are noted in the Figures. It is seen that strong RFI is observed mainly when the feeds are pointed to the South. For antennas, C5-E, E2-E, W2-S, C11-W, C8-W and W3-N RFI is observed every ~ 920 kHz apart and is likely to arise from the GMRT electronics. In this Figure 1(c), the Right hand side plots of Fig 1(a) for antenna feeds to the South are enlarged for better display.

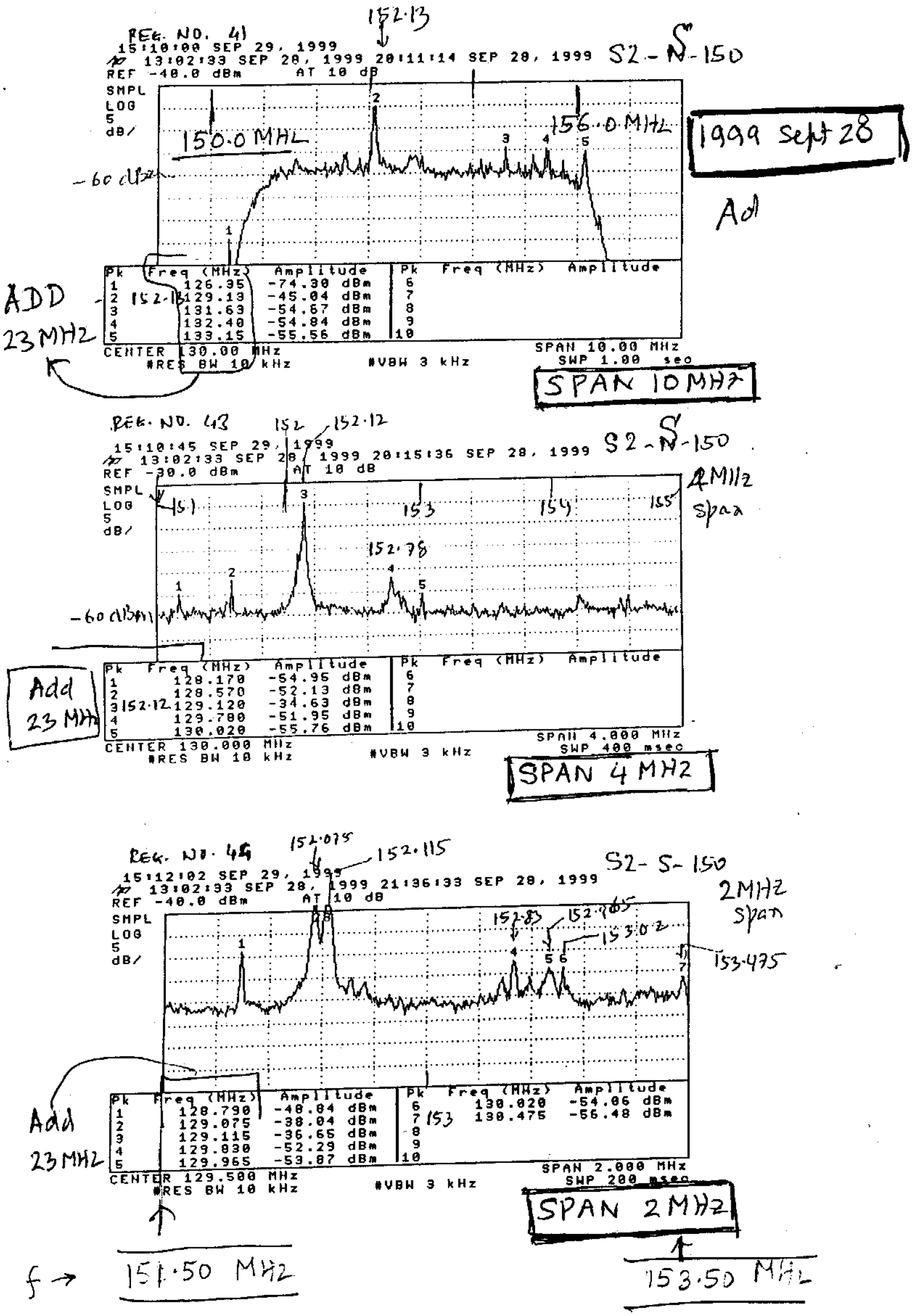
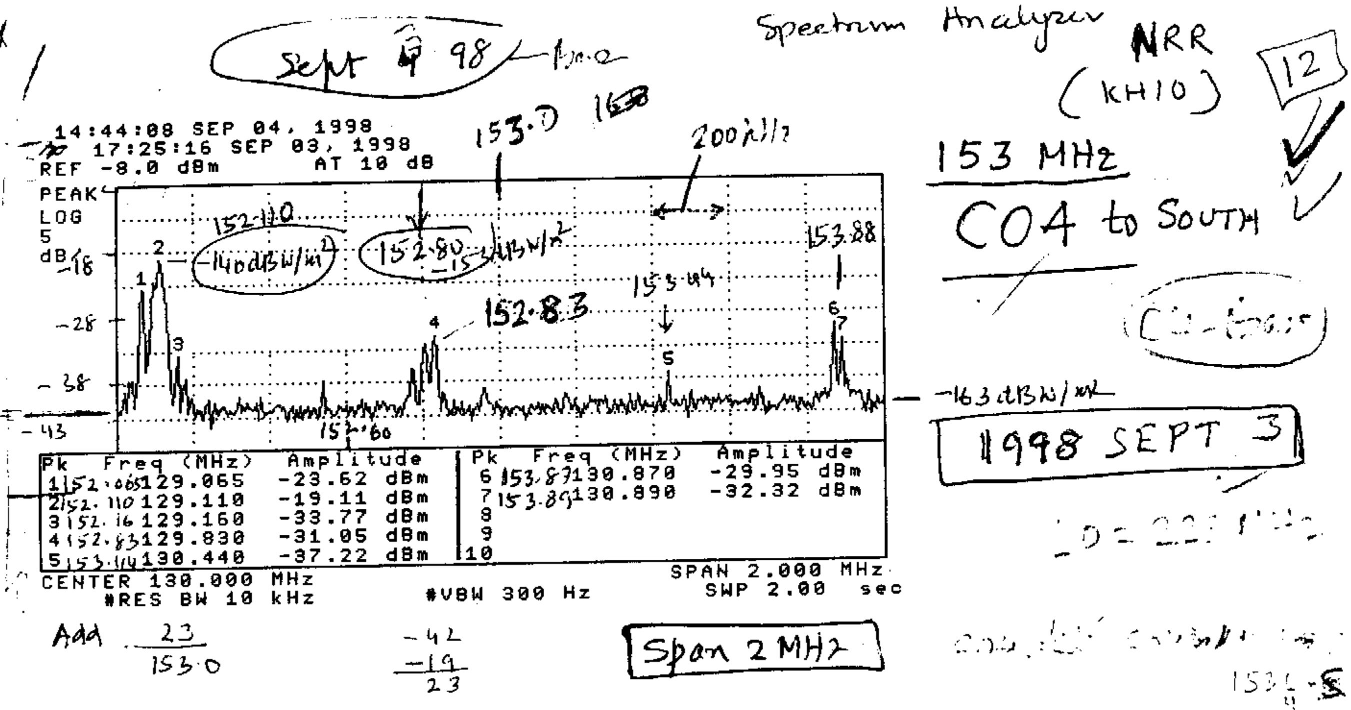
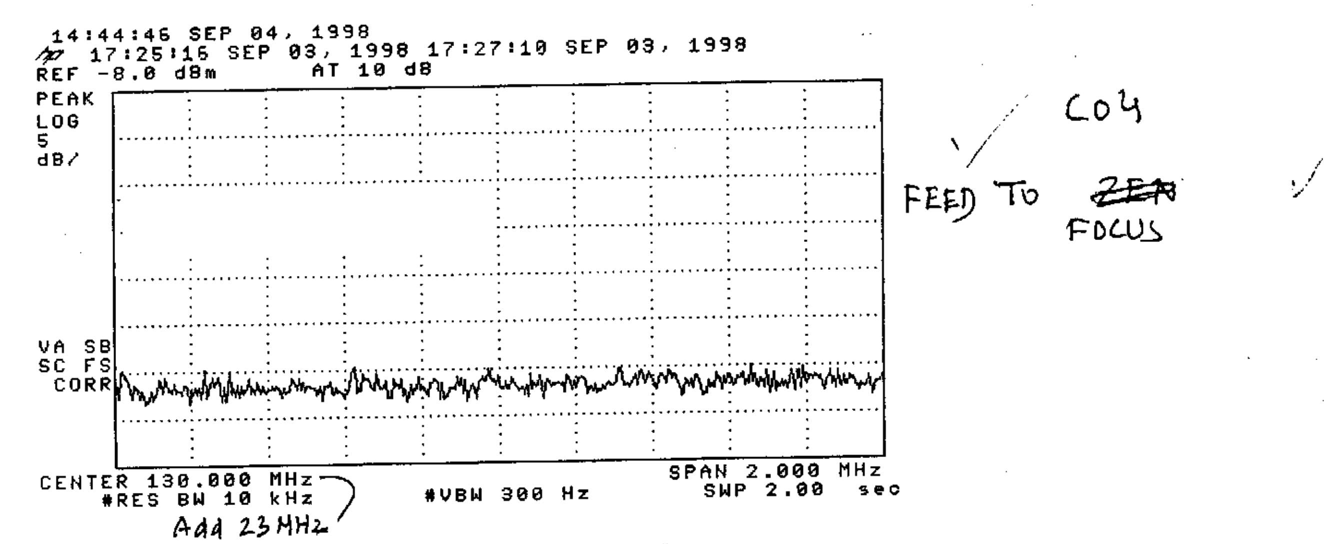


FIG.1 (d) : [Also Fig. 1(e) & Fig. 1(f) and particularly Fig. 1 (f)] detailed characteristics of RFI (FM or FSK modulation) observed in the frequency range of about 152.000 to 152.200 MHz. It seems that there may be present 3 different transmitters centered at 152.06, 152.10 and 152.116 MHz (see also Table-4).





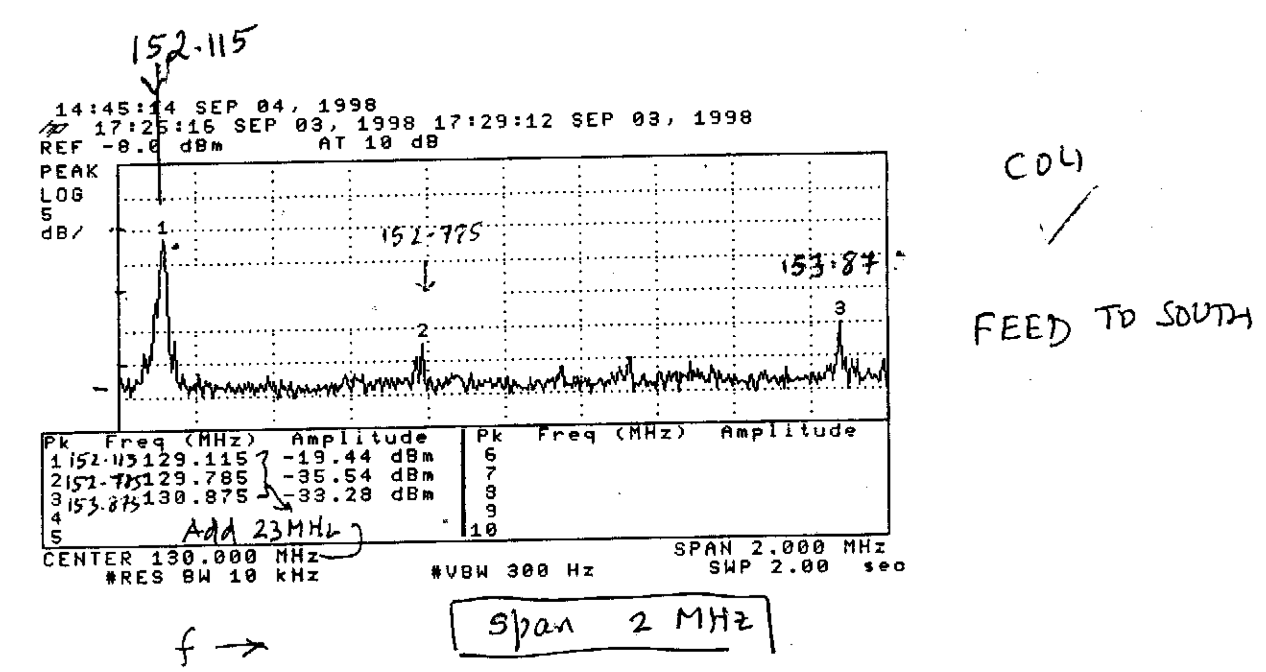


FIG. 1(e) : see caption of Fig. 1(d)

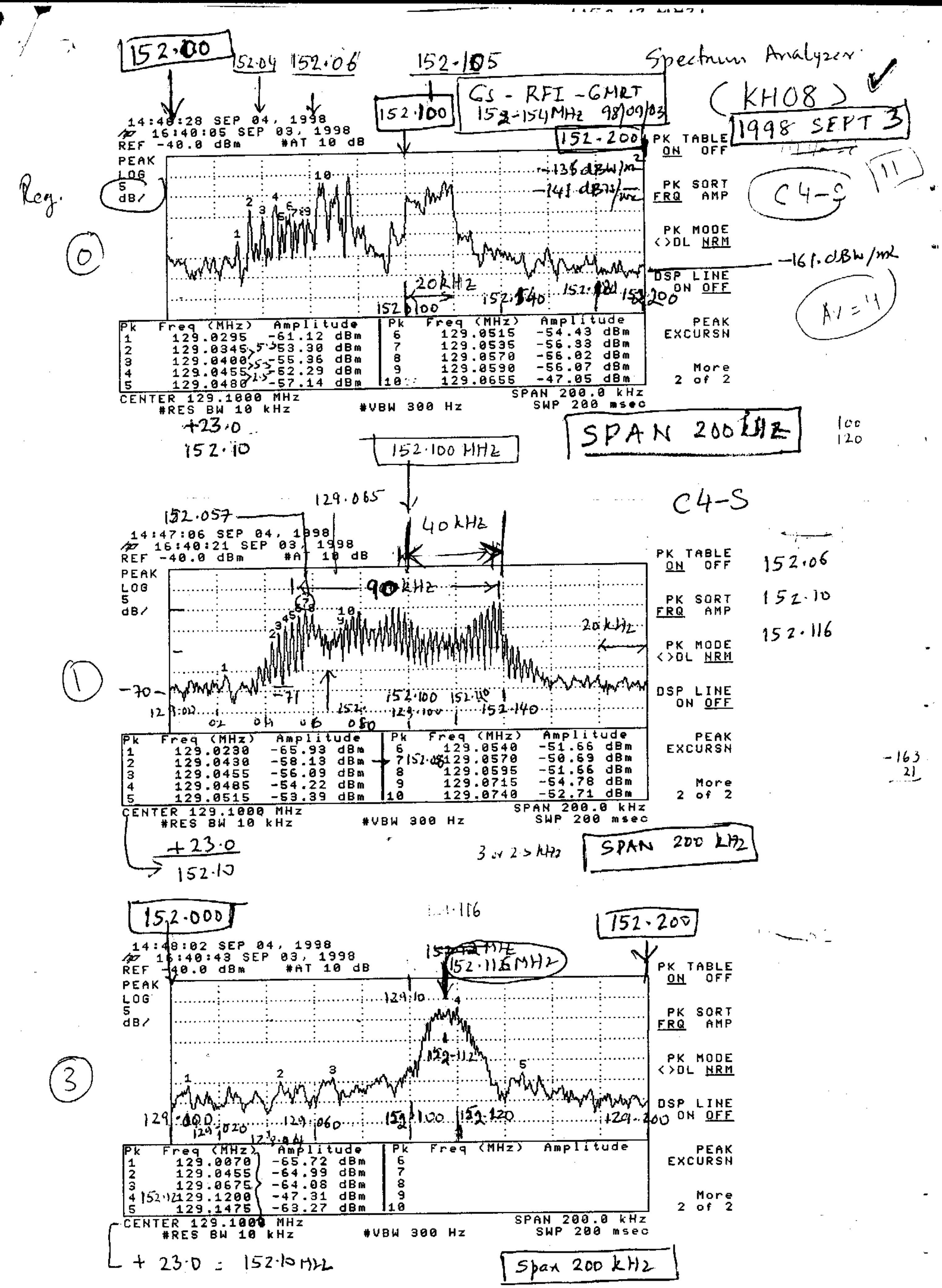


FIG. 1(f) : see caption of Fig. 1(e)

5

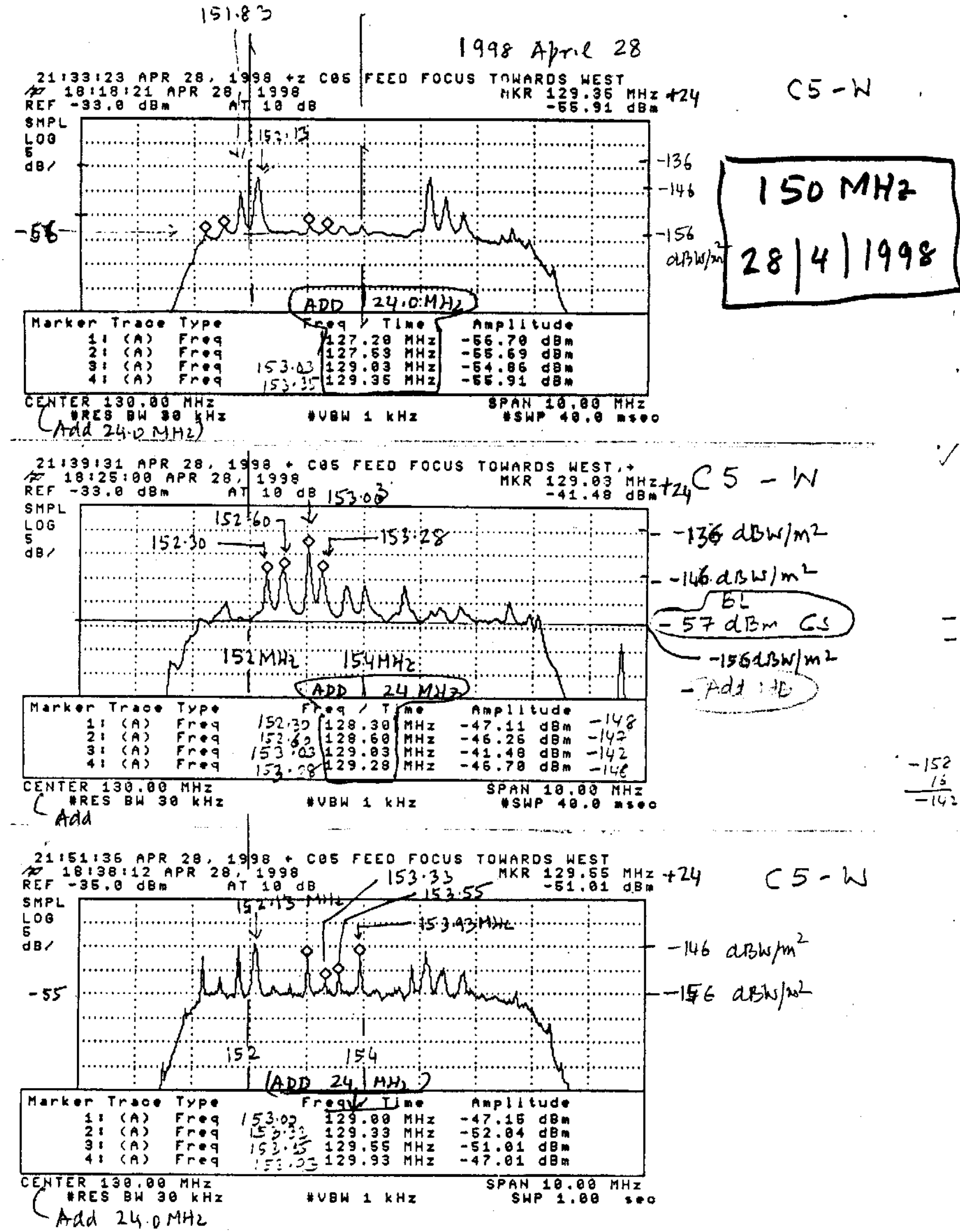
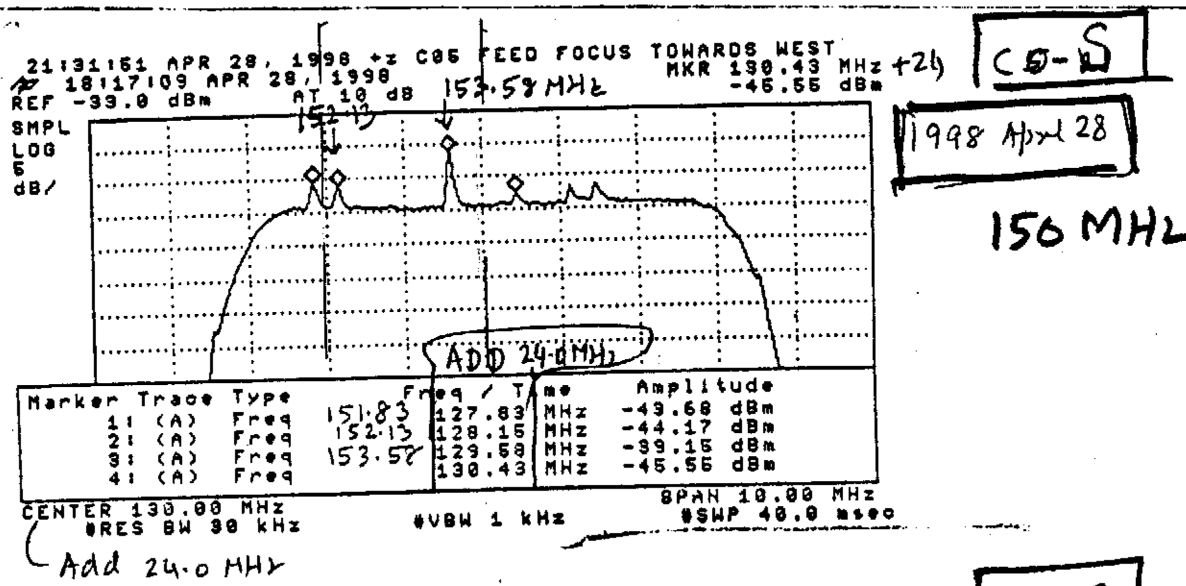
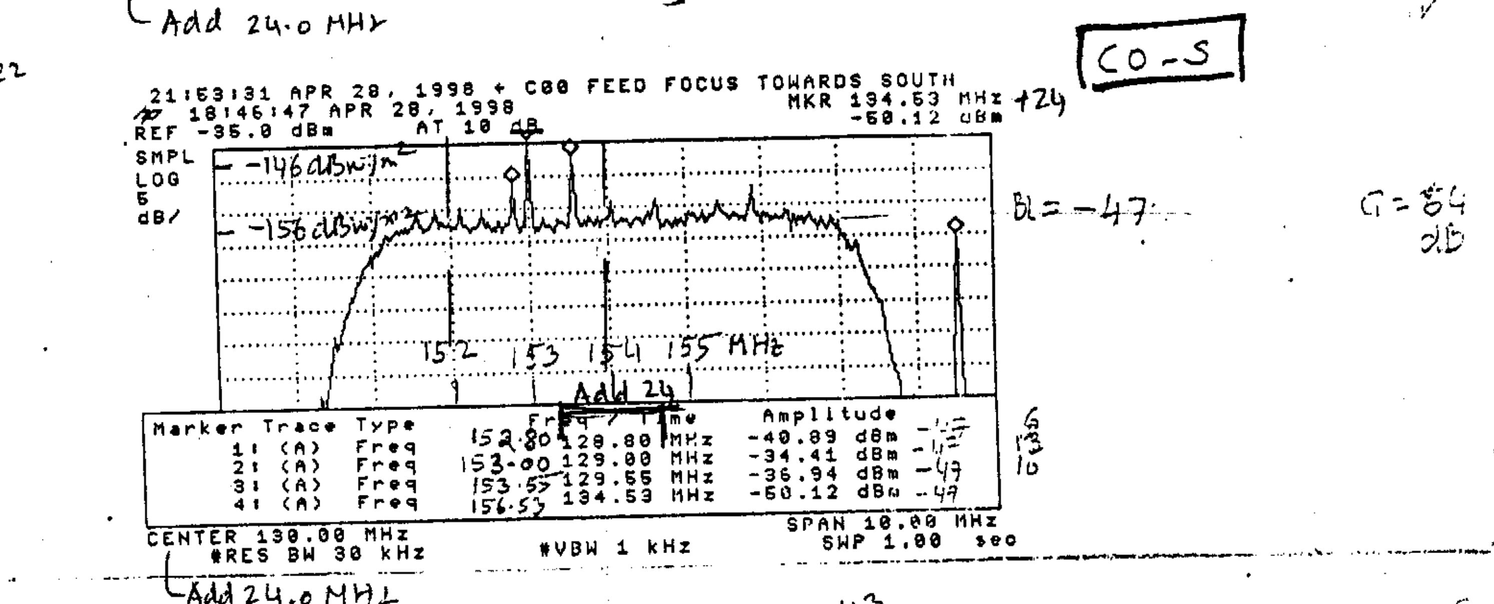


FIG. 1(g) : RFI observed in the 150 MHz-156 MHz band on 28th April 1998 with the 150 MHz dipole feed of C5 antenna pointed towards West. Strong RFI is observed in the 152 MHz-154 MHz band which is protected for GMRT ! The bandwidth of the IF Saw filter was 5.6 MHz.

the band 152-154 MHz .





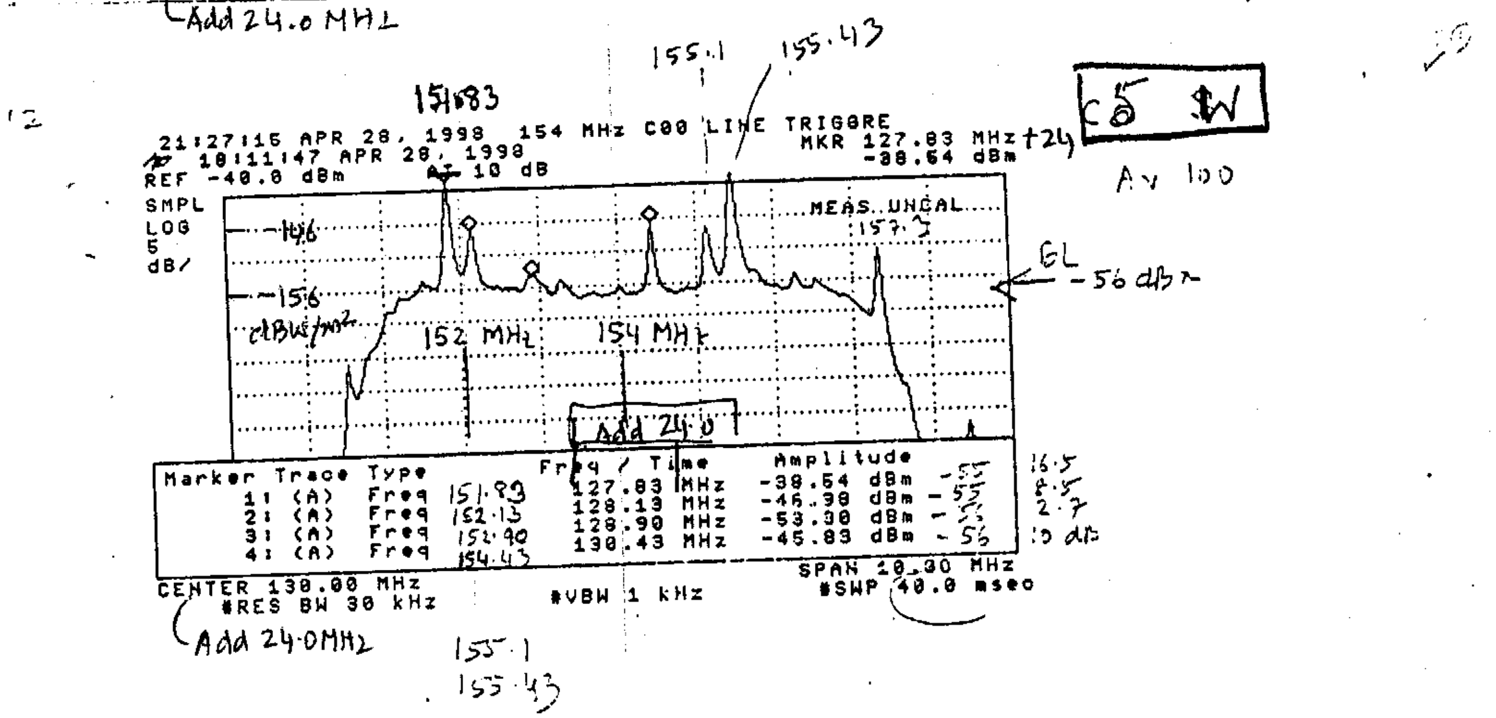


FIG. 1(h) : Same caption as for Fig. 1(g) for C0 antenna feed towards South and C5 towards West.

1998 April 28

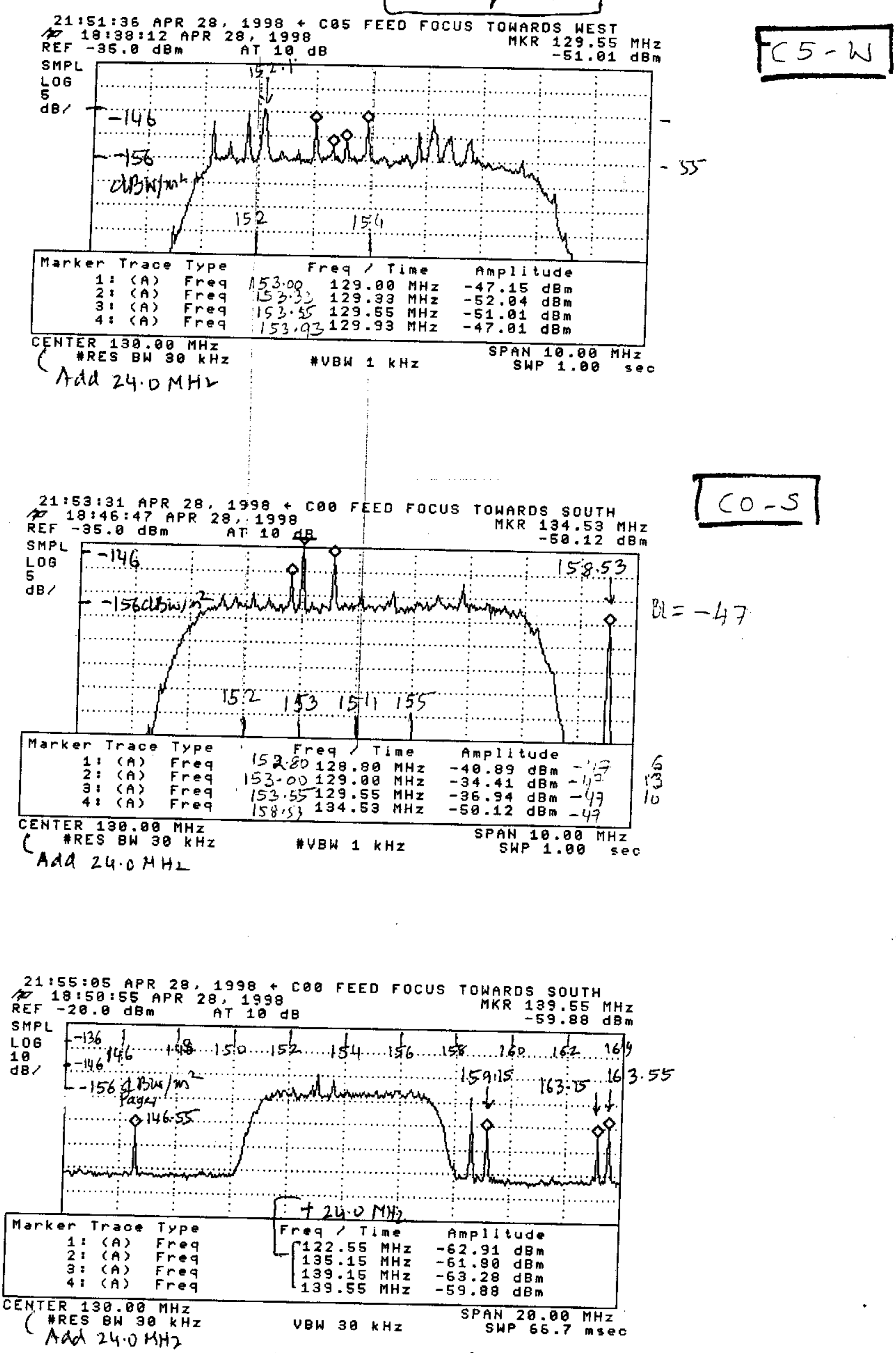


FIG. 1(i) : Same caption as for Fig. 1(g) for C0-S and C5-W.

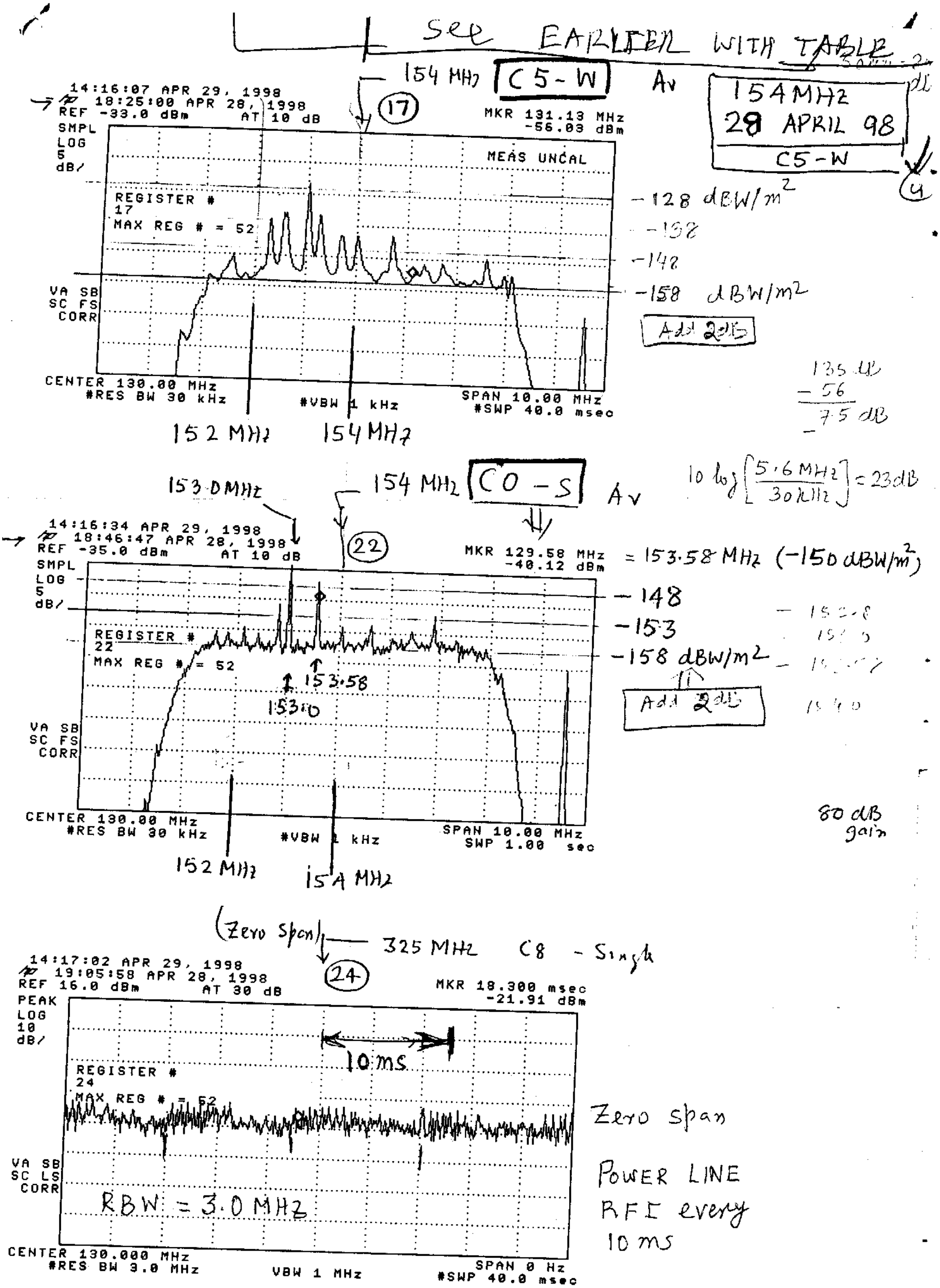
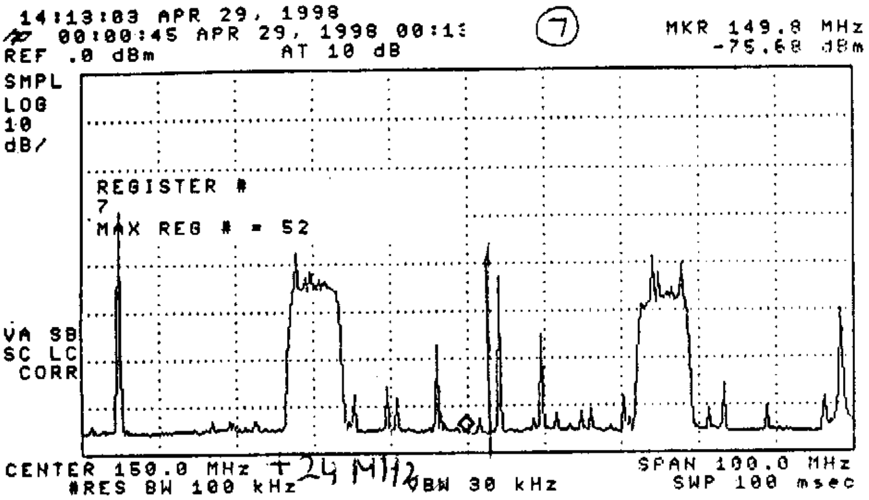
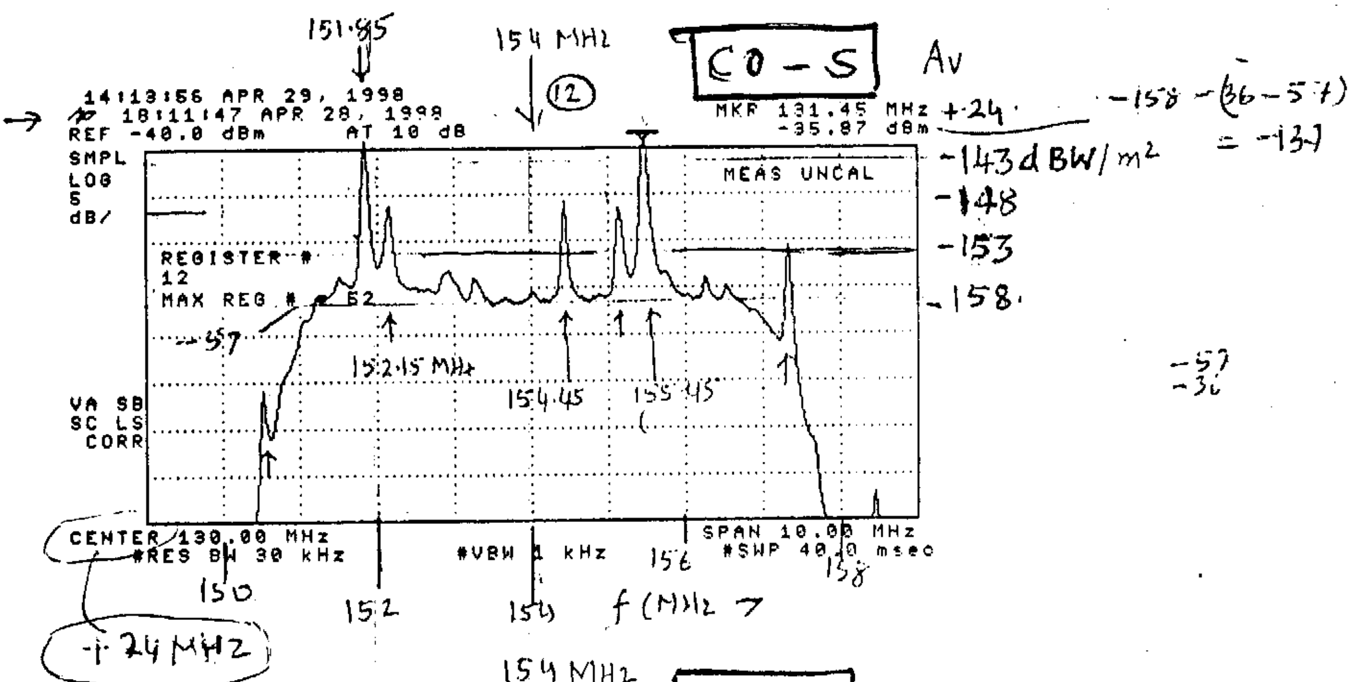


FIG. 1(j) : Same caption as for Fig. 1(g) for C5-W, C0-S ~~and C0-8~~ antennas. C8 SCAN IS for "ZERO SPAN" MODE & shows power line RFI

1998 Apr 29





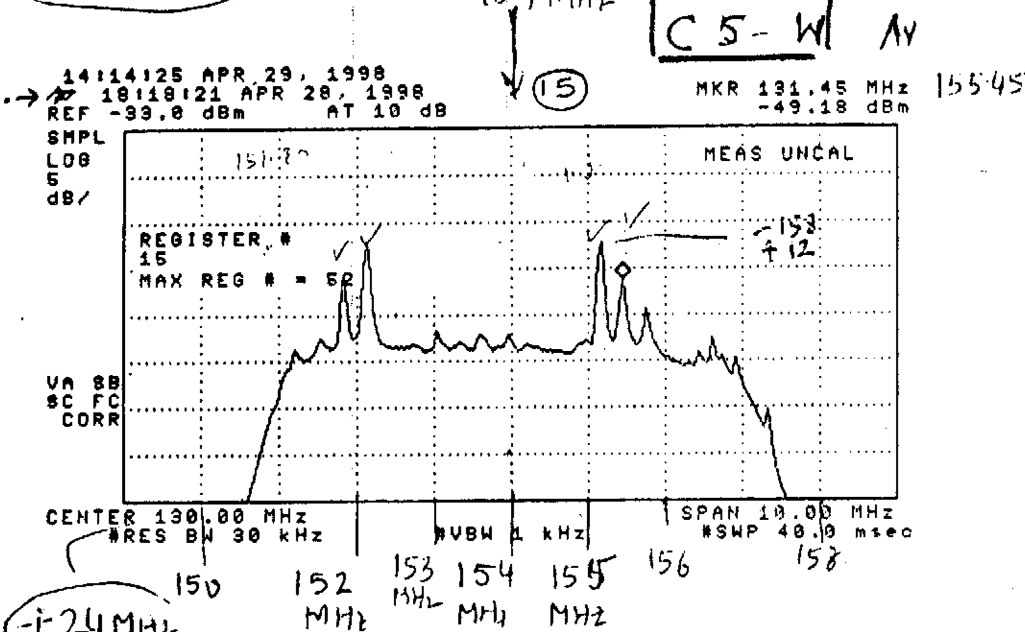
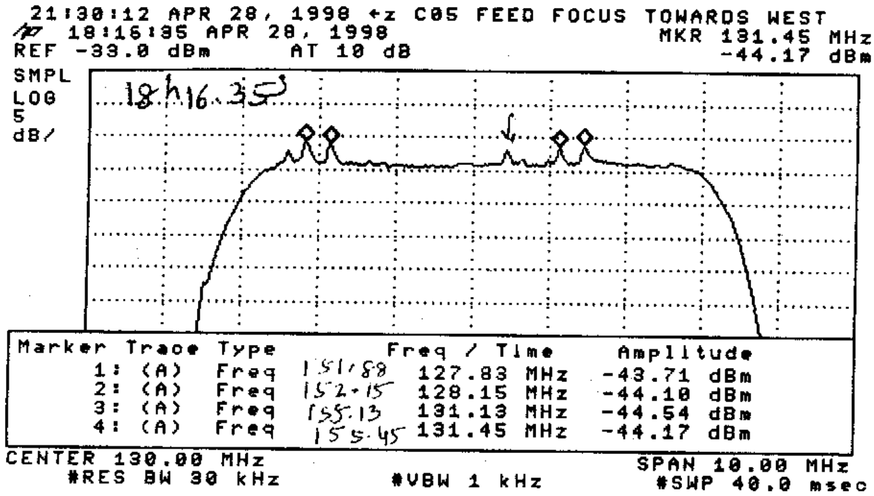


FIG. 1(k) : Same caption as for Fig. 1(g) for C0-S and C5-W antennas.

C5 W

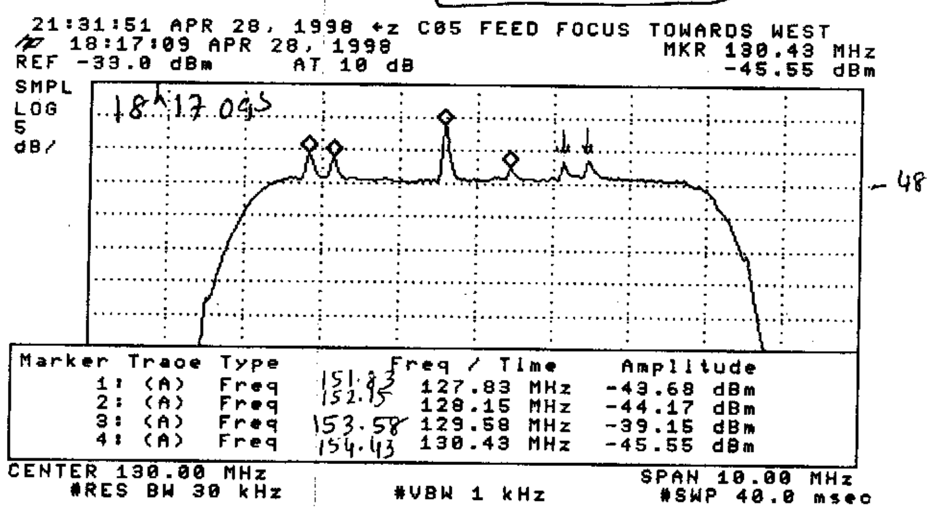
28/4/98

150 MHz



1998 April 28

C5 W



C5-W

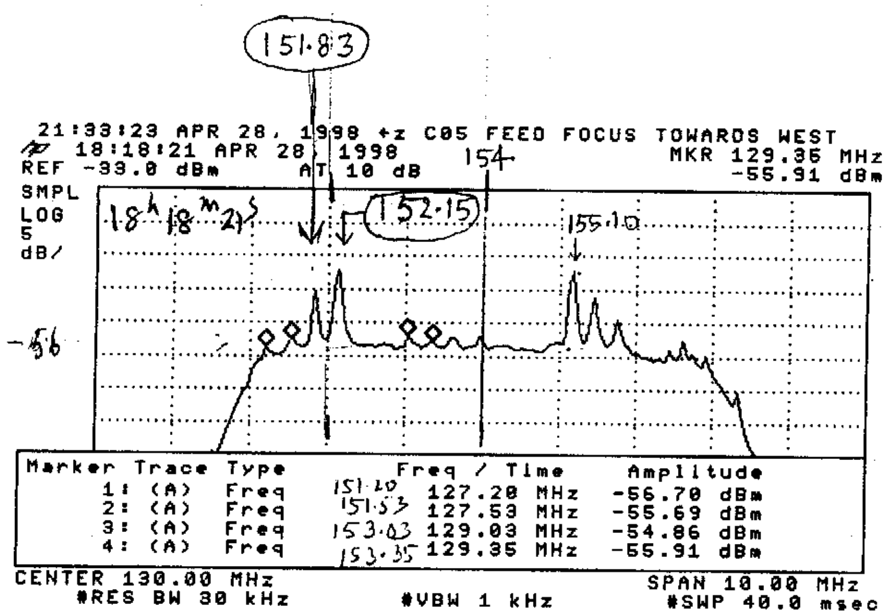
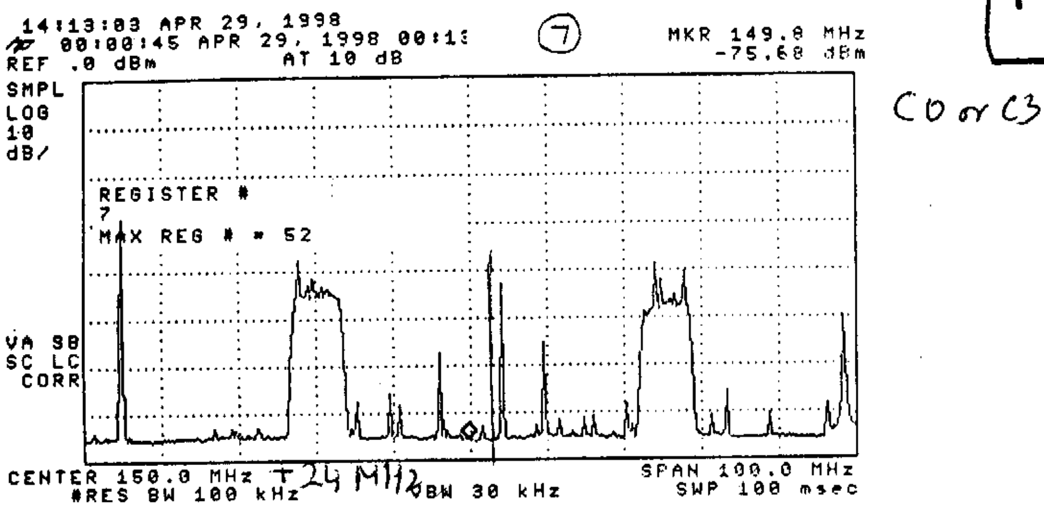
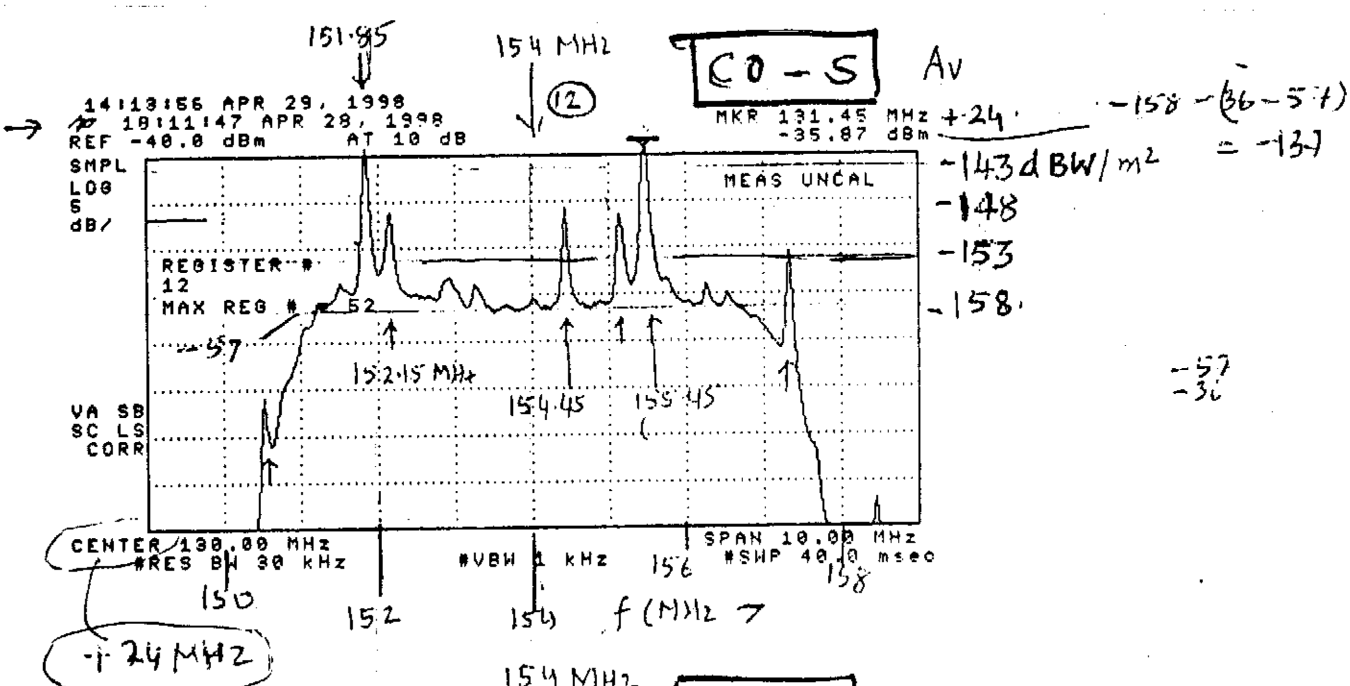


FIG. 1(l) : Same caption as for Fig. 1(g) for C5-W at 3 different times showing that RFI varies rapidly with time.

1998 Apr 29





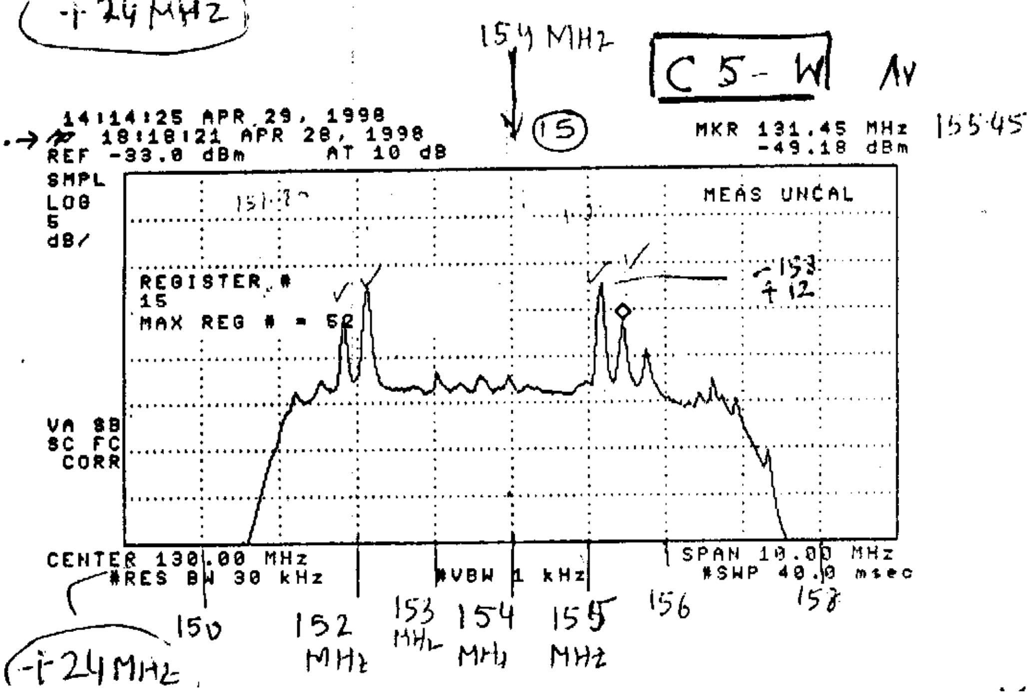
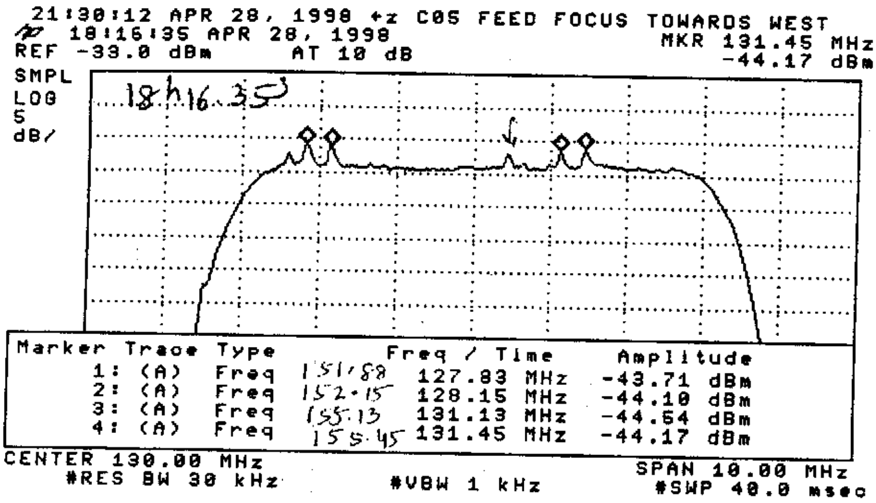


FIG. 1(k) : Same caption as for Fig. 1(g) for C0-S and C5-W antennas.

C5 W

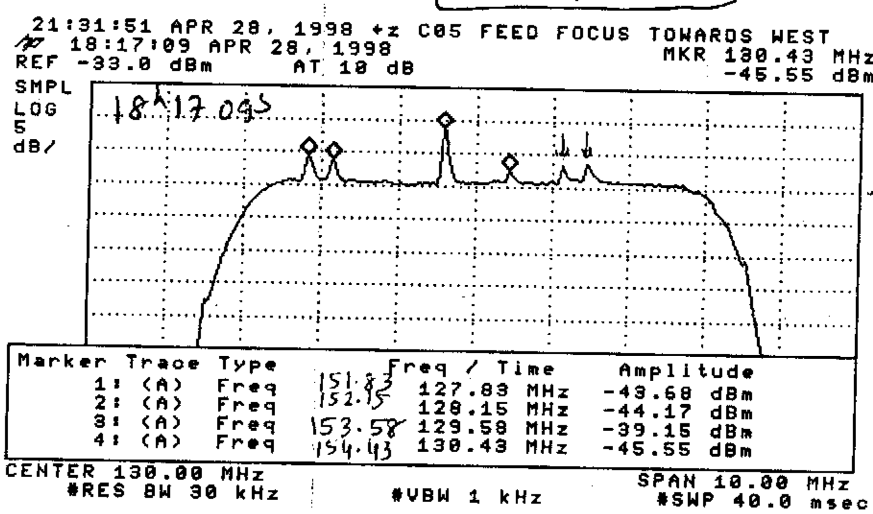
28/4/98

150 MHz



1998 April 28

C5 W



C5-W

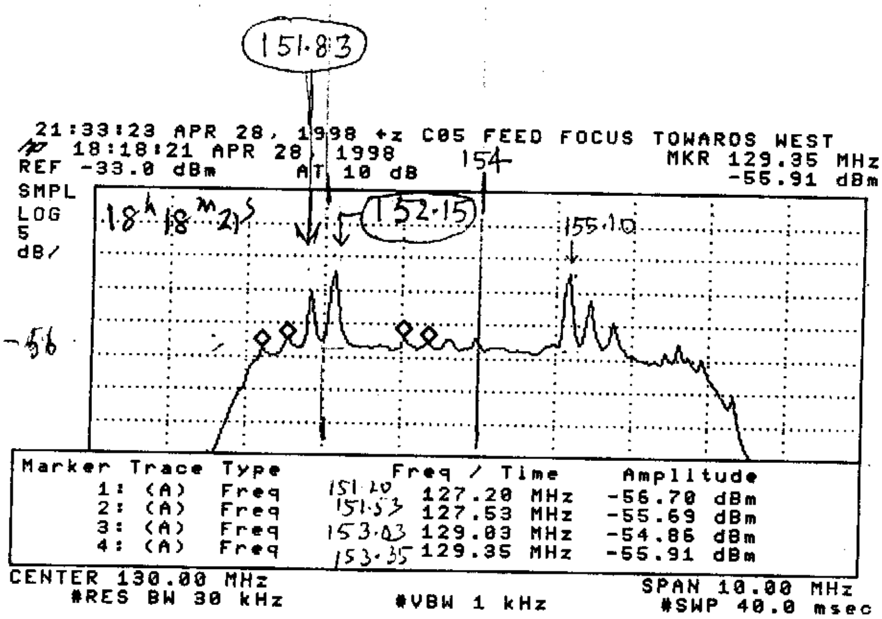
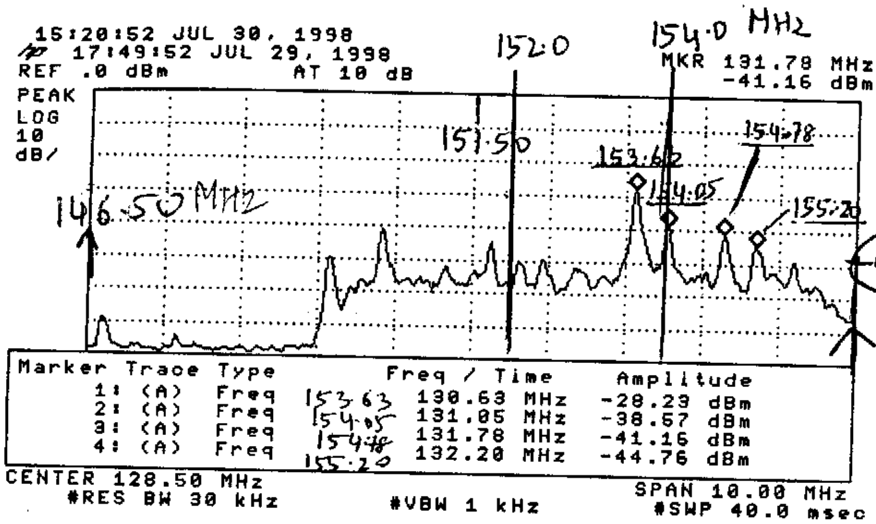


FIG. 1(l) : Same caption as for Fig. 1(g) for C5-W at 3 different times showing that RFI varies rapidly with time.

REG 2 WITH DIFFERENT MARKER SETTINGS

1998 July 30

7



15h 20m 52s

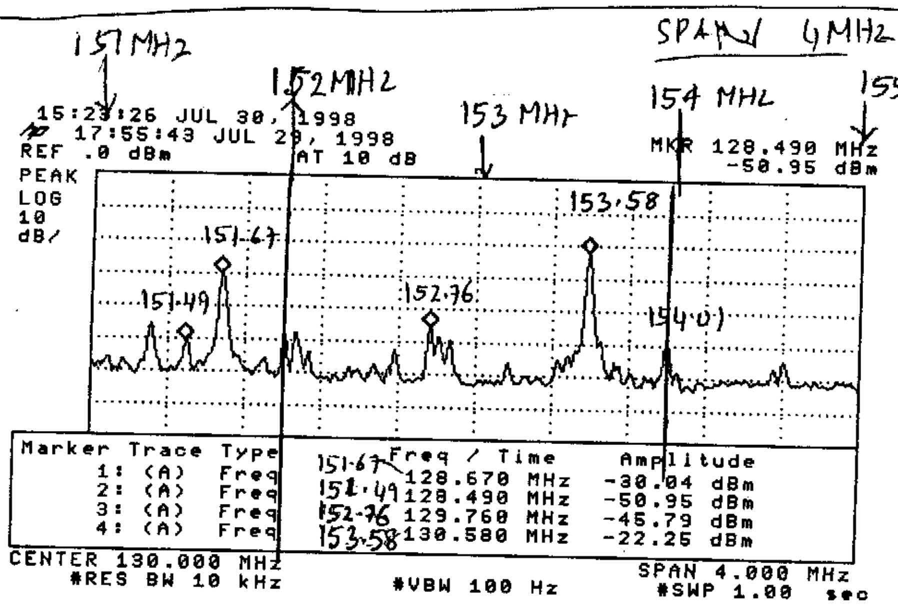
S2 -SW

Same as prev. fig. but different Marker setting

Span 10 MHz

Add 23 MHz

REG. 3



S2 -SW

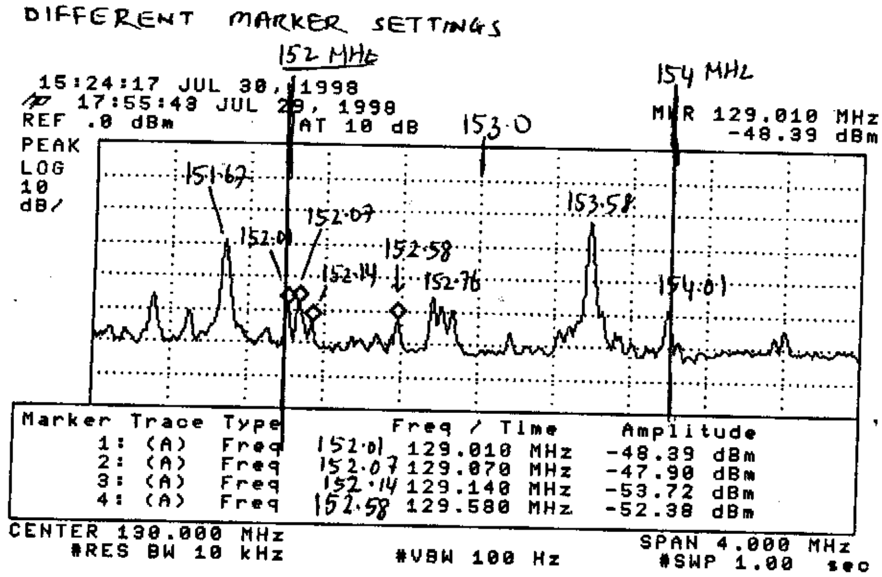
Span 4 MHz

15h 23m 26s

Add 23 MHz

4 MHz

REG 3 WITH DIFFERENT MARKER SETTINGS



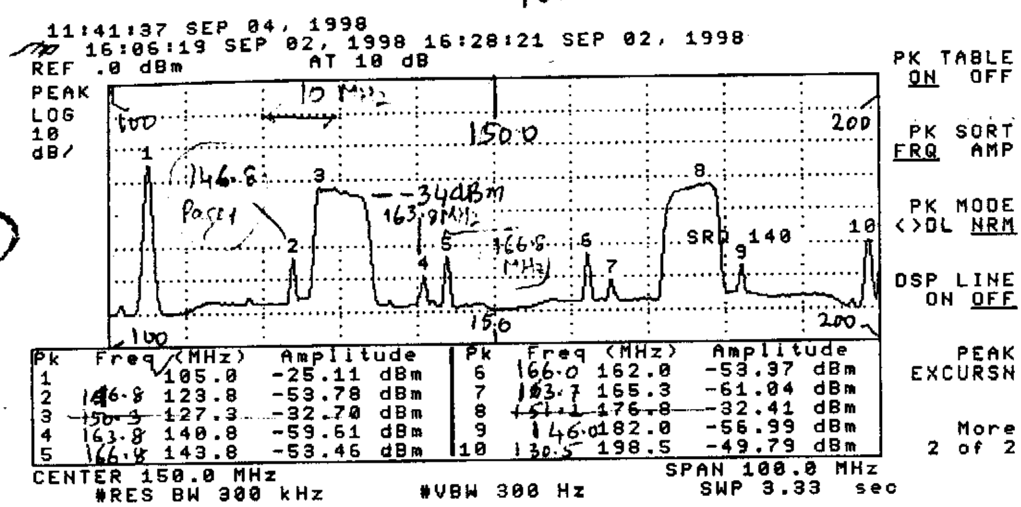
S2 -SW

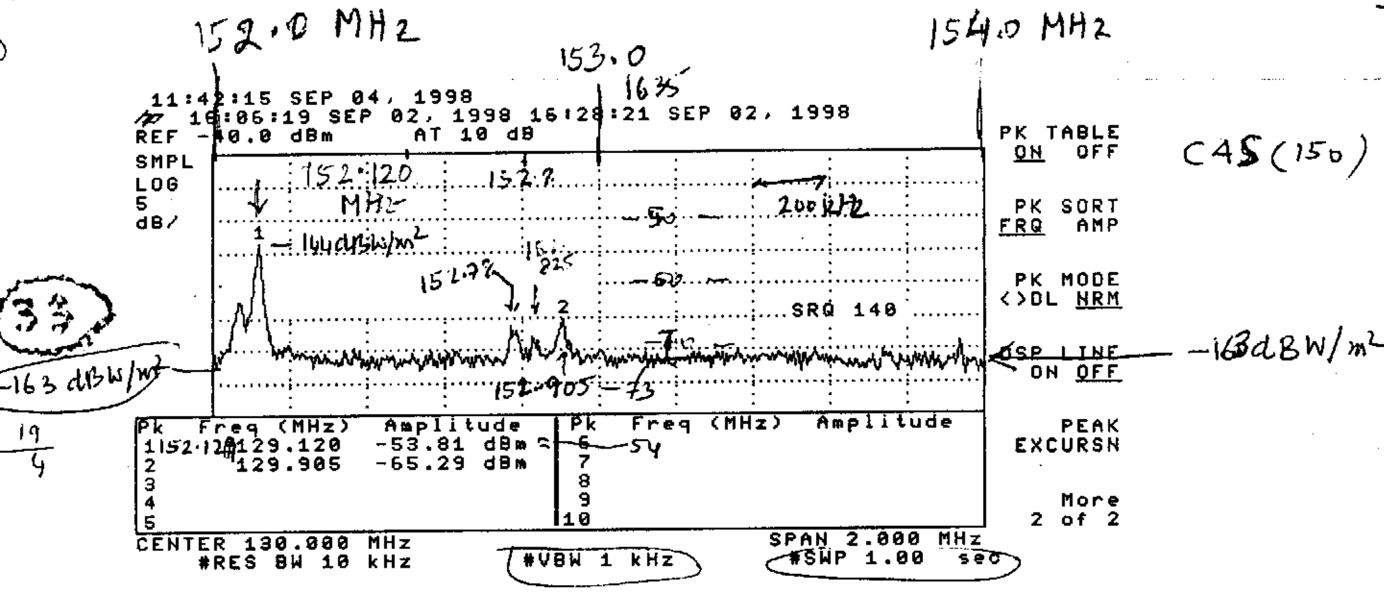
15h 24m 17s

different Markers

FIG. 1(m) : Same caption as for Fig. 1(g) for scans obtained on July 30, 1998. Strong RFI signals are seen at S2 antennas with feed pointed towards S-W near 152.10 MHz, 152.80 MHz and 153.58 MHz. These signals are also seen on 28th April 1998 for different antennas (see Table 4).

1998 SEPT 2





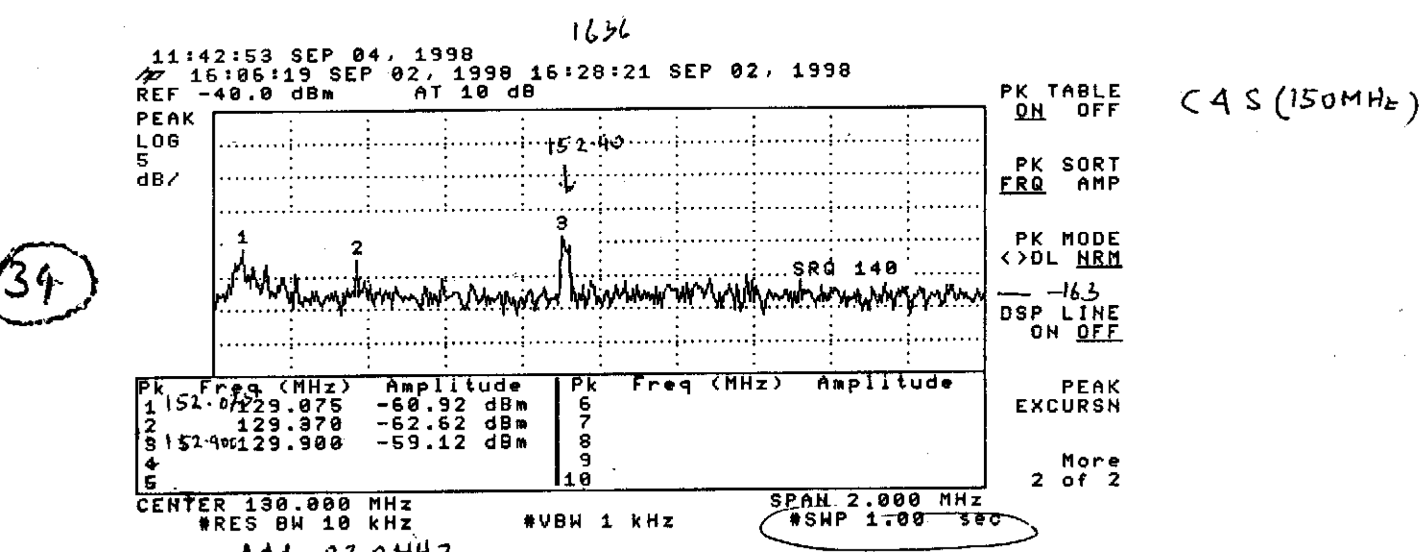
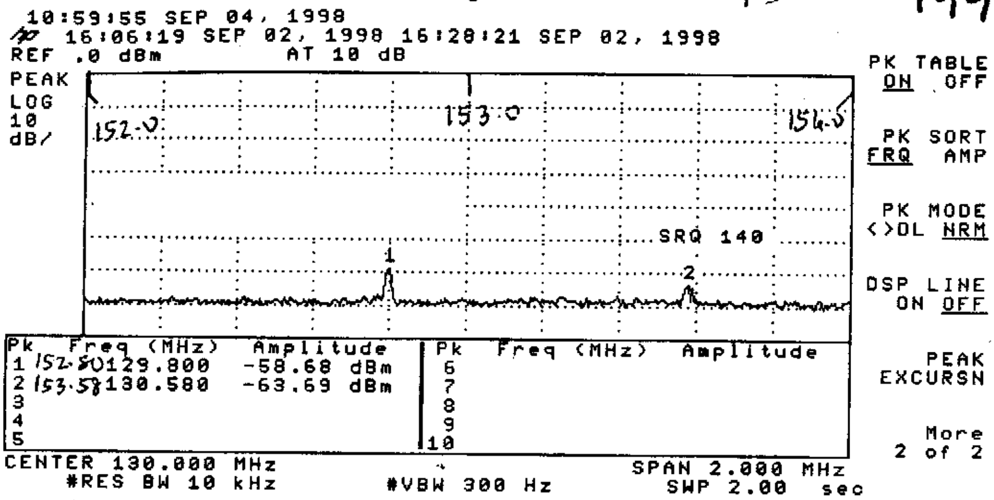
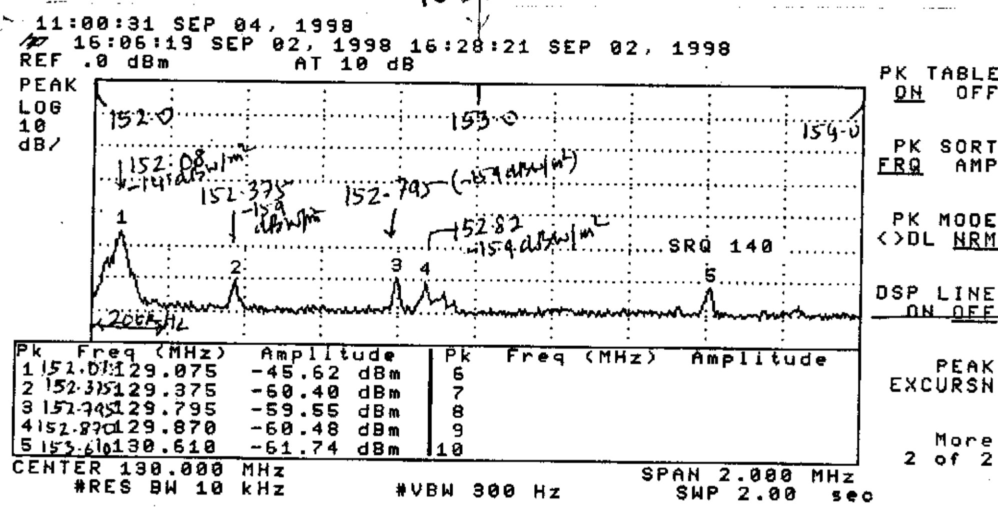


FIG. 1(n) : Caption as for Fig. 1(g) for scans obtained on September 2, 1998 showing presence of RFI at 152.12 MHz, near 152.8 MHz and 152.9 MHz.

1998 SEPT 2





Span 2MHz

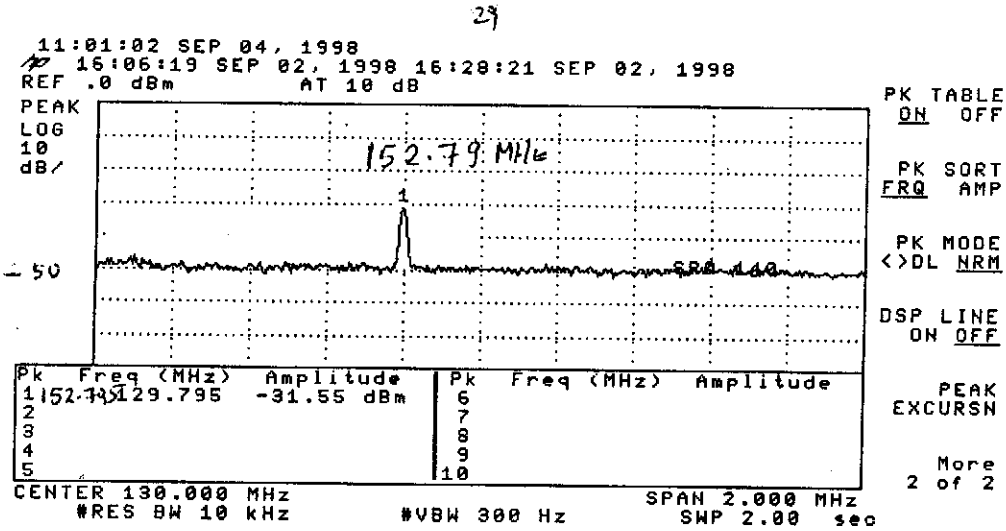


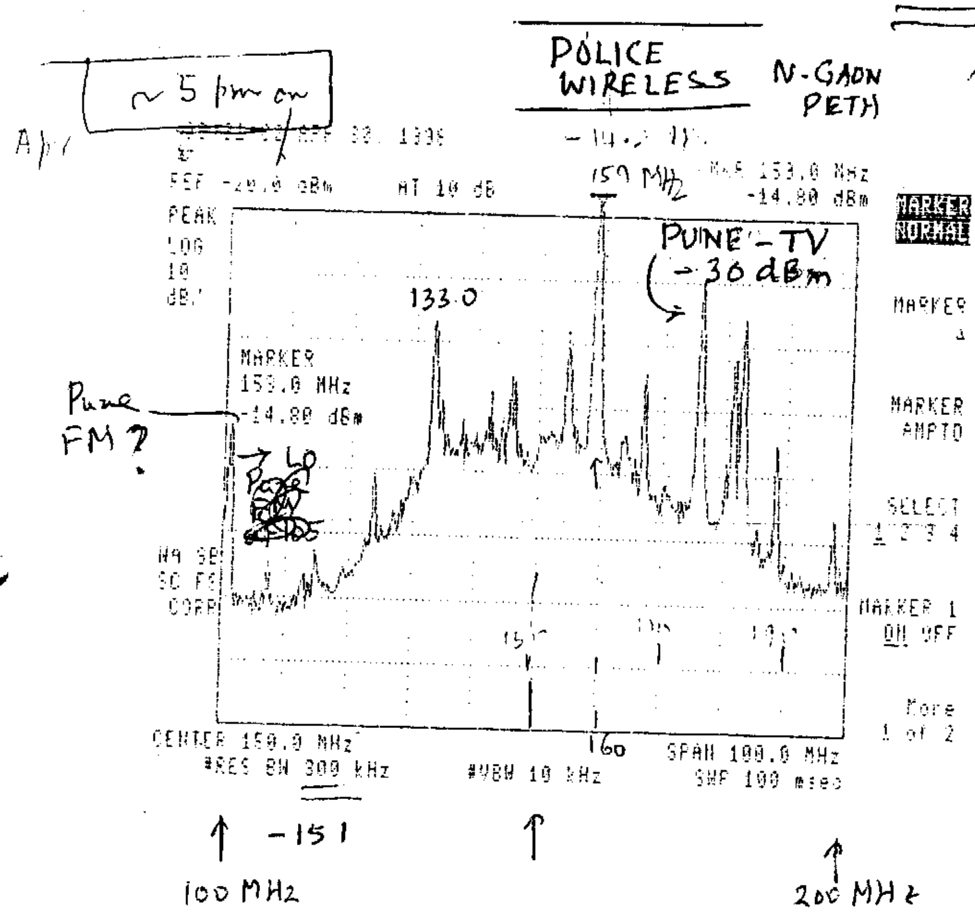
FIG. 1(o) : Same caption as for Fig. 1(n).

C9 antenna

150 MHz Feed pointing north
Antenna to zenith

HP 8590L

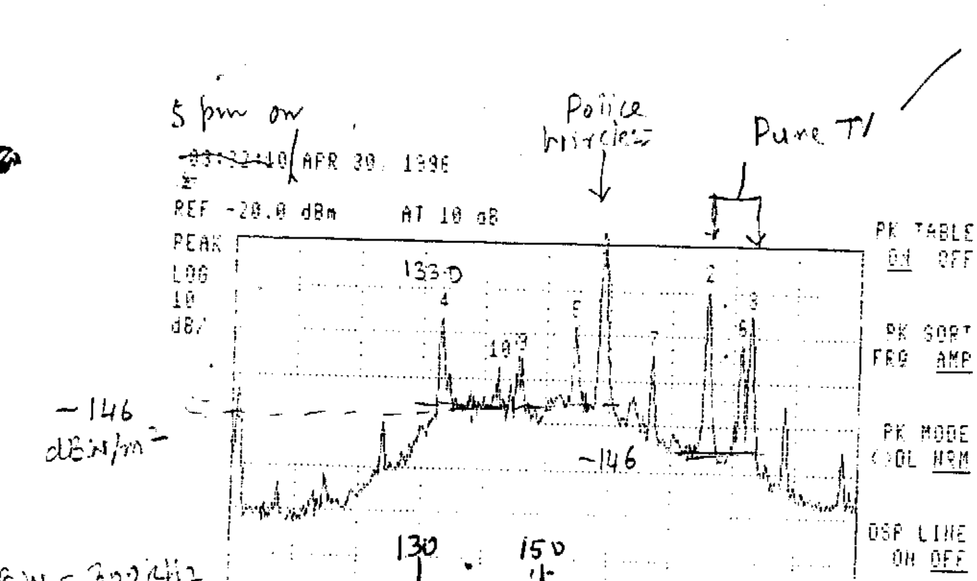
April 30, 1996



15

150 MHz
Antenna feed
to North

Measured frequencies may be 0.55 MHz higher than the correct value since Pune TV is at 175.25 MHz for carrier and 182.25 MHz for video



PK	Freq (MHz)	Amplitude	PK	Freq (MHz)	Amplitude
1	159.0	-14.80 dBm	6	181.3	-41.79 dBm
2	176.8	-23.37 dBm	7	167.0	-44.57 dBm
3	182.8	-35.39 dBm	8	145.5	-45.96 dBm
4	133.0	-36.99 dBm	9	146.0	-45.99 dBm
5	154.5	-39.12 dBm	10	142.3	-47.53 dBm

CENTER 150.0 MHz #RES BW 300 kHz #VBW 10 kHz SPAN 100.0 MHz SWP 100 msec

FIG. 1(p) : Spectrum of RF signals received at the output of the 150 MHz front end at the base of C-9 with feed pointed towards N (see Appendix-C for more scans).

FIG. 2 & FIG. 3 : CHARACTERISTICS OF RFI NEAR 146 MHz and 165 MHz.

FIG. 2 : In Fig. 2(a) to 2 (d) are shown detailed characteristics (modulation) for the strong RF signal near 146.6 MHz due to Pager transmitter near Pune as recorded at different times. It seems that there may exist two pager operating at 146.57 and 146.62 MHz or it may be an FSK transmitter. Strong RF signals are also seen at 146.88 MHz for C4-S and at 150.0 MHz (see Fig. 2(d)). The received p.f.d. at the GMRT site is about -110 dBW/m^2.

FIG. 3 : Shows RF signals in the band near 165 MHz. The signals near 166.165 to 166.450 are perhaps due to a Pager Transmitter near Pune.

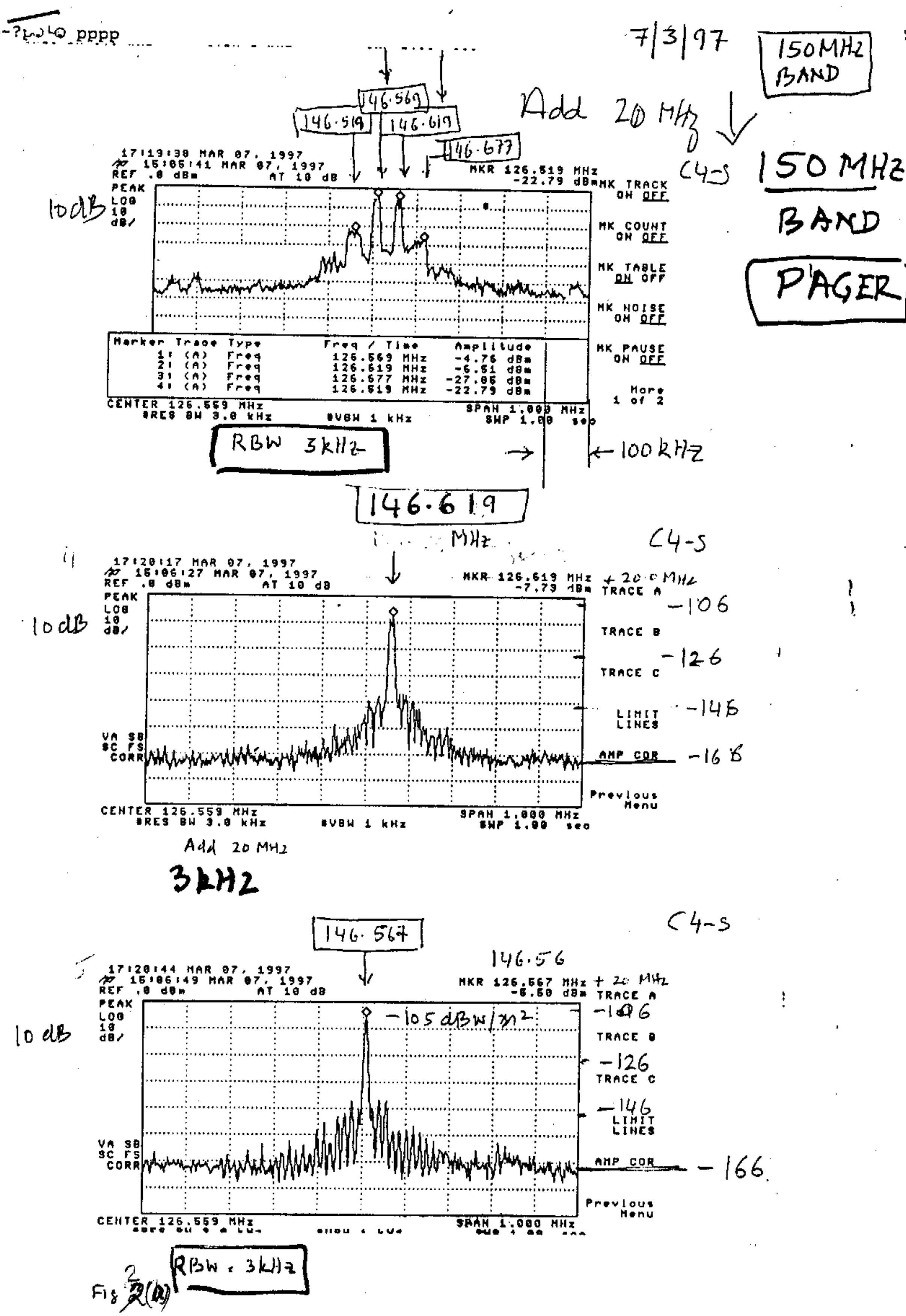
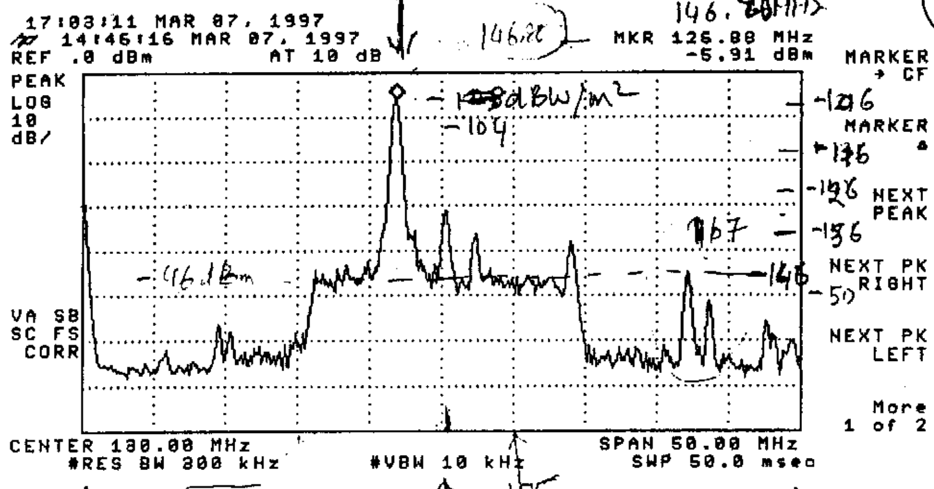


FIG. 2 : In Fig. 2(a) to 2 (d) are shown detailed characteristics (modulation) for the strong RF signal near 146.6 MHz due to Pager transmitter near Pune as recorded at different times. It seems that there may exist two pager operating at 146.57 and 146.62 MHz or it may be an FSK transmitter. Strong RF signals are also seen at 146.88 MHz for C4-S and at 150.0 MHz (see Fig. 2(d)). The received p.f.d. at the GMRT site is about -110 dBW/m^2.

GS / MS / PHJ

Add 20 MHz → (A)

Fig → 0

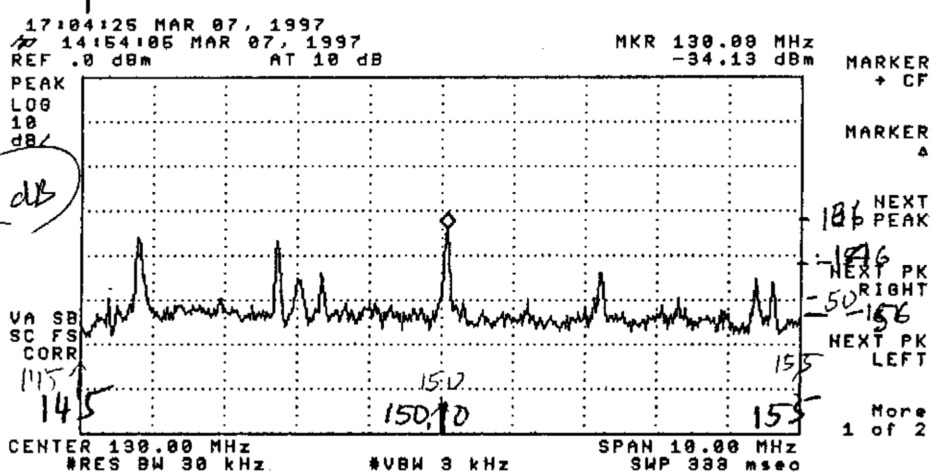


Max hold

(LO = 220 MHz)

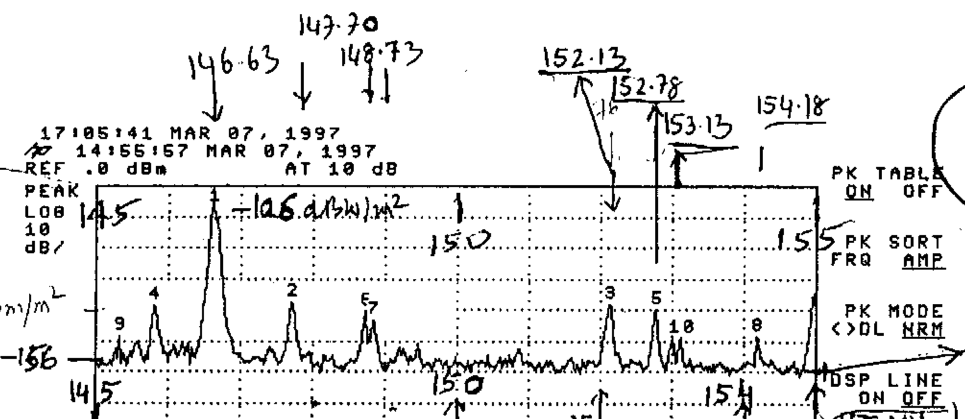
C4-S

1



Snap Shot

2



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	(146.65) 126.63	-5.32 dBm	6	128.73	-40.73 dBm
2	(147.70) 127.70	-37.64 dBm	7	128.83	-48.30 dBm
3	(152.13) 132.13	-38.11 dBm	8	134.18	-48.29 dBm
4	125.80	-38.71 dBm	9	125.33	-48.34 dBm
5	(152.78) 132.78	-40.02 dBm	10	133.13	-49.13 dBm

CENTER 130.00 MHz SPAN 10.00 MHz
#RES BW 30 kHz #VBW 3 kHz SWP 333 msec

C4-S 150

2 min max hold

SPAN 10 MHz

Fig 2(b)

Antenna, C4

150 Feed towards South (el ~ 20°).

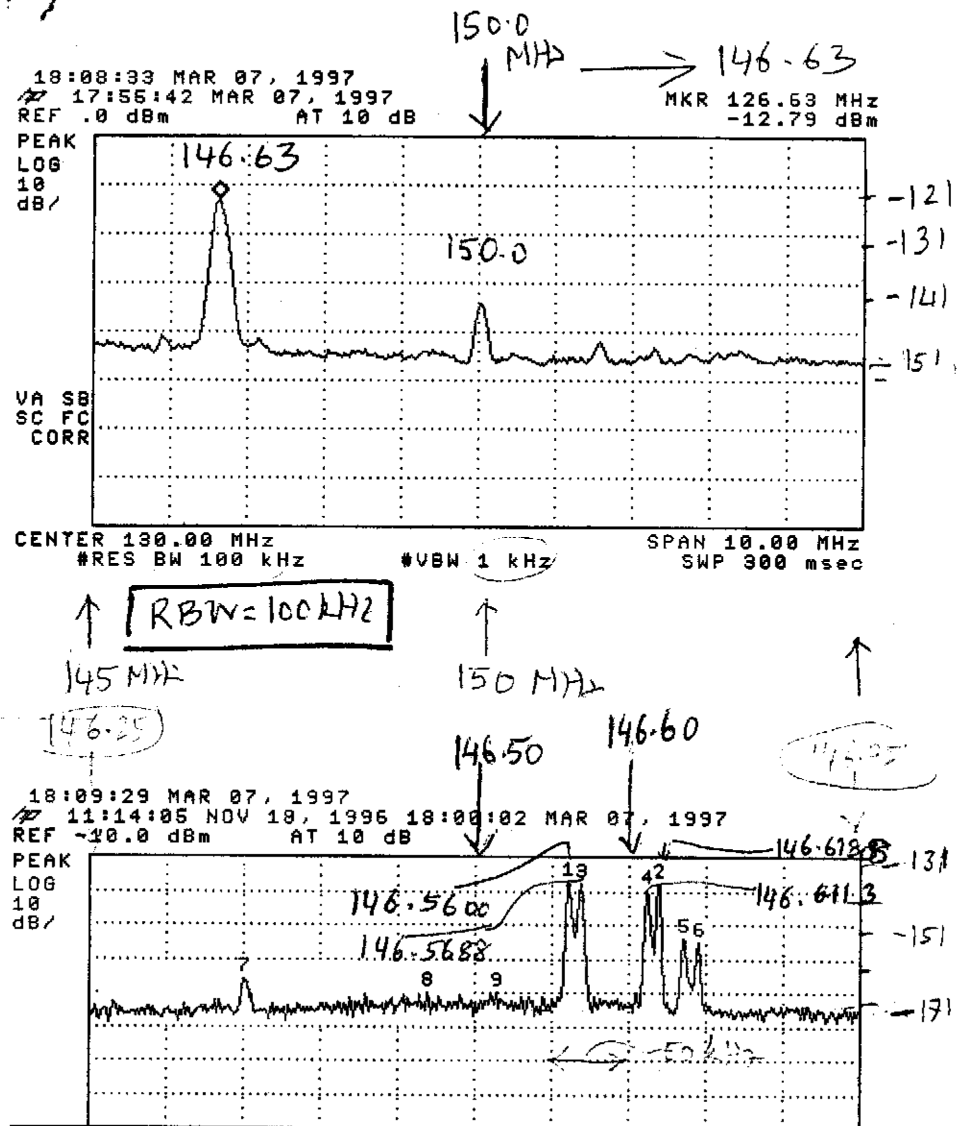
1445 - 1745 hrs

7/3/97

150 Feed toward Mumbai.

7/3/97

Add +20 MHz for Actual IF.



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	126.5600	-17.55 dBm	6	126.6450	-35.06 dBm
2	126.6188	-17.83 dBm	7	126.3500	-45.88 dBm
3	126.5688	-18.07 dBm	8	126.4688	-49.97 dBm
4	126.6113	-19.60 dBm	9	126.5138	-50.23 dBm
5	126.6350	-33.89 dBm	10		

Add 20 MHz

CENTER 126.5000 MHz SPAN 500.0 kHz

#RES BW 1.0 kHz #VBW 1 kHz SWP 1.50 sec

RBW = 1kHz

RBW = 1kHz

100 kHz

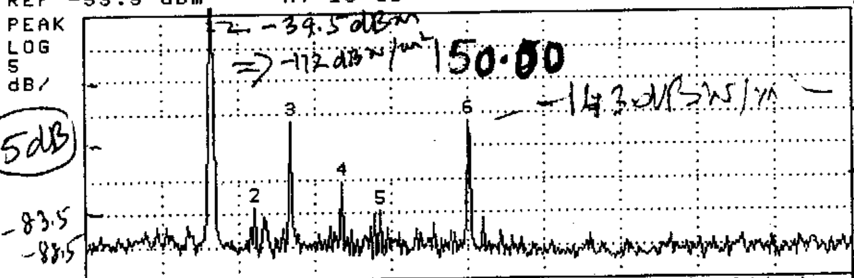
Fig. 3(c)

146.65 MHz (Pager)

C4-S

5.25 PM

14:45:58 SEP 04, 1998
17:25:16 SEP 03, 1998 17:31:44 SEP 03, 1998
REF -53.5 dBm AT 10 dB



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	146.65	-39.85 dBm	6	150.00	-69.75 dBm
2	147.20	-82.61 dBm	7		
3	147.68	-69.76 dBm	8		
4	148.35	-78.96 dBm	9		
5	148.85	-83.34 dBm	10		

CENTER 150.00 MHz SPAN 10.00 MHz
#RES BW 10 kHz #VBW 300 Hz SWP 10.0 sec

$-161 + (88.5 - 39.9)$

48.6

-112 dBW/m²

Fig 2(d)

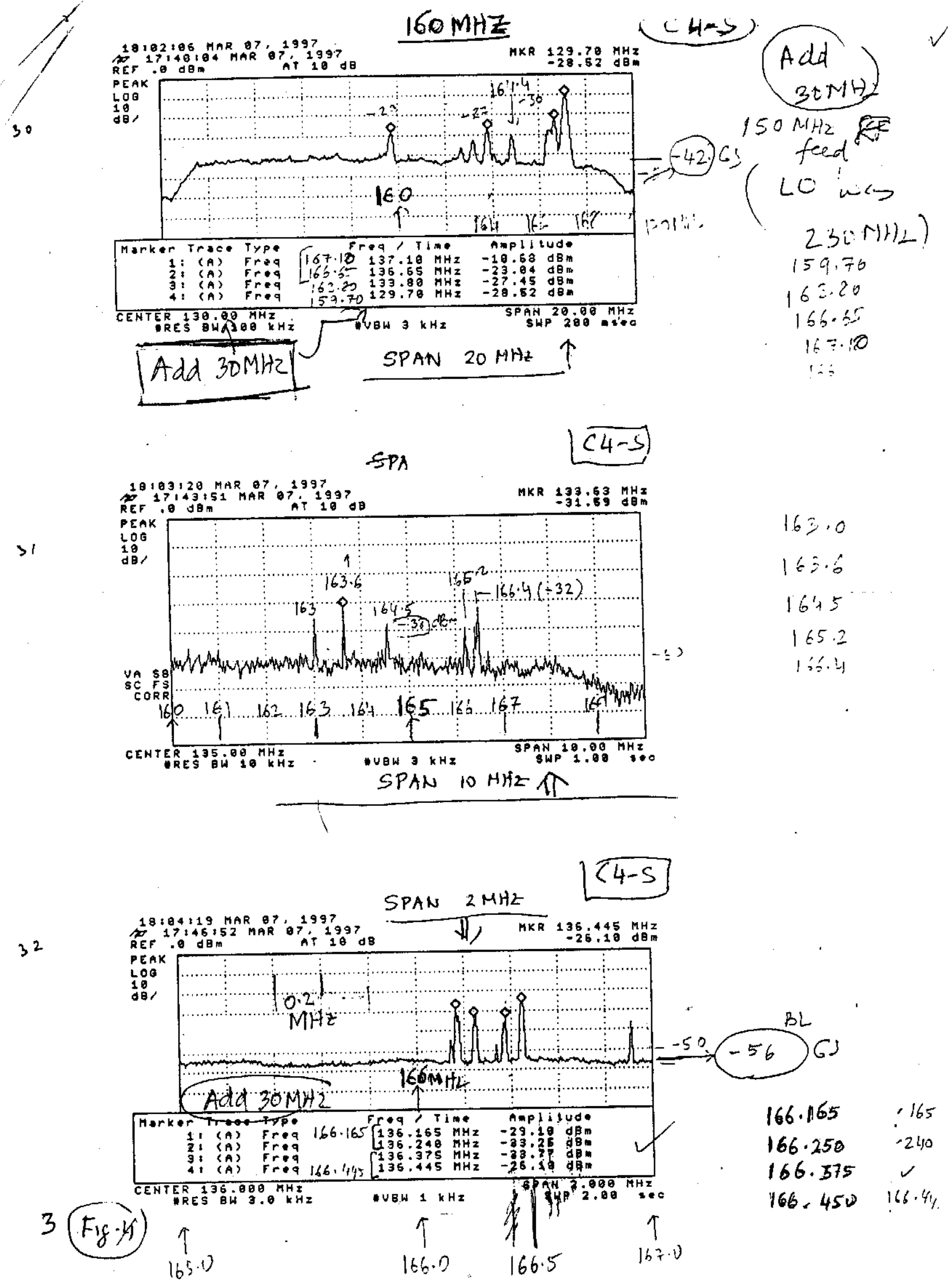


FIG. 3 : Shows RF signals in the band 160-166 MHz. The signals near 166.165 to 166.450 are perhaps due to a Pager Transmitter near Pune.

Fig 3

FIG. 4 : RFI MEASUREMENTS IN THE 232 MHz BAND

FIG. 4 : Fig. 4 shows RFI measurements in the band 235 ± 8 MHz made at the GMRT site in May & June 1998. Figures 4(a) to 4(f) shows plots of HP spectrum analyzer (SpA) scans obtained for the 130 MHz. IF channel at the output of the optical fibre in the Receiver Room of the GMRT.

FIG. 4(a) : Shows Spectrum Analyzer scans for the RFI Survey made on 29th May 1998 in the band 235 MHz ± 8 MHz with the W3 235 MHz antenna feed pointed towards North (labelled as W3-N). Several strong narrow-band RFI signals were observed.

FIG. 4(b) Shows scans for W2 feed towards South observed a few minutes earlier. In Figs.

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.

The following conclusions can be made (see text) :

i) RFI at 229.75 MHz is stronger towards South (-124 dBW/m^2) and was seen on both May 27th & May 29th 1998.

ii) Strong signals at 233.50 & 239.6 MHz which were observed on 29th May 1998 around 22 hrs. for W3-N were not seen in the afternoon of 27th May 1998 for W3-N.

iii) Signal at 237.10 MHz was observed on 29th May 1998 around 22^h 10^m 1998 as well as on 27th May 1998 around 15^h 39^m. Similarly signal near 233.10 MHz was present on both days for W3-N (and not seen for W2-5 and S6-E).

iv) In S6-E was present a signal near 233.80 MHz whose frequency varied by 0.3 MHz from about 233.65 to 233.95 MHz over minutes (see Fig. 4(e))

v) A strong signal was observed for W3-N on 27th May 1998 around 16^h 03^m whose frequency was seen to vary by about 0.7 MHz from about 241.575 MHz to 242.255 MHz over minutes (Fig. 4f).

vi) Signal at 243.9 MHz had on an average same p.f.d. for W3-N and S6-E and may have occurred in the north-east direction.

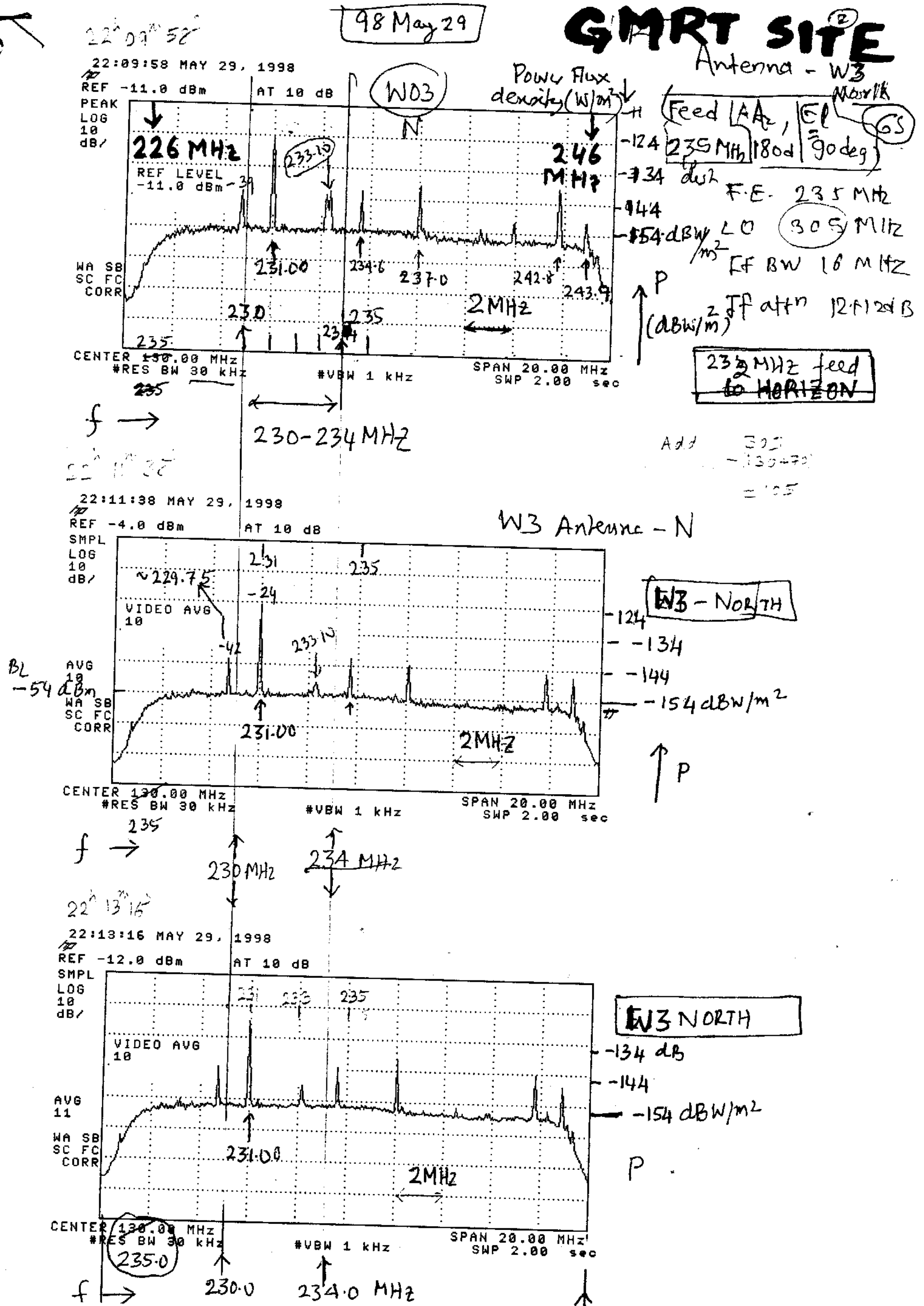


FIG. 4(a) : Shows Spectrum Analyzer scans for the RFI Survey made on 29th May 1998 in the band 235 MHz ± 8 MHz with the W3 235 MHz antenna feed pointed towards North (labelled as W3-N). Several strong narrow band RFI

98 May 29 GS ①

Antenna - W2 —

A Az El Feed

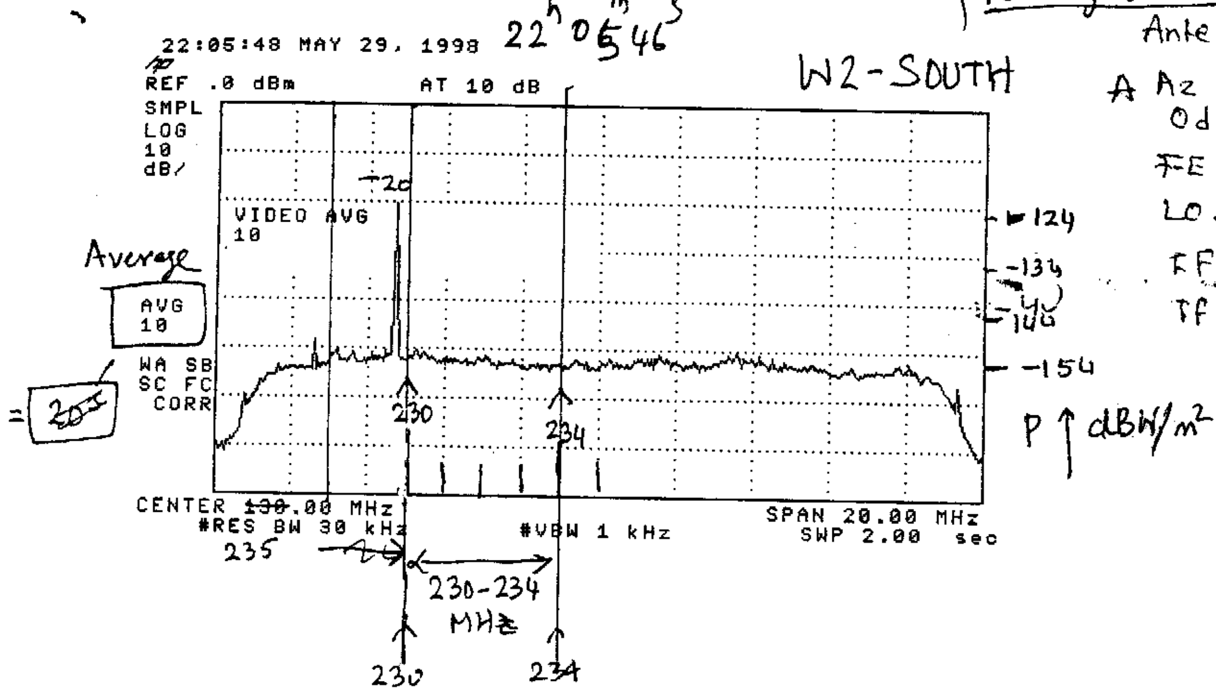
0d 90d 325 MHz

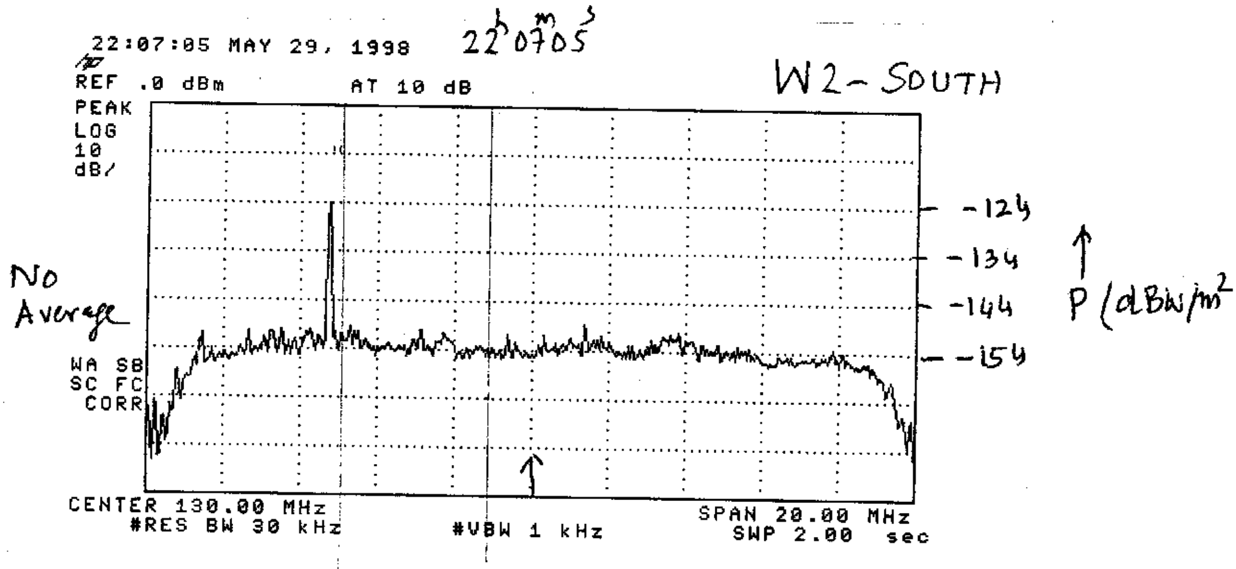
FE · 235 MHz

LO · 305 MHz

IF BW - 16 MHz

IF attn 12+12 dB





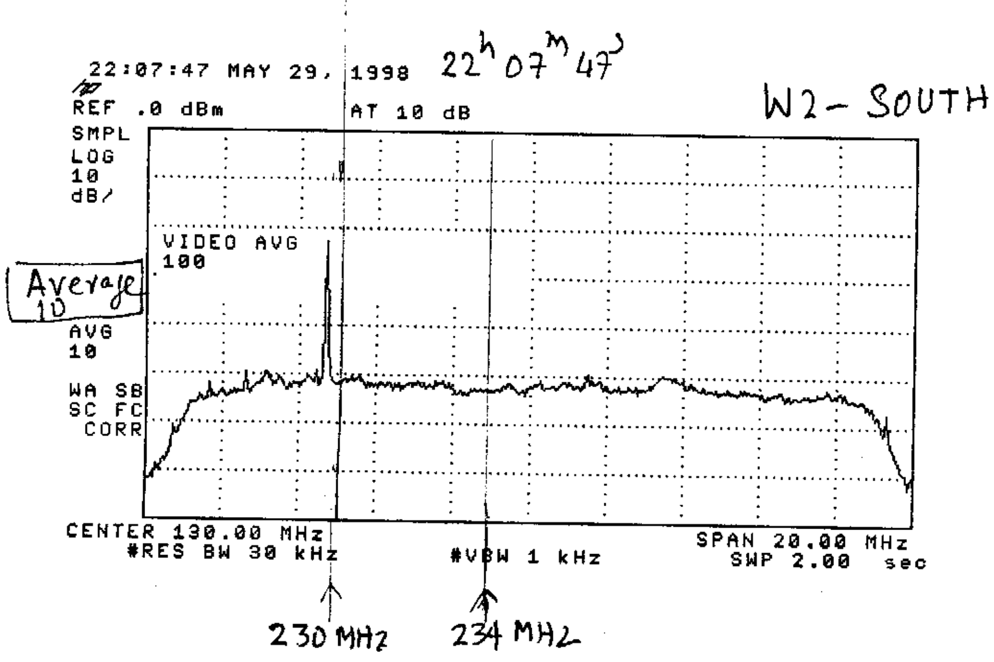


FIG. 4(b) showS scans for W2 feed towards South observed a few minutes earlier. In Figs.

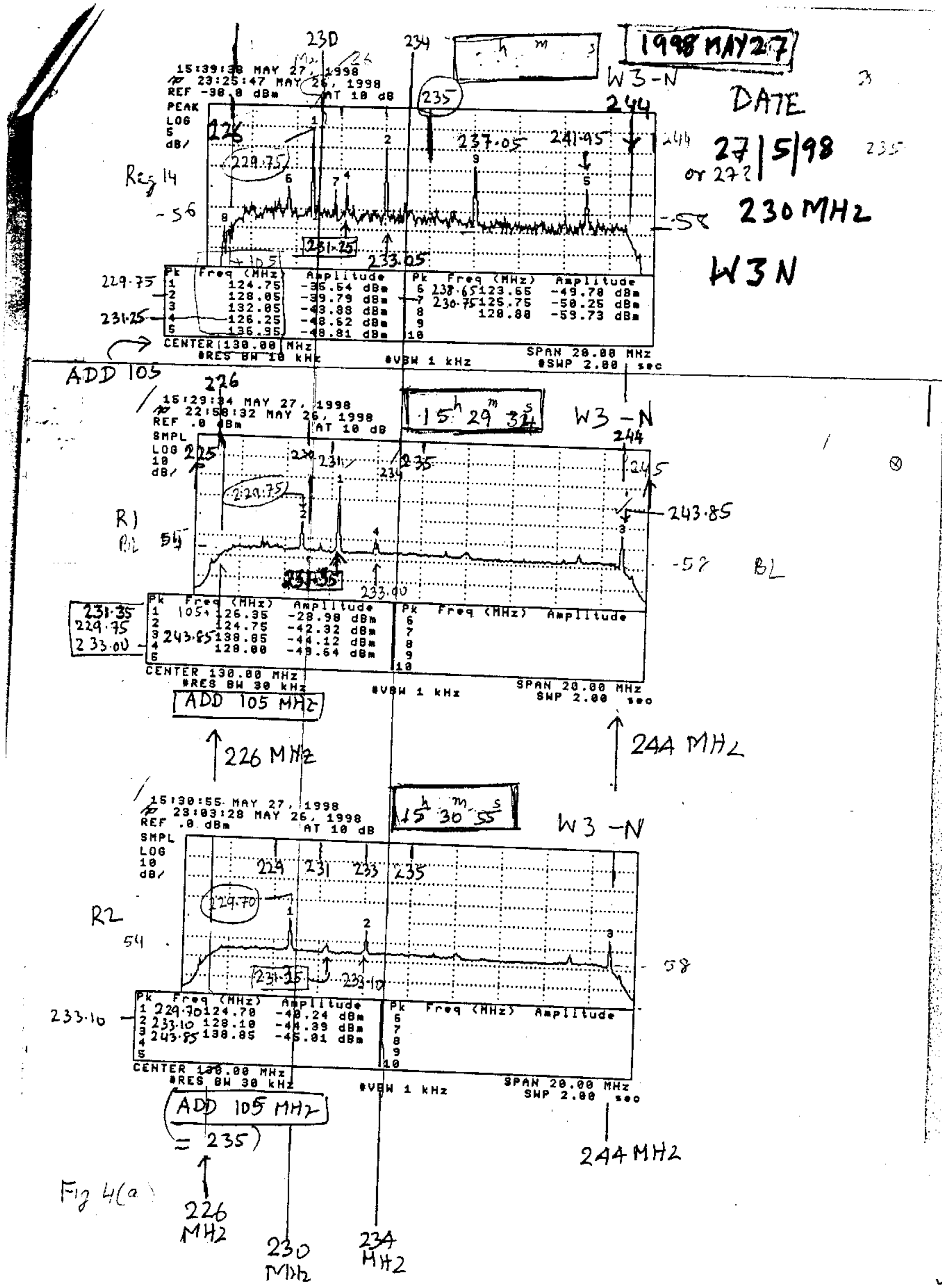


Fig. 4(c)

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.

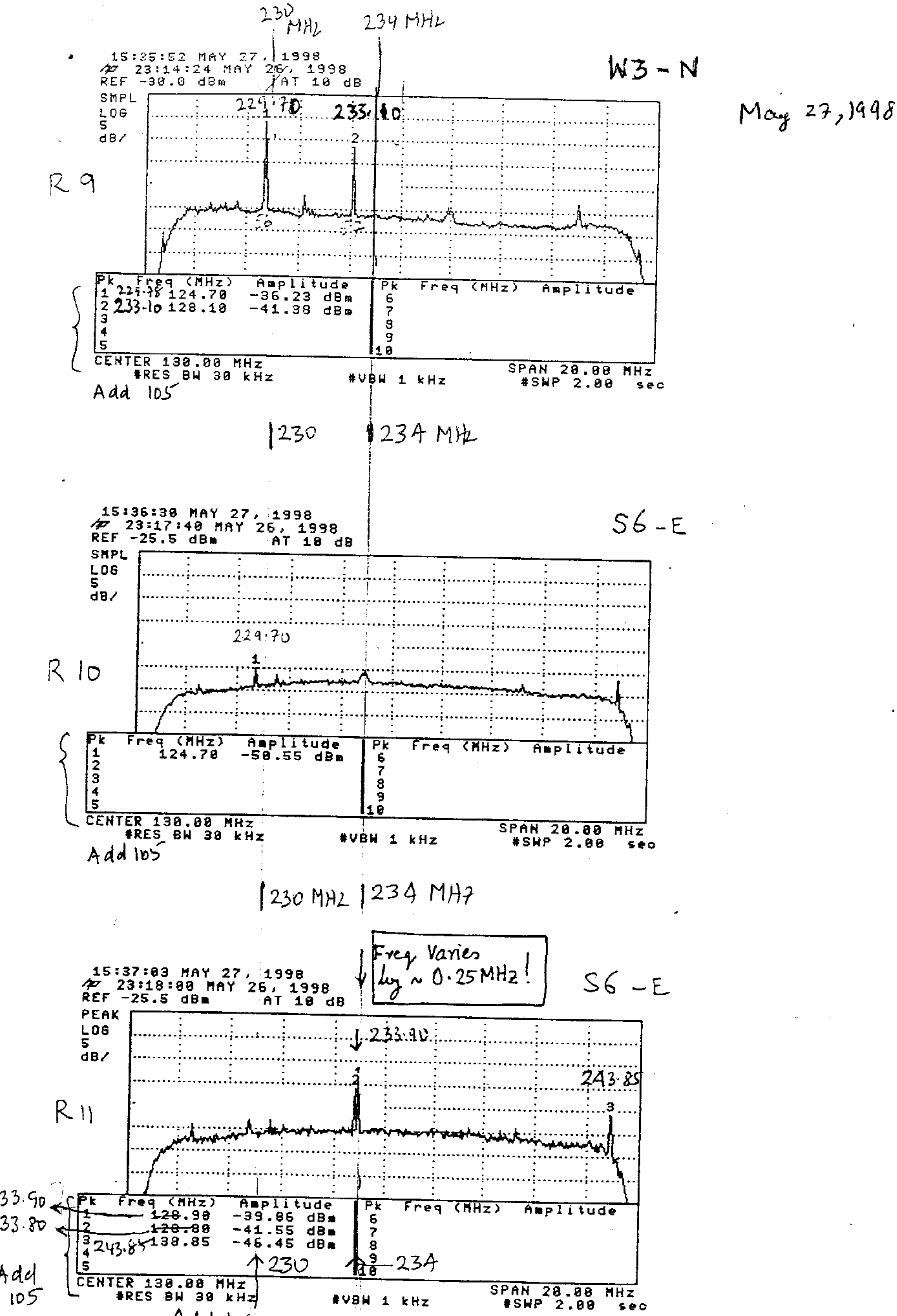
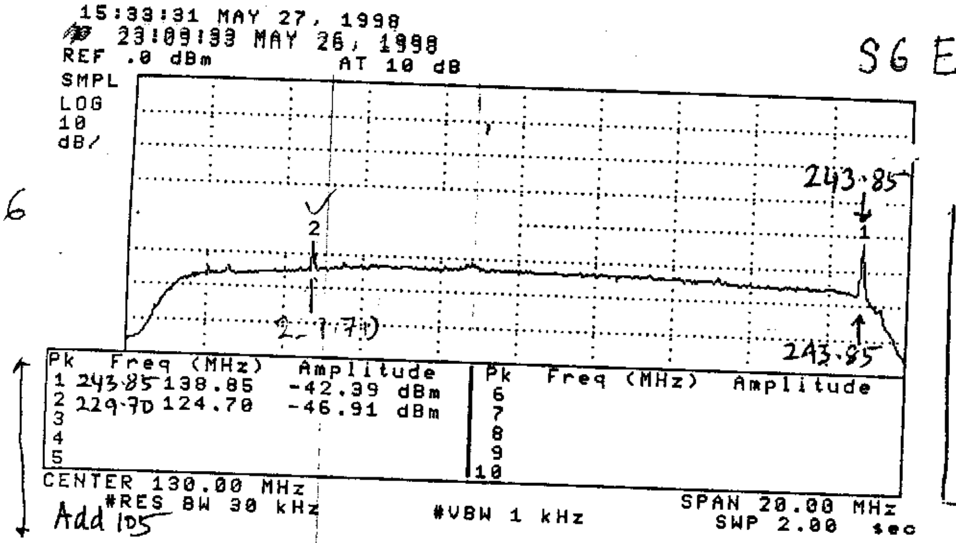


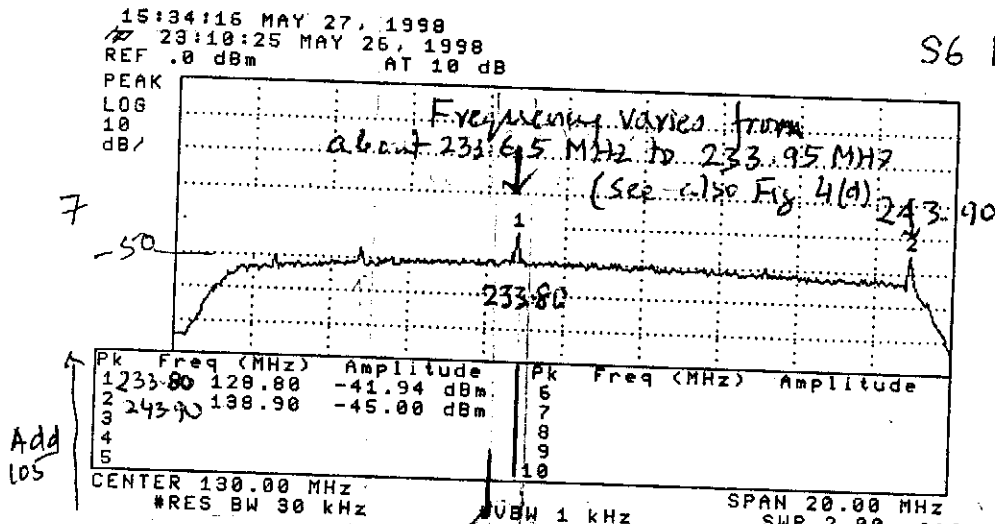
Fig. 4(d)

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.



Frequency Varies from 243.65 to 243.95 MHz (See below)

1



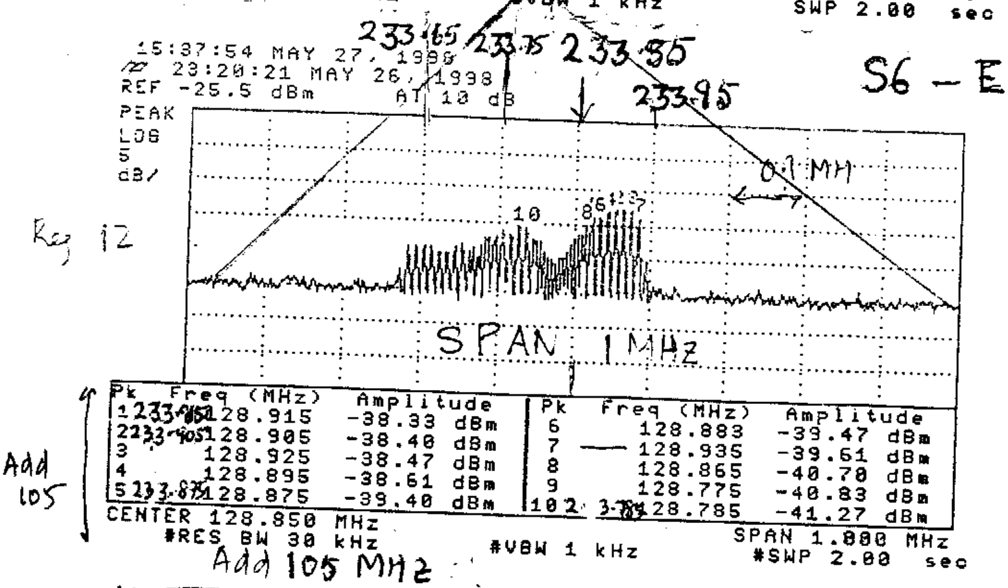


Fig (4e)

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.

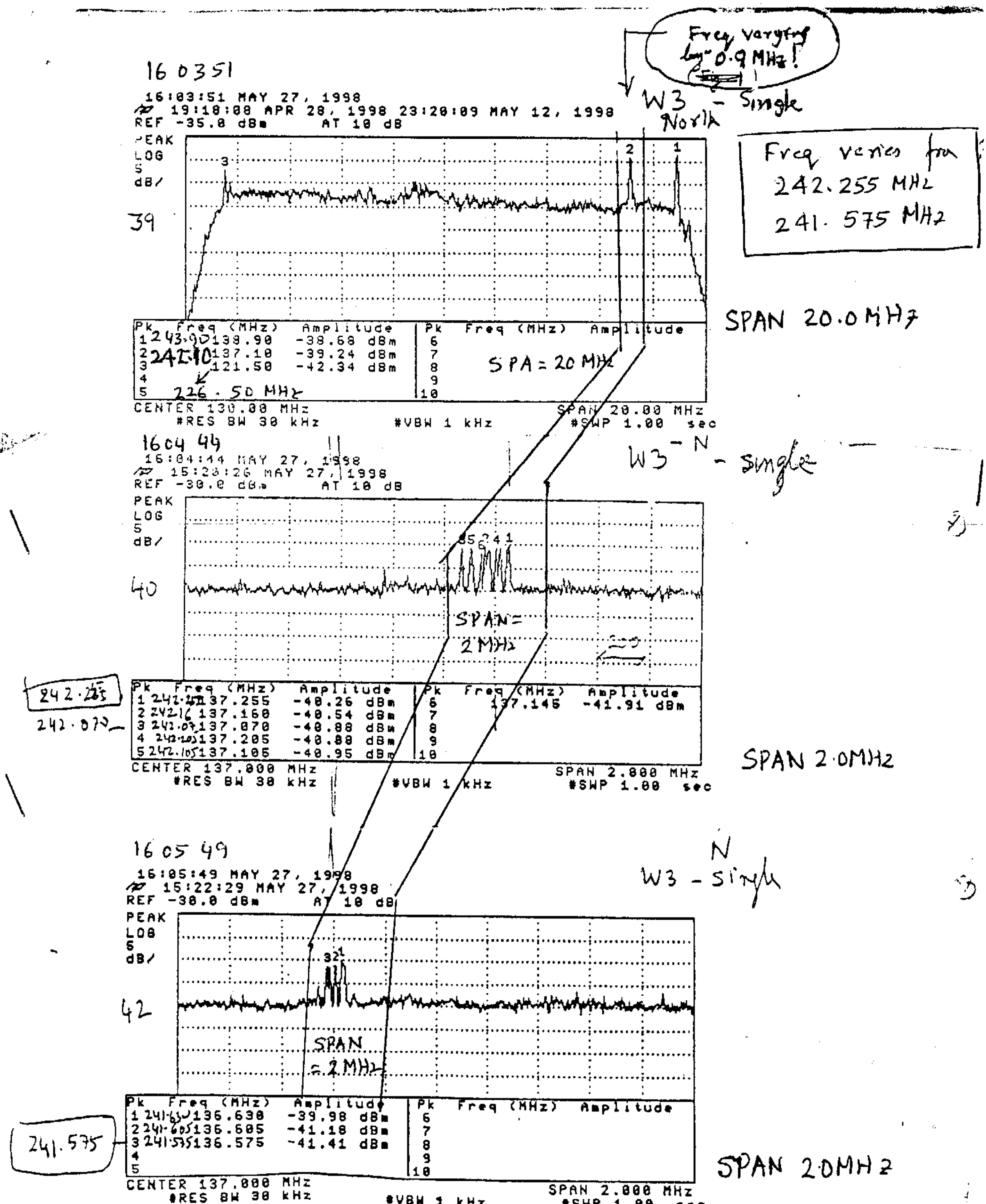
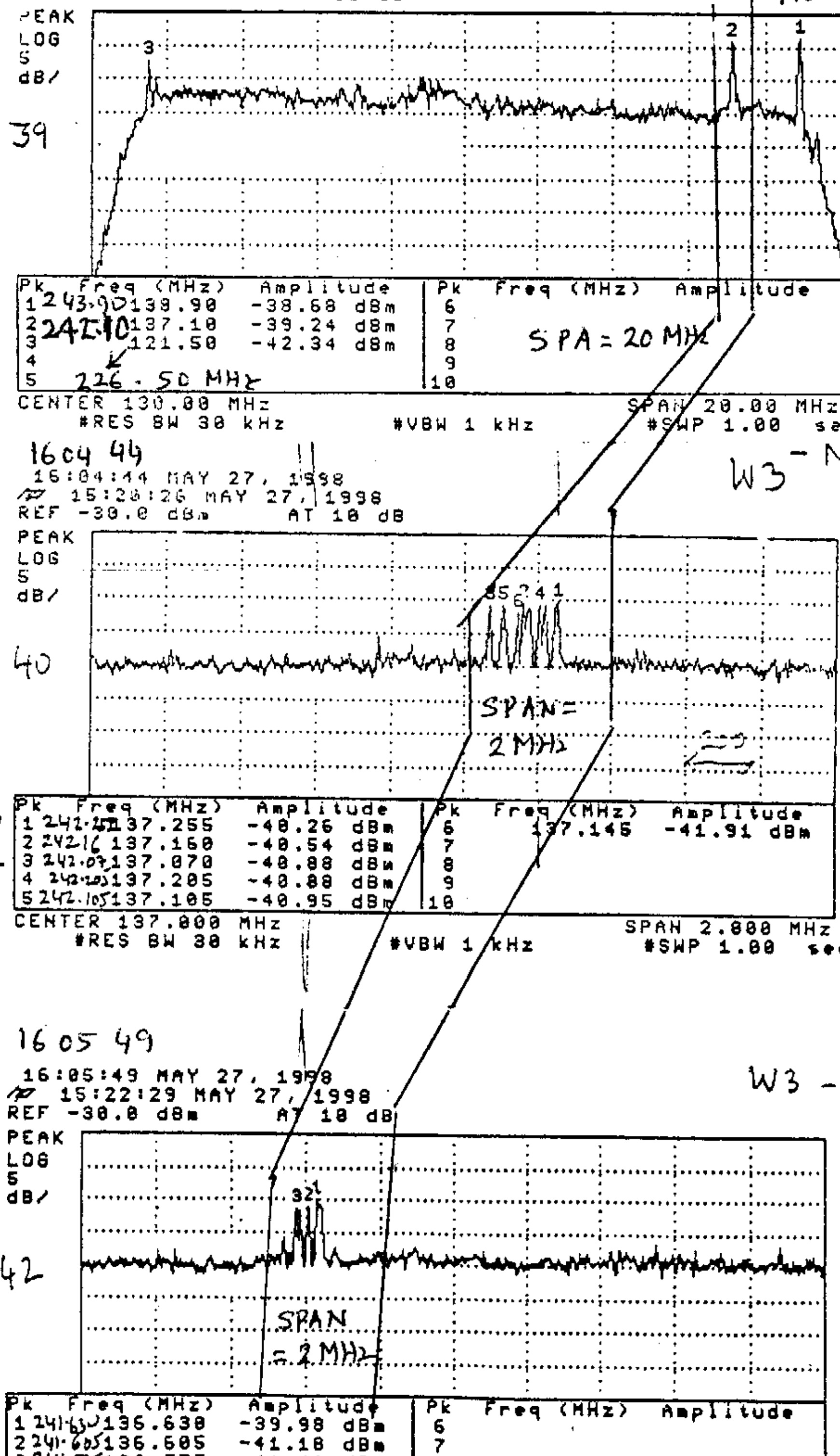


Fig. 4(f)

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	139.90	-38.68 dBm	6		
2	137.10	-39.24 dBm	7		
3	121.50	-42.34 dBm	8		
4			9		
5			10		

Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	137.255	-40.26 dBm	6	137.145	-41.91 dBm
2	137.160	-40.54 dBm	7		
3	137.070	-40.88 dBm	8		
4	137.205	-40.88 dBm	9		
5	137.105	-40.95 dBm	10		

Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	136.630	-39.98 dBm	6		
2	136.605	-41.18 dBm	7		
3	136.575	-41.41 dBm	8		
4			9		
5			10		

Fig. 4(f)

FIG. 4(c) to 4(f) are shown scans observed on 27th May 1998 for W3, S6-E, S1-S and W2-S.

FIG. 5 : RFI IN THE 232 MHz BAND WITH 4 ANTENNAS EACH TOWARDS NORTH, EAST, SOUTH & WEST

FIG. 5 (a) to 5 (h) : Fig 5 shows RFI measurements made in the frequency band of about 231 MHz to 237 MHz at the output of the 130 MHz channel in the Receiver rooms by Frezot et al on 6th September 2000. The 230 MHz feeds of W01, E03, C00 and C09 were pointed towards N; W02, E04, C02 and C10 to E; W04, E05, C03 and C12 to S; and W05, E06, C04 and C13 to W. A signal at 234.0 MHz of -10 dBW connected to a log-periodic antenna was transmitted from the root of a 2-storey building of the Narayangaon Housing Colony of GMRT. The Spectrum Analyzer output (RBW = 10 kHz, VBW = 10 Khz, Sweep time = 240 ms) in the Rx room was connected to a PC, and data recorded and analyzed using the GMRT computer system.

FIG. 5(a) to 5 (d) : show signals received at the above group of antennas and show several sources of RFI in addition to 234.0 MHz signal transmitted as above before 1556 hours and 235 MHz after 1556 hours. The following conclusions may be made from Fig. 5(a) to 5 (d).

i) RFI signals are seen at discrete frequencies (in addition to 234.0 and 235.0 MHz) which are present at more than one antenna pointed in the same direction and in a few cases even adjacent directions

* 231.29 MHz at W01-N; C00-N and W02-E
* 232.6 MHz at E05-S and C12-S
* 233.3 MHz at C04-W and W02-E
* 236.9 MHz at W01-N; C00-N; C02-E, W02-E, C10-E

However, the above are not seen at all the antennas pointed in the same direction, perhaps due to propagation effects.

ii) Several RFI signals are seen at only one of the antennas out of a group of 3 or 4 working antennas pointed in the same direction. It is not clear whether these arise due to any local or nearby sources.

FIG. 5(e) : Show "plot with integration time = 6 plots of 10 seconds" for the case when signal transmitted by us from the Narayangaon Housing Colony was at 234.0 MHz (-10 dBW) connected to a log-periodic antenna with a gain of about 8 dB). Surprisingly, most of the discrete signals observed in the scans of Figs. 5(a) to 5(d) are absent in these average plots. However, the 234.0 MHz signal transmitted by us is clearly seen. However, its strength is more than 20 to 30 dB lower than expected considering the distance of the receiving antennas for the case of both Figs. 5(a) to 5(d) and Fig. 5(e).

FIG. 5 (f) : Same caption as for Fig. 5(e) but for the case when the signal transmitted had a frequency of 235.0 MHz.

FIG. 5(g) Gray Scale Plot for RFI survey made over the 231-237 MHz band on 6th September 2000 with 230 MHz feed to the horizon towards E, S, W and N for 4 antennas in each direction. Horizontal axis is frequency and vertical axis is time. Each block is of same duration = about 40^m, although of different width due to a programming problem. The following conclusion can be made :

i) There are discrete RFI signals seen at 231.4, 235.6 and 236.9 MHz. There is also a RFI signal at about 232 MHz whose frequency varies with time (perhaps a varying frequency source).

FIG. 5(h) : Colour gray scale plot similar to Fig. 5(g) but for C04-W, C03-S and C02-E antennas only. The presence of RFI signals are much better seen in this plot

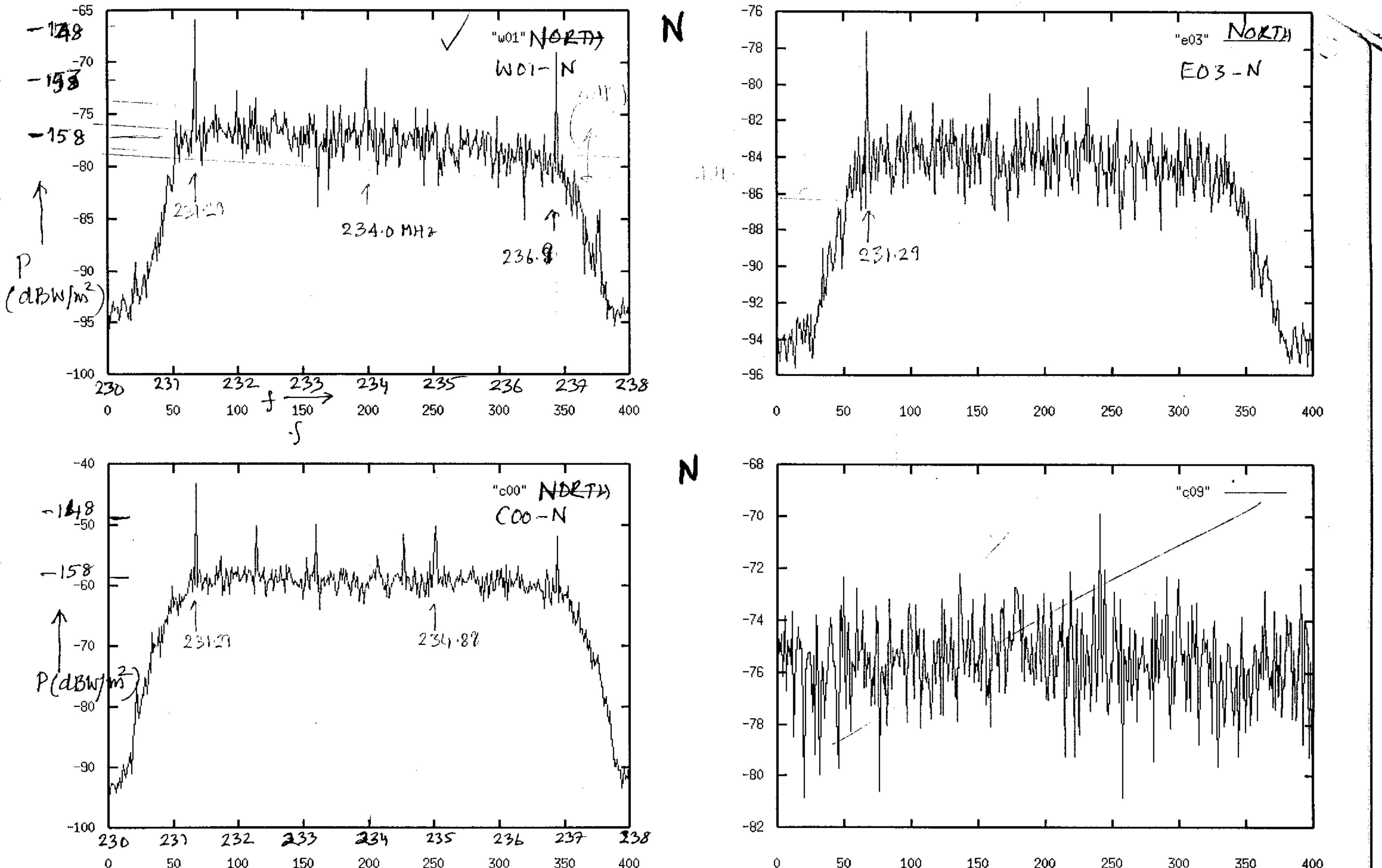
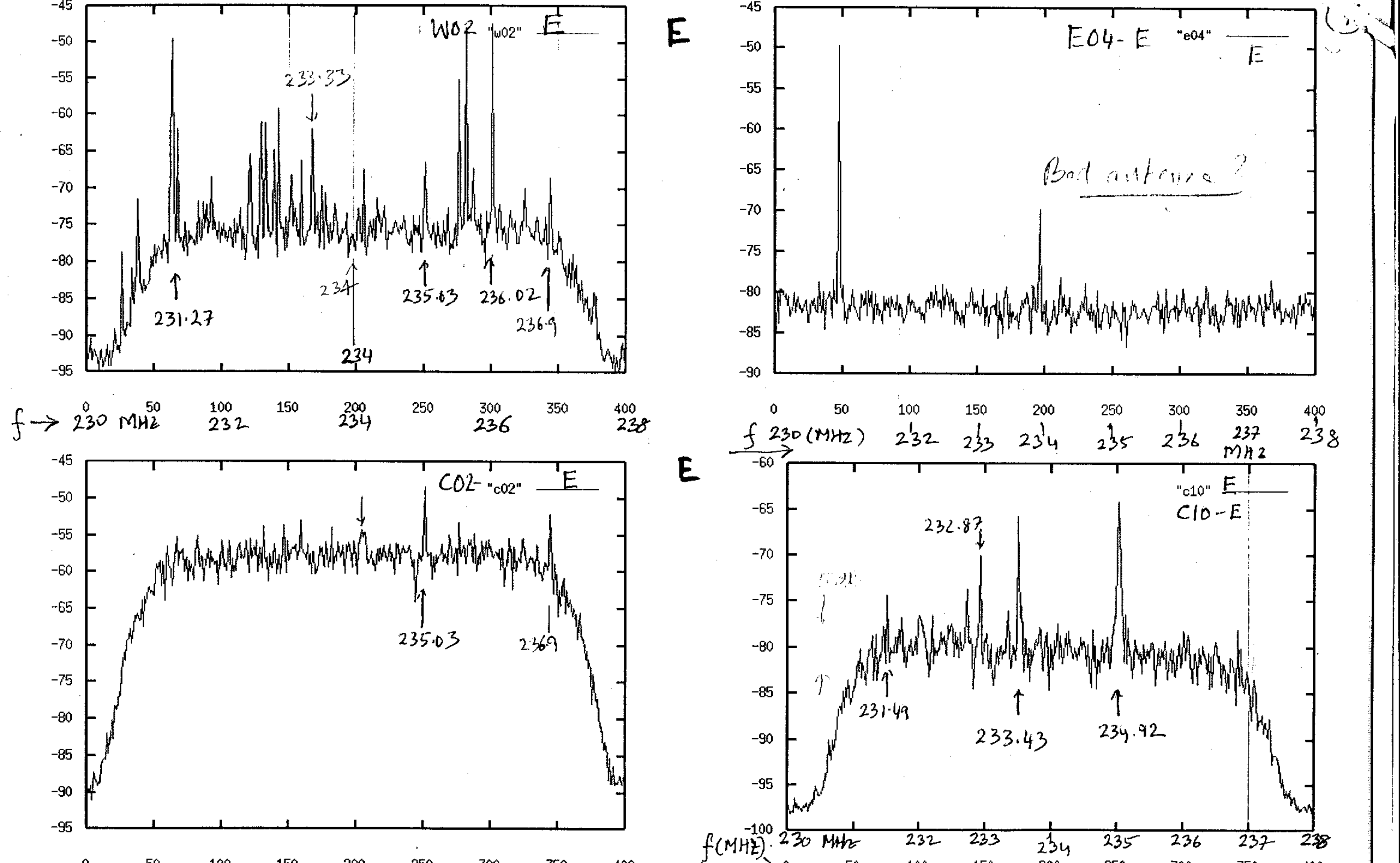

"w01" NORTH
W01-N
N
231.29
234.0 MHz
236.8
P (dBW/m²)
f
"e03" NORTH
E03-N
231.29
"c00" NORTH
C00-N
N
231.29
234.88
P (dBW/m²)
"c09"

FIG. 5(a)



W02 "w02" E
E
E04-E "e04" E
Bad antenna?
C02 "c02" E
E
"c10" E
C10-E
233.33
231.27
234
235.03
236.02
236.9
f → 230 MHz 232 234 236 238
f 230 (MHz) 232 233 234 235 236 237 MHz 238
235.03
236.9
232.87
231.49
233.43
234.92
f(MHz) 230 MHz 232 233 234 235 236 237 238

Fig. 5(b)

Gnuplot

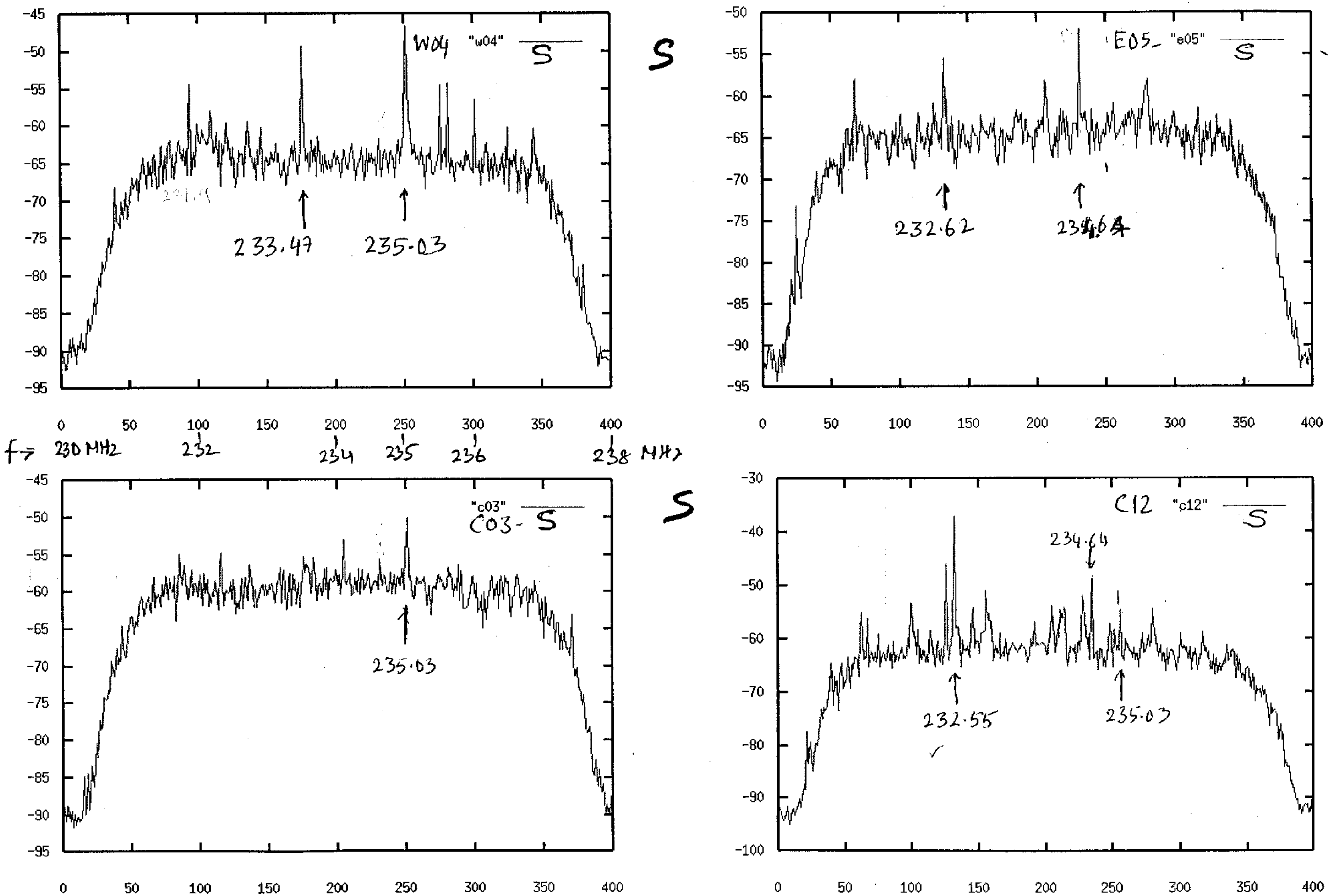
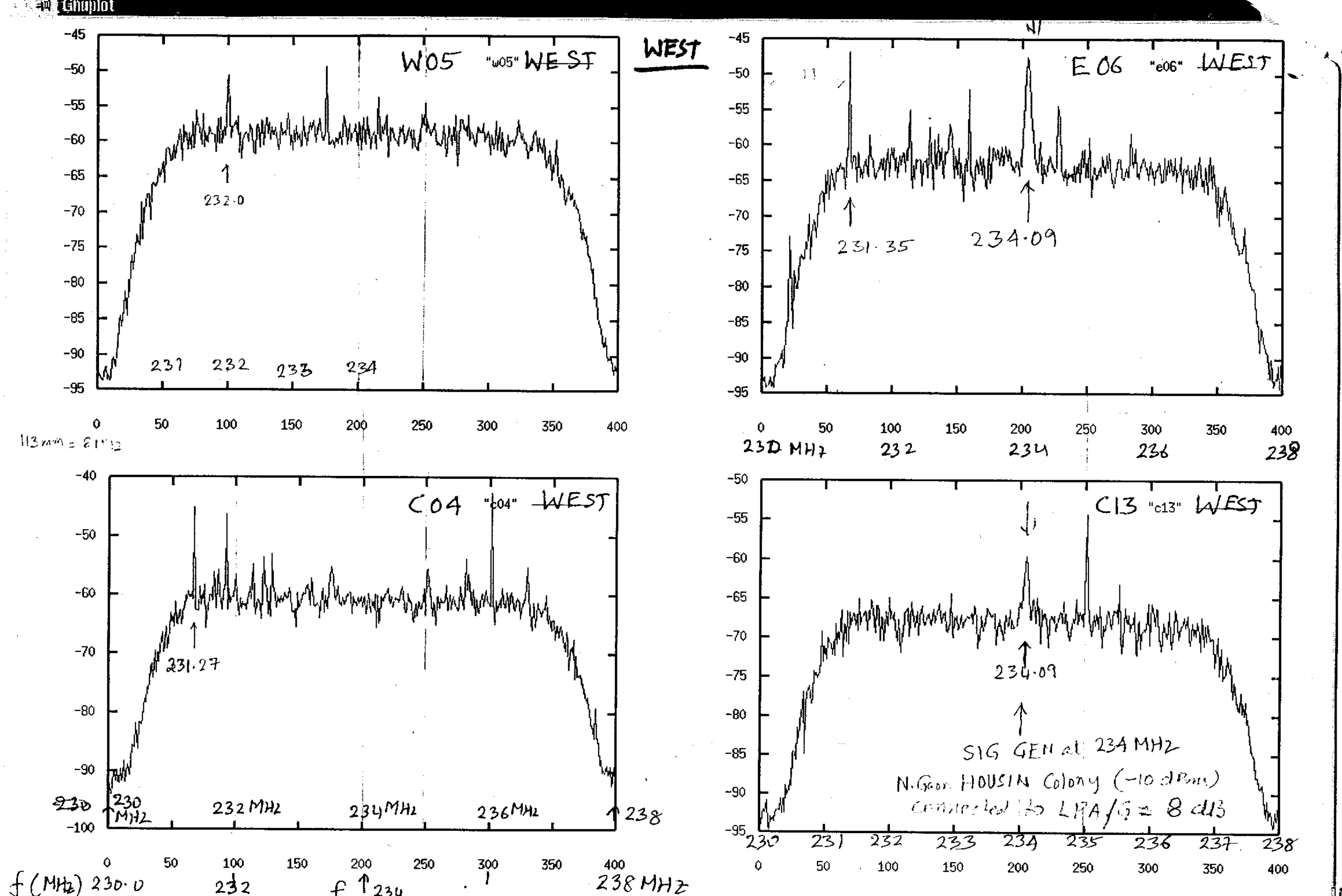
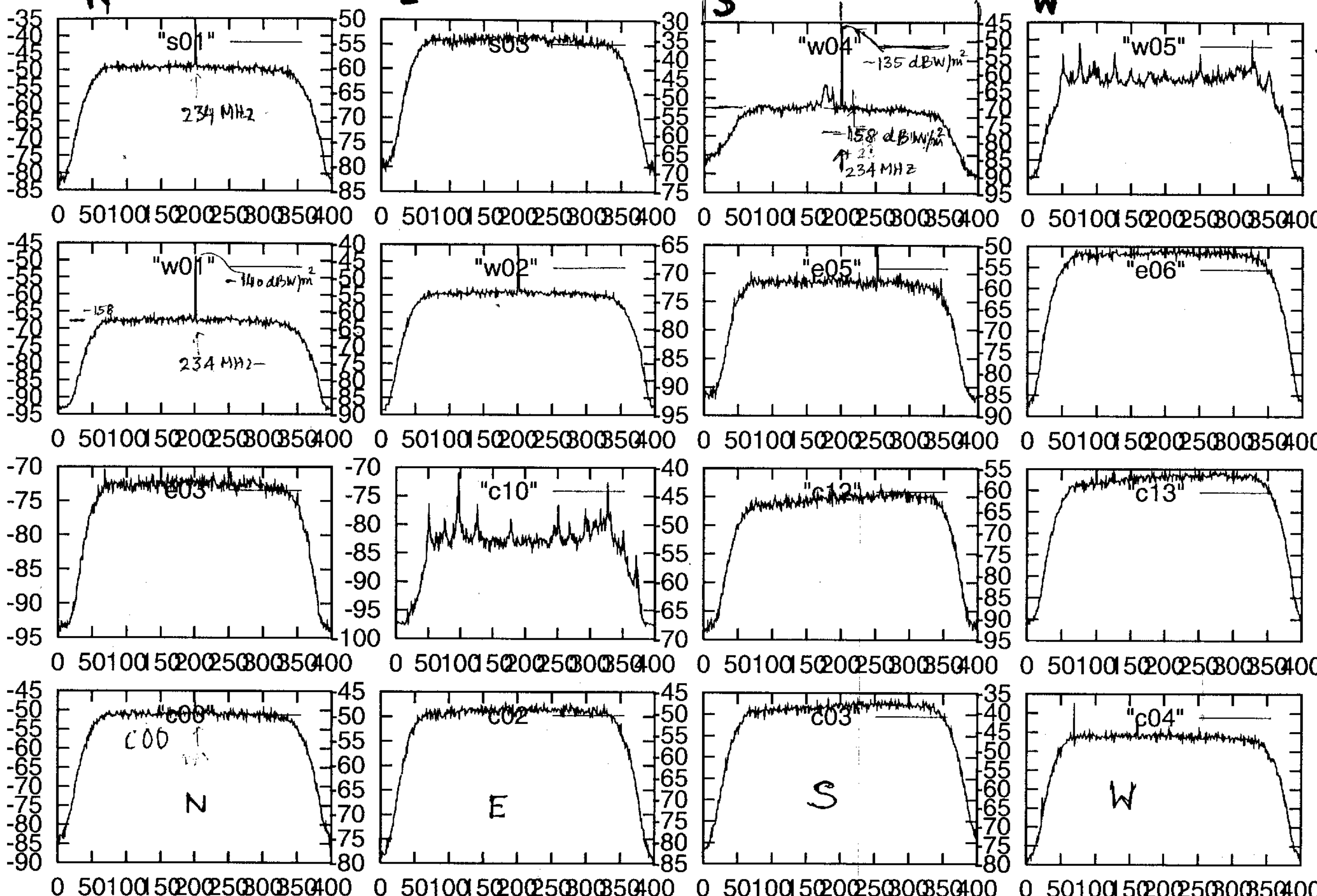


Fig. 5(c)



Gnuplot
W05 "w05" WEST
WEST
232.0
231 232 233 234
113 mm = 8 MHz
E06 "e06" WEST
231.35
234.09
230 MHz 232 234 236 238
C04 "c04" WEST
231.27
230 MHz 232 MHz 234 MHz 236 MHz 238
f (MHz) 230.0 232 f 234 238 MHz
C13 "c13" WEST
234.09
SIG GEN at 234 MHz
N. Gan. HOUSIN Colony (-10 dBm)
Connected to LPA / G = 8 dB
230 231 232 233 234 235 236 237 238

FIG 5(d)



ıG. 5(e) : Show "plot with integration time = 6 plots of 10 seconds" for the case when signal transmitted by us from the Narayangaon Housing Colony was at 234.0 MHz (-10 dBW) connected to a log-periodic antenna with a gain of about 8 dB

Fig 5(e)

W

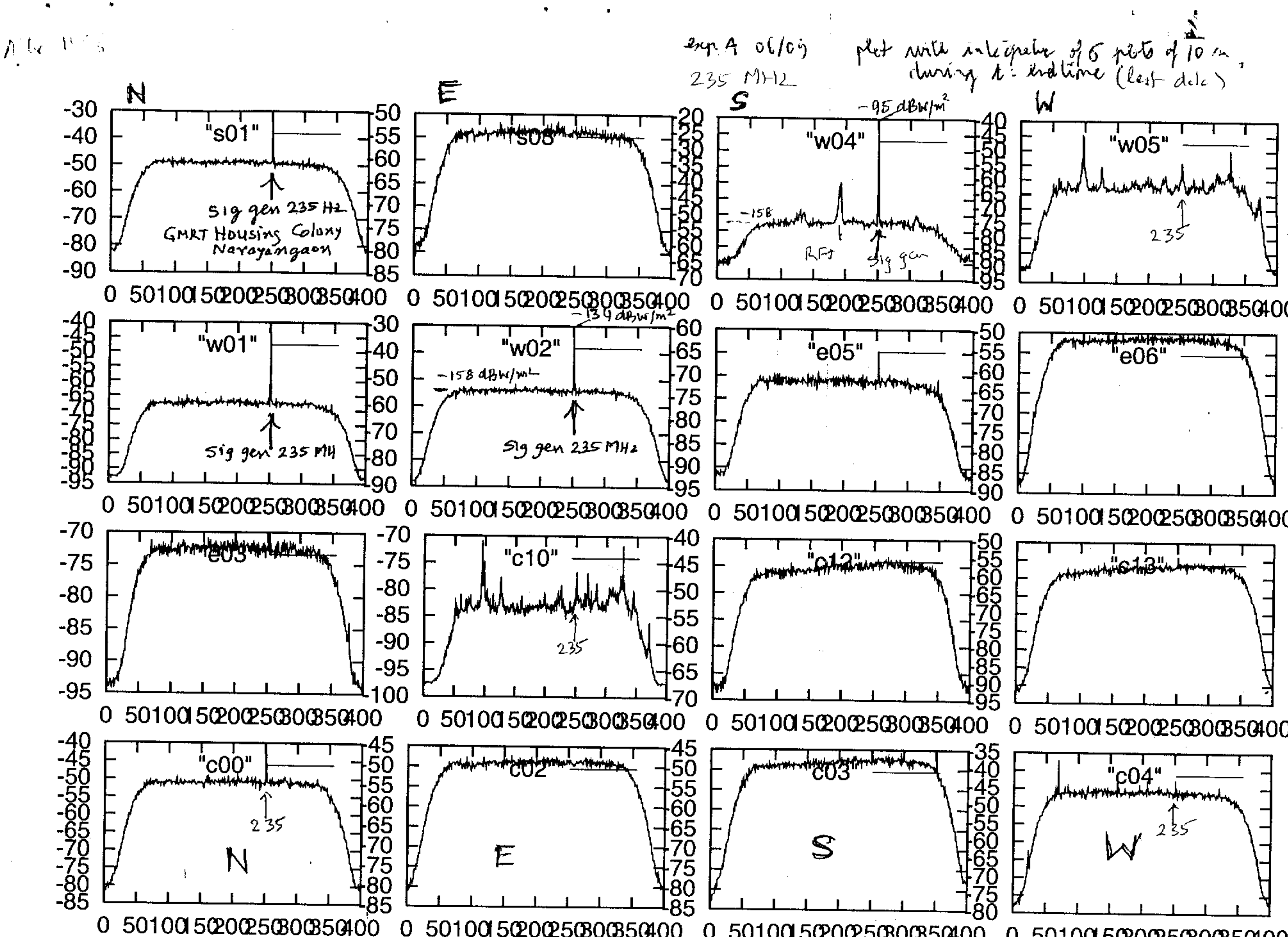


Fig. 5(f

FIG. 5 (f) : Same caption as for Fig. 5(e) but for the case when the signal transmitted had a frequency of 235.0 MHz.

Fig 5(g) GREY SCALE PLOT FOR RFI SURVEY for 231 - 237 MHz BAND ON 06.09.2000 (230 MHz feed to horizon towards E, S, W & N for 4 antennas each

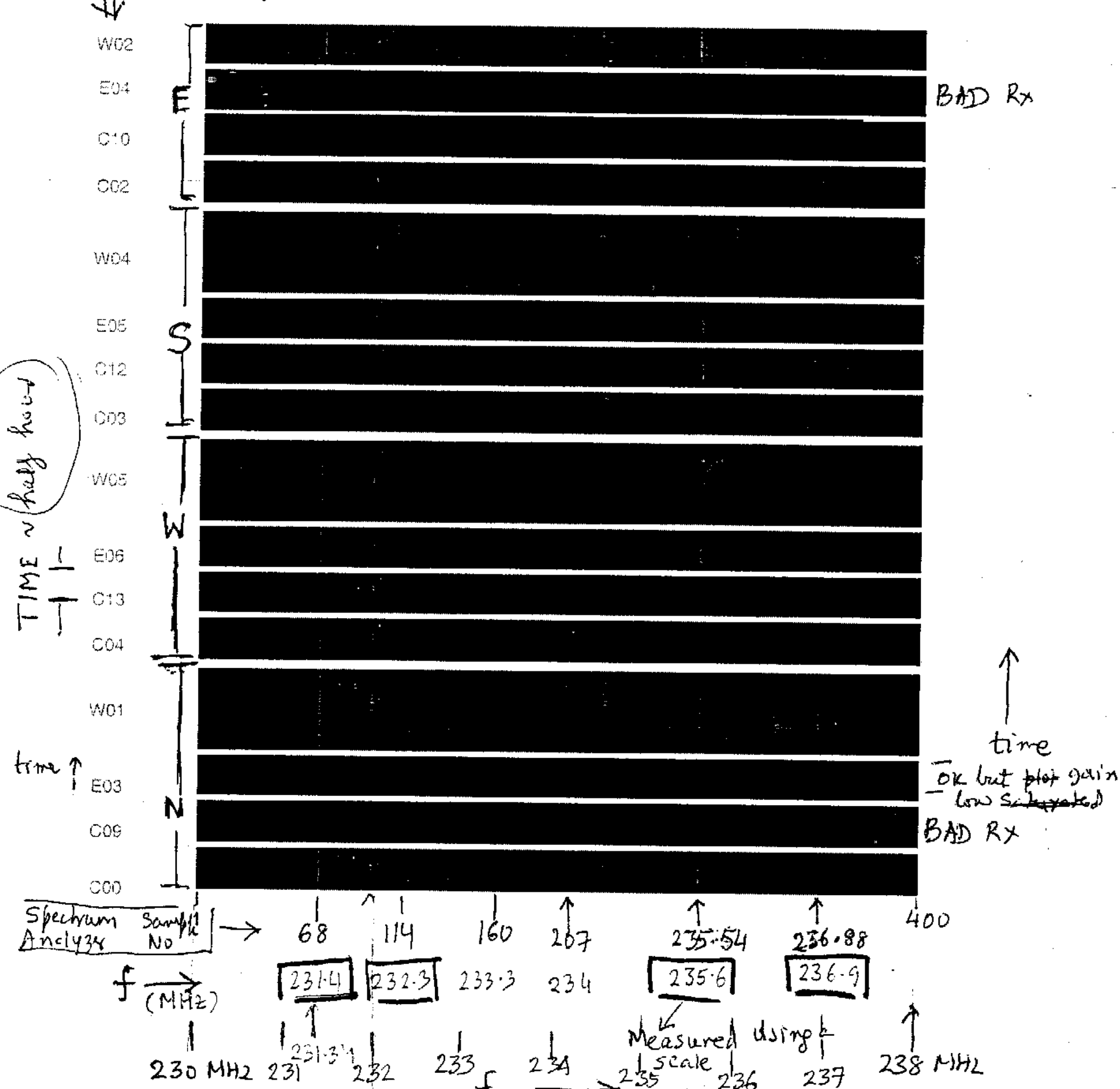


FIG. 5(g) Gray Scale Plot for RFI survey made over the 231-237 MHz band on 6th September 2000 with 230 MHz feed to the horizon towards E, S, W and N for 4 antennas in each direction. Horizontal axis is frequency and vertical axis is time. Each block is of same duration = about 40^m, although of different width due to a programming problem.

6th SEPT 2000

RFI SURVEY : COLOUR GREY SCALE PLOTS

231-237 MHz feeds to horizon

C04 – to WEST,
C03 – to SOUTH
C02 – to EAST

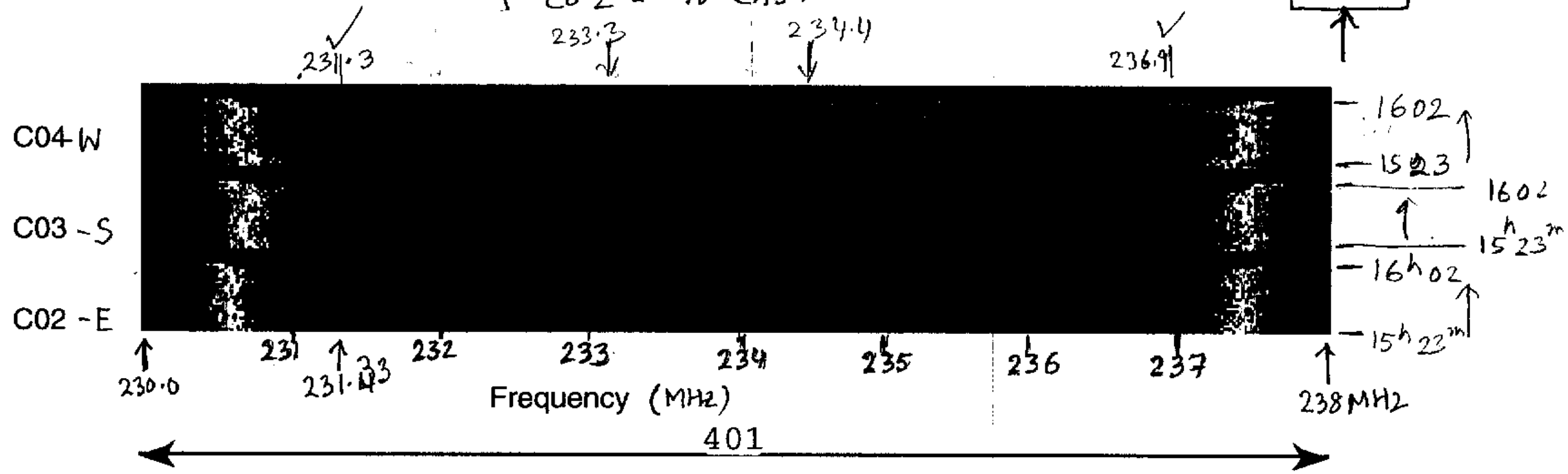


FIG. 5(h) : Colour gray scale plot similar to Fig. 5(g) but for C04-W, C03-S and C02-E antennas only. The presence of RFI signals are much better seen in this plot

RFI Survey

OBS, Somsekhar, Sircar, Frezot

Transmitted 234/235 MHz from housing colony at N. Gaon

176 mm = 8 MHz
88 4
44 2

Plots by Olivere Frezot

Expt suggested by G. Swarup

FIG. 6 : RFI IN THE BAND NEAR 325 MHz

FIGS. 6(a) to 6(g) : show RFI measurements made in the GMRT band 325 MHz. No significant RFI is seen in this band.

FIG. 6(a) : Shows Spectrum Analyzer output obtained in 306-346 MHz on 26th July 1996. The Spectrum Analyzer was connected to the output of the front-end boxes at the base of the antenna W2-S.

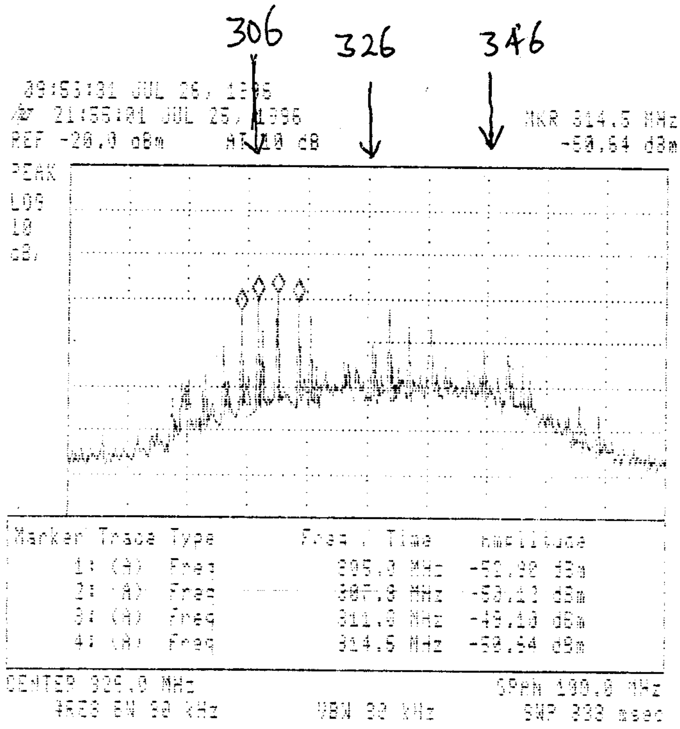
FIGS. 6(b) to 6(e) : Shows the Spectrum Analyzer output obtained in the band 325 ± 8 MHz on 2nd September 1997. Spectrum Analyzer was connected to the 130 MHz channel at the output of the optic fiber in the receiver room. No RFI was observed for C1, C4, C6 & C9 antenna above the level of -160 dBW/m^2. It may be noted that vertical scale was 0.5 dB per division and therefore the output showed ripples across the passband. By taking single scans with free running trigger as well as 50 trigger, scans were made for H_3 zero(0) mode span with 5.0 MHz bandwidth. No significant powerline interference was noted at the above antenna (Fig. 6(e) : top scan).

FIG. 6(f) :In 6(f) and (g) are presented correlator outputs for the C00 & C04 antenna pair with 325 MHz feeds pointed towards the southern horizon. The data was observed for two minutes. Interference of about 20 times rms noise at an estimated pfd level of about -190 dBW/m^2 was noted only in channel 19 & 55.

26 July 96 09h56m

W2-S

326



W2-S

09h57M

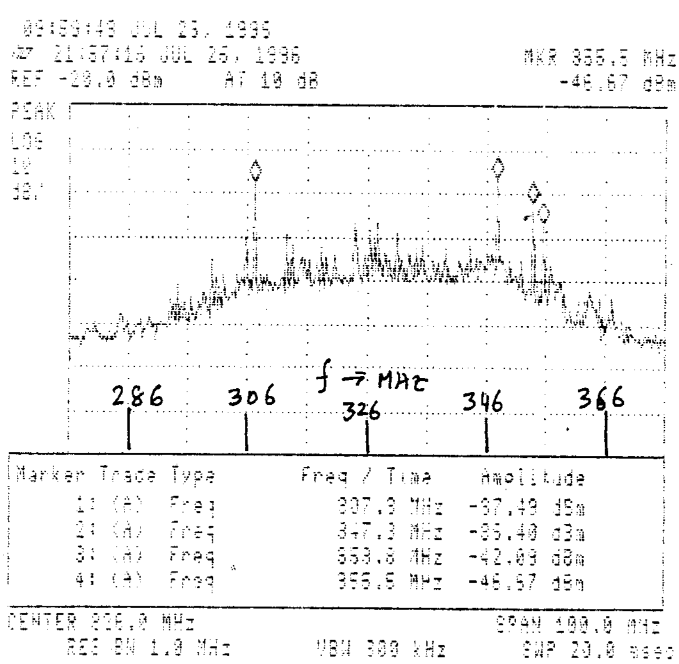


FIG. 6(a) : Shows Spectrum Analyzer output obtained in 306-346 MHz on 26th July 1996. The Spectrum Analyzer was connected to the output of the front-end boxes at the base of the antenna W2- S.

C– -5

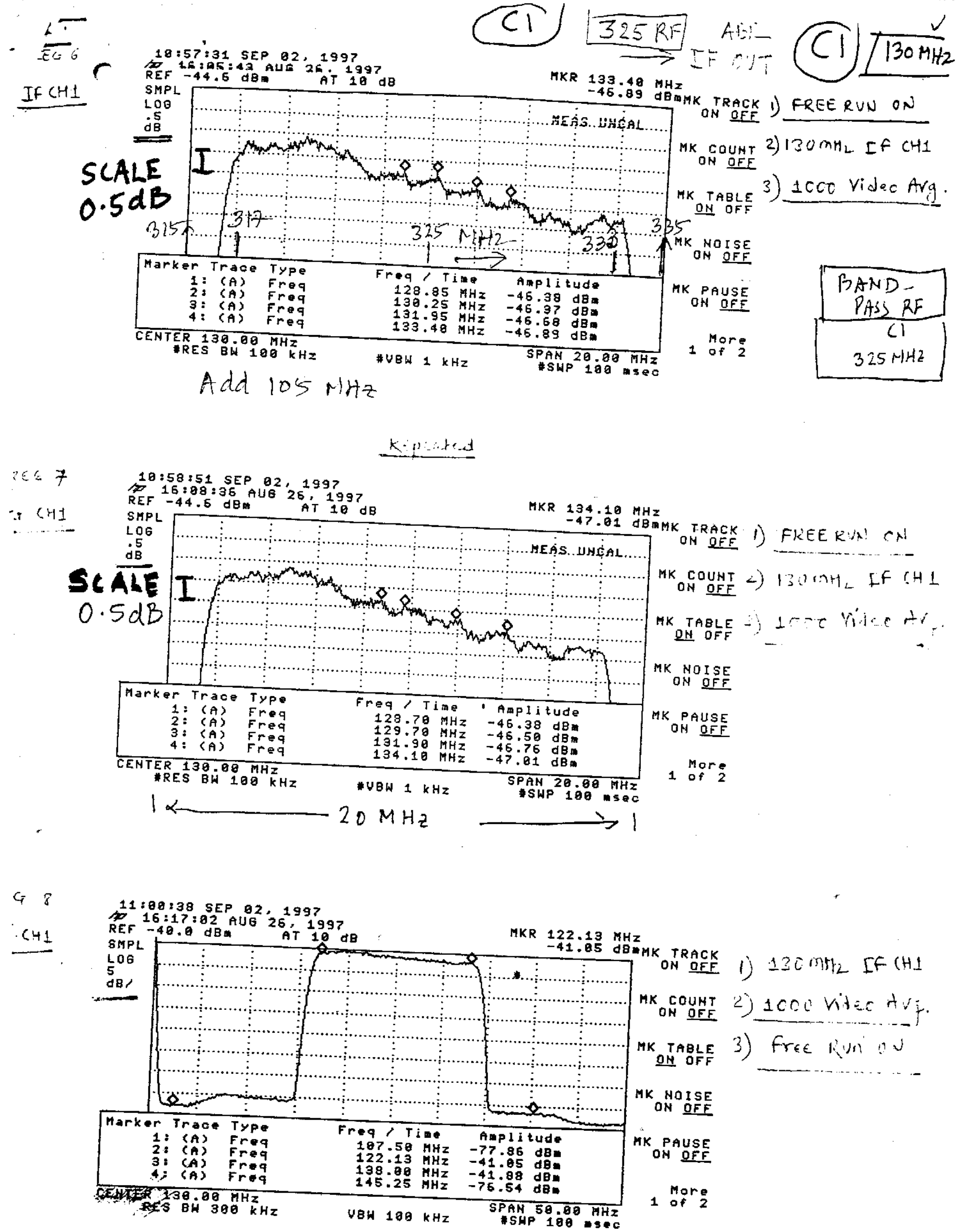


FIG. 6(b) : Scans across the band 317-333 MHz for C1 antenna.

C4 Antenna 130 MHz

C4

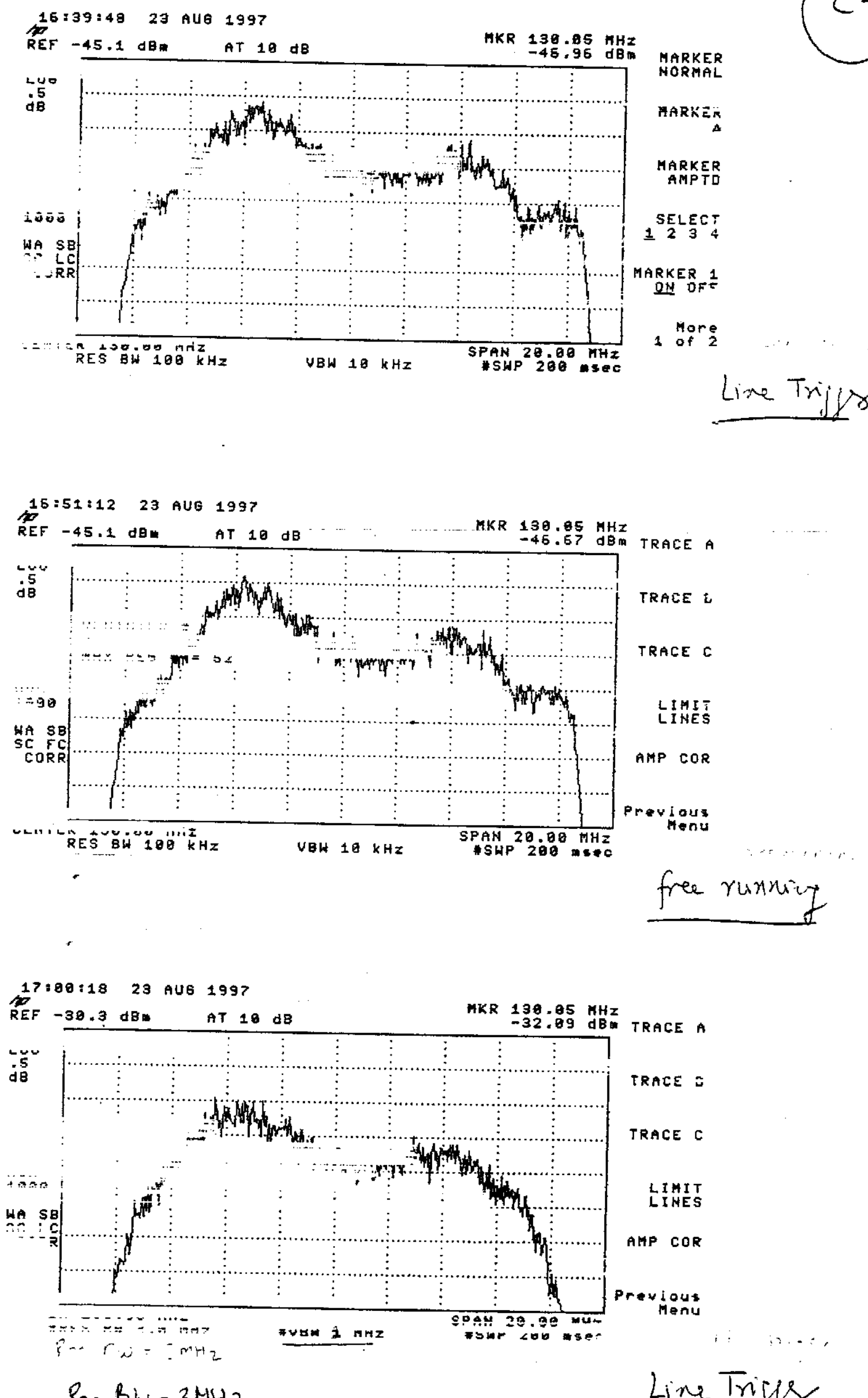
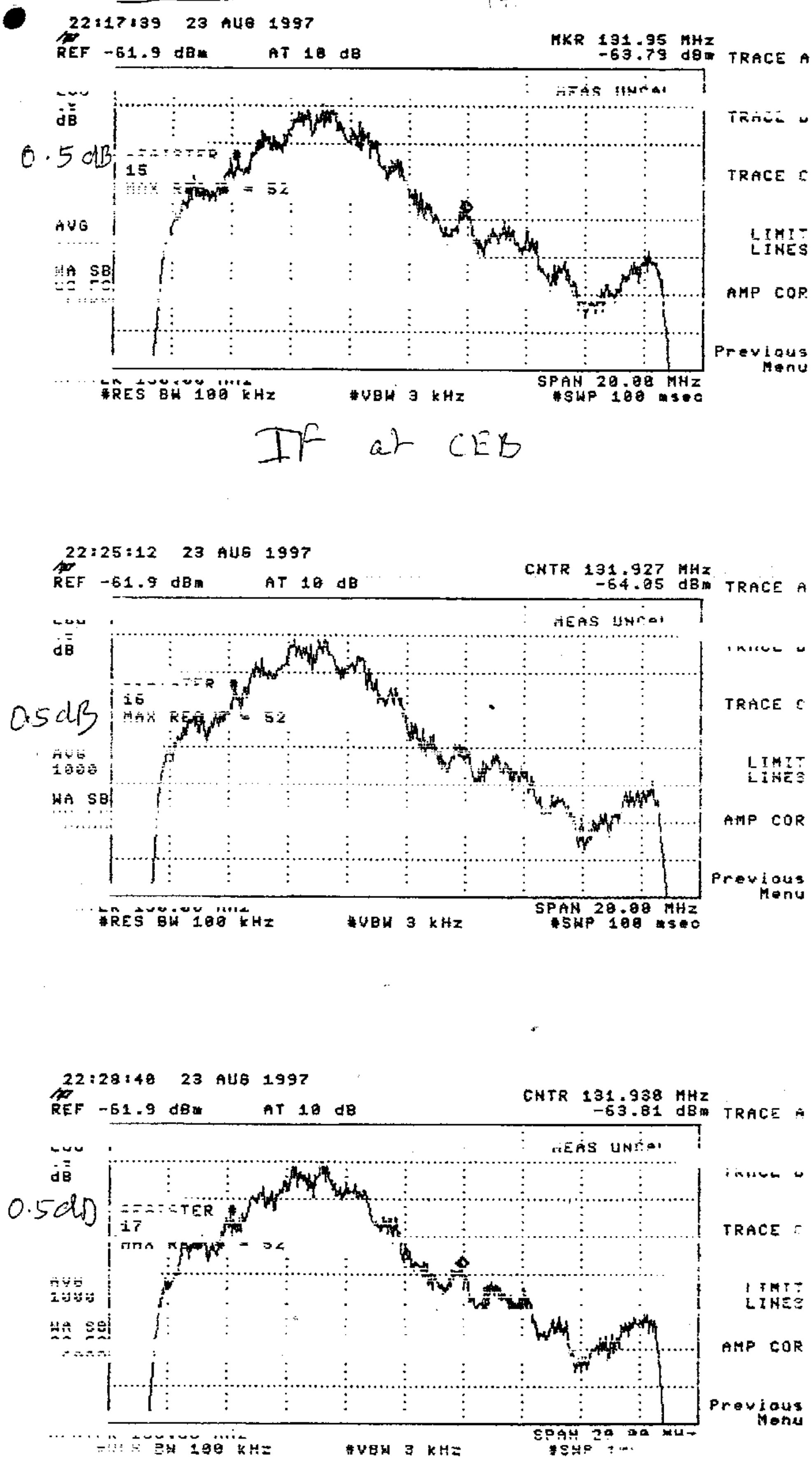


FIG. 6(c) : Scans across the band 317-333 MHz for C4 antenna.

23 AUG 97 — C6 — GS/SAK — AUG 1997 — 325 MHz Pass Band



Line Trigger

Free Run

FIG. 6(d) : Scans across the band 317-333 MHz for C6 antenna.

23/8/97 | 325 MHz . PASSBAND
• Power Line RFI
C6 / C9

23 AUG 97

23 AUG 97

C9 antenna

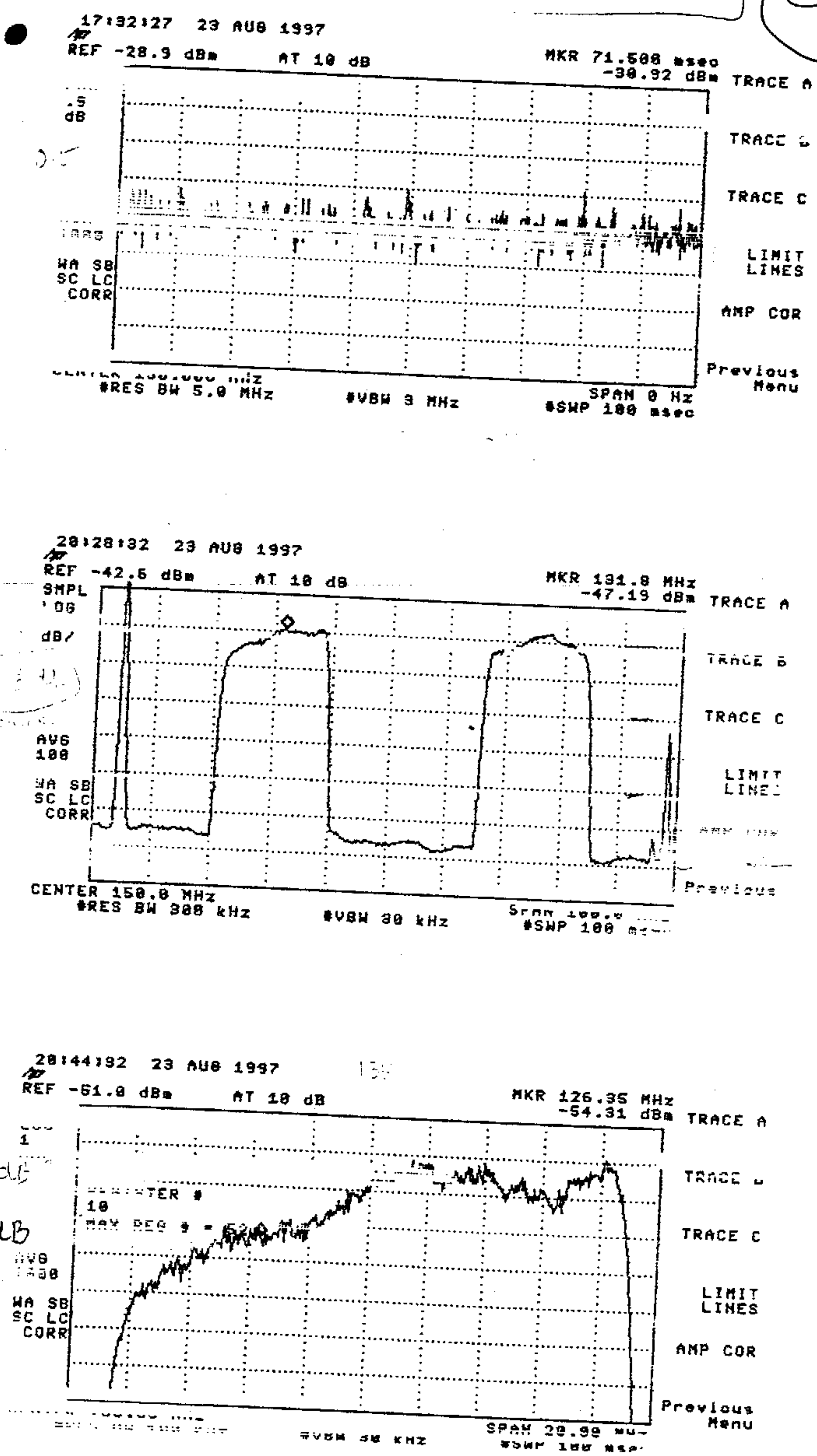


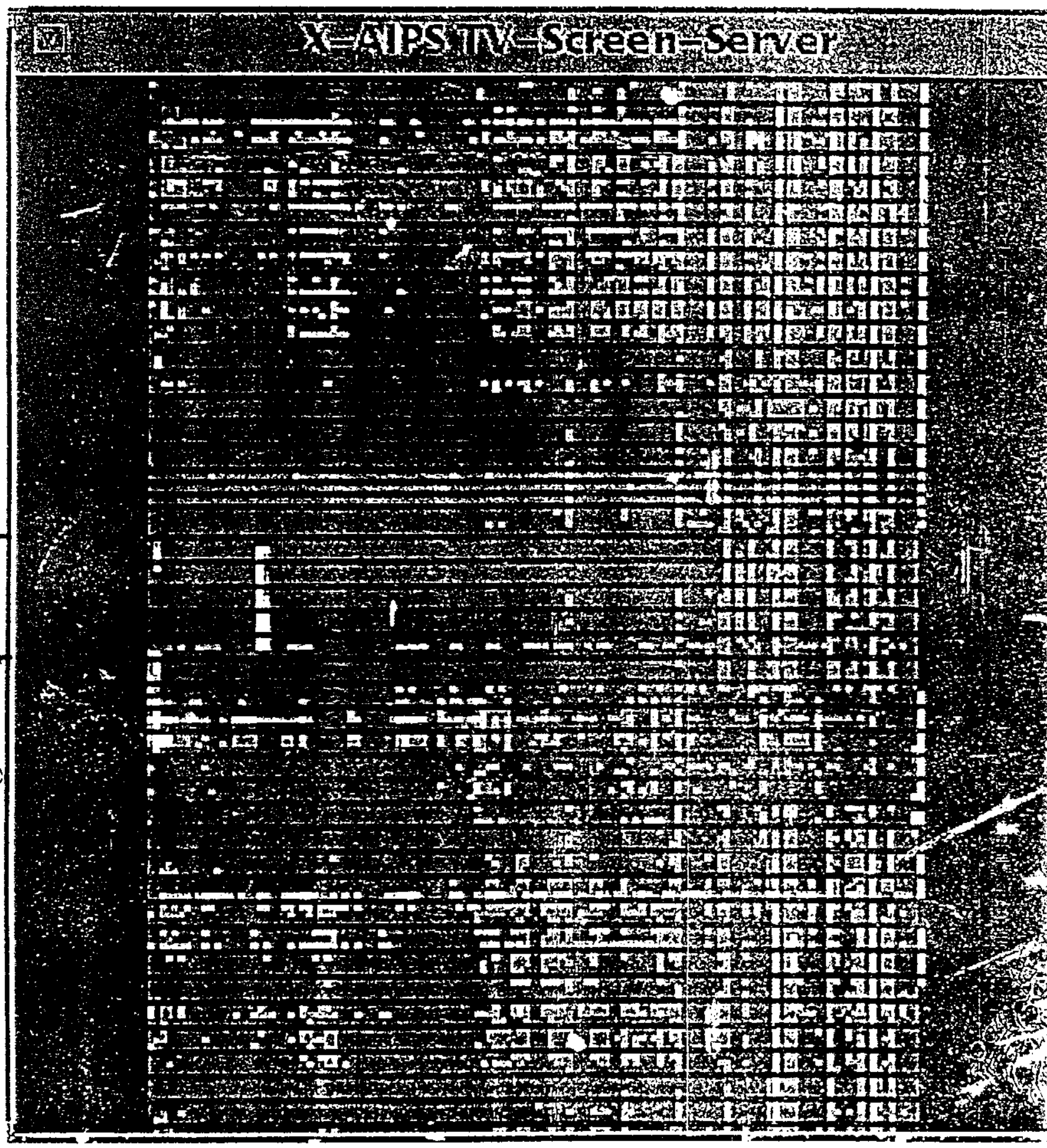
FIG. 6(e) : Scans across the band 317-333 MHz for C9 antenna.

GMRT 325 FEEDS TO HORIZON
2 ANT INTERFEROMETER (C00 - C04)

(2 MIN = 120^s Average

→ FREQ

TIME ↑



ρ_c → 0.018

ρ = 0.0008

↑ Channel (19)

FIG. 6(f) : Correlator output for C00-C04 pair 325 MHz.

Ch.55

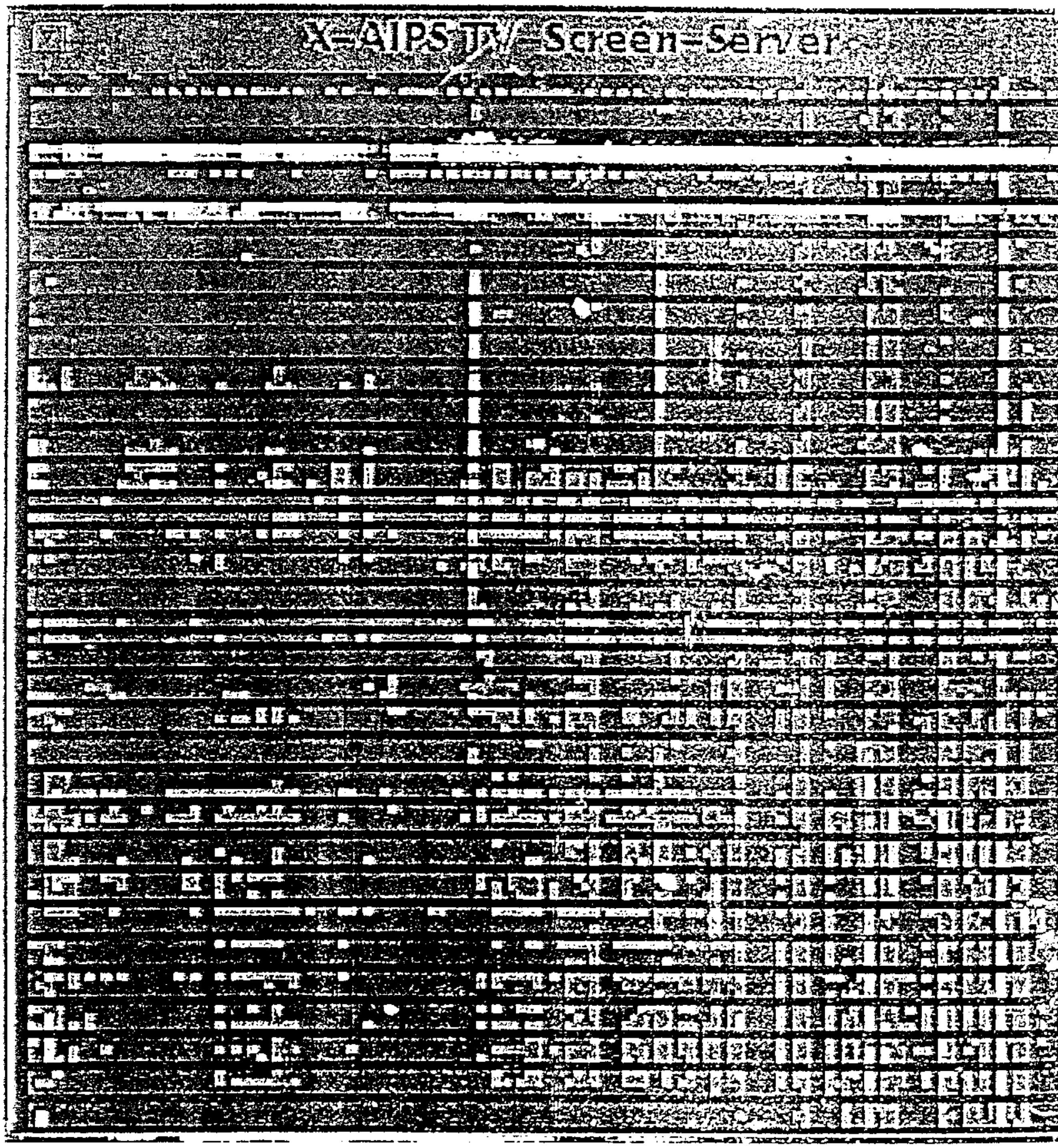


FIG. 6(g): Correlator output for C00-C04 pair 325 MHz.

FIG. 7 : A Summary of RFI Surveys made by T.L. Venkatasubramani in the frequency range of about 125 MHz to 1400 MHz in mid-1996, early 1997 and July 1999

RFI surveys were made by T.L. Venkatasubramani in the frequency range of about 125-1400 MHz during June to August 1996 (Venkatasubramani 1996) and January/February 1997 and July 1999. GMRT primary feeds were pointed towards the horizon and azimuth angle of the GMRT dishes was changed from + 180° to -180° in steps of -45° with dwell of 15 minutes. The cycles were repeated for many hours or days. The measurements were made by connecting the output of the front-end boxes to a Spectrum Analyzer at the base of the GMRT antennas. Using the Min-Max mode, the minimum and maximum power received was recorded. RFI-Report Part-V-A gives details of the above surveys. Typical scans are presented in this Report in Fig. 7(a) to 7(g). In case the resolution bandwidth (RBW) of the Spectrum Analyzer and the video bandwidths are the same, we should expect the difference in power received between maximum and minimum to be about 7 dB = (± 2.5 standard deviation) for pure random receiver noise. However, the difference will be smaller in case of integration or averaging of several scans. Larger difference than expected show the presence of RFI.

The following conclusions can be made :

From the Figs. 7(a & b) it is seen that RFI was not present in January/February 1997 in the frequency band of 230 to 235 MHz, 322-326.6 MHz, 608-614 MHz and 900-1500 MHz at the sensitivity level of -155 to -160 dBW/m^2. However, appreciable RFI was noted in the 150 MHz band.

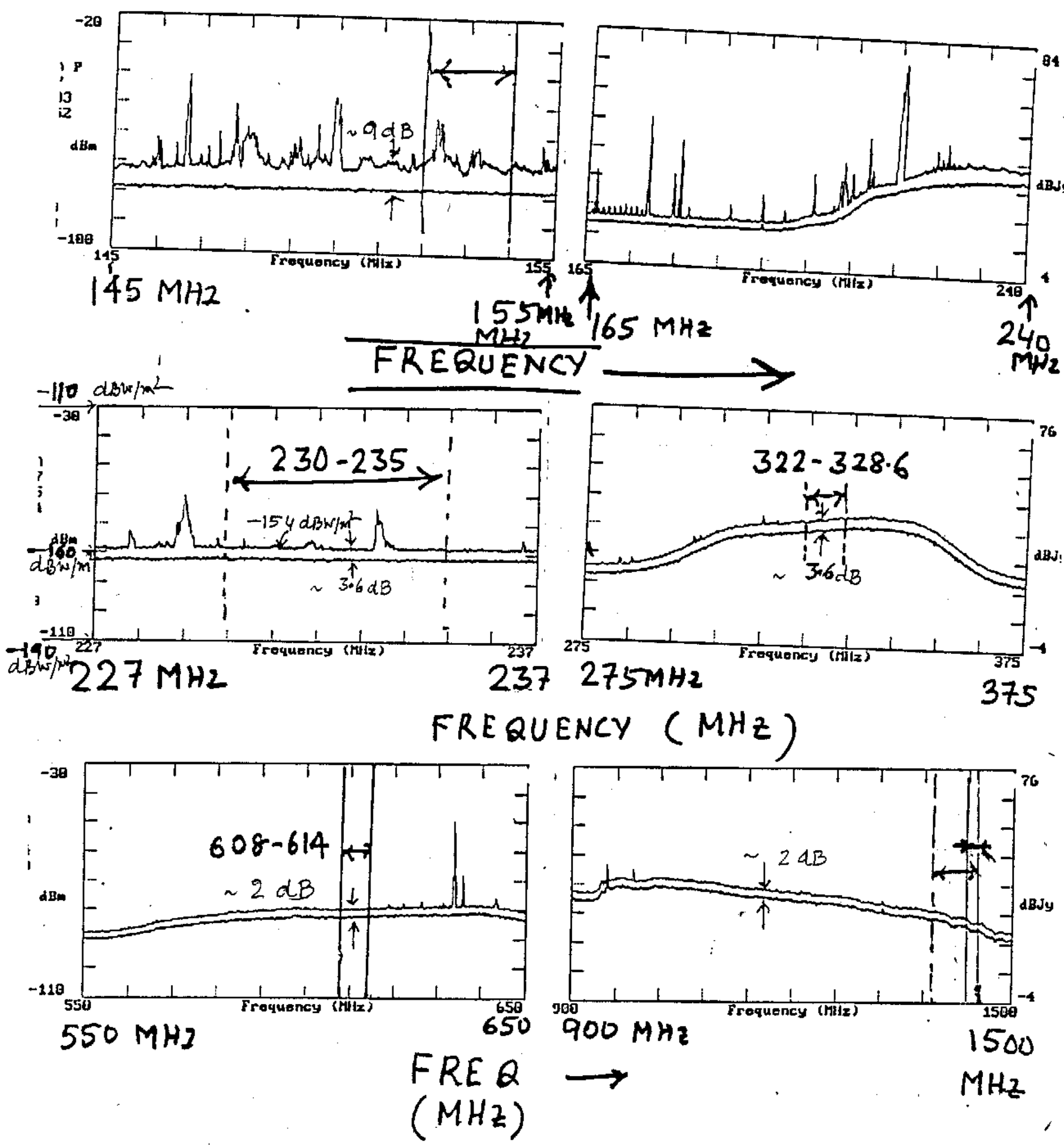
From Figs. 7 (c & d) it is seen that the level of RFI has increased considerably in the 150 to 154 MHz and also in 230-235 MHz bands between early 1997 to mid 1999.

FIG. 7(a & b) : shows a summary of RFI plots made by T.L. Venkatasubramani during the month of January/February 1997.

FIG. 7(c) : shows some typical RFI plots made by T.L. Venkatasubramani for several hours during the month of July 1999. Hatched portions show the bands 152-154 MHz protected for operation of GMRT. The difference between Maximum & Minimum shows Very High (VH), high (H) or relatively low (L) levels of RFI.

FIG. 7(d) : shows some typical RFI plots made by Venkatasubramani in July 1999 in the bands near 210-260 MHz and 570-650 MHz. Hatched portions show the protected bands for GMRT.

DAY TIME (~8 HRS)



DAY TIME
RFI AT THE GMRT SITE

RFI IS LIKELY TO INCREASE A GREAT DEAL OVER THE NEXT DECADE

7(a) 39

FIG. 7(a & b) : shows a summary of RFI plots made by T.L. Venkatasubramani during the month of January/February 1997.

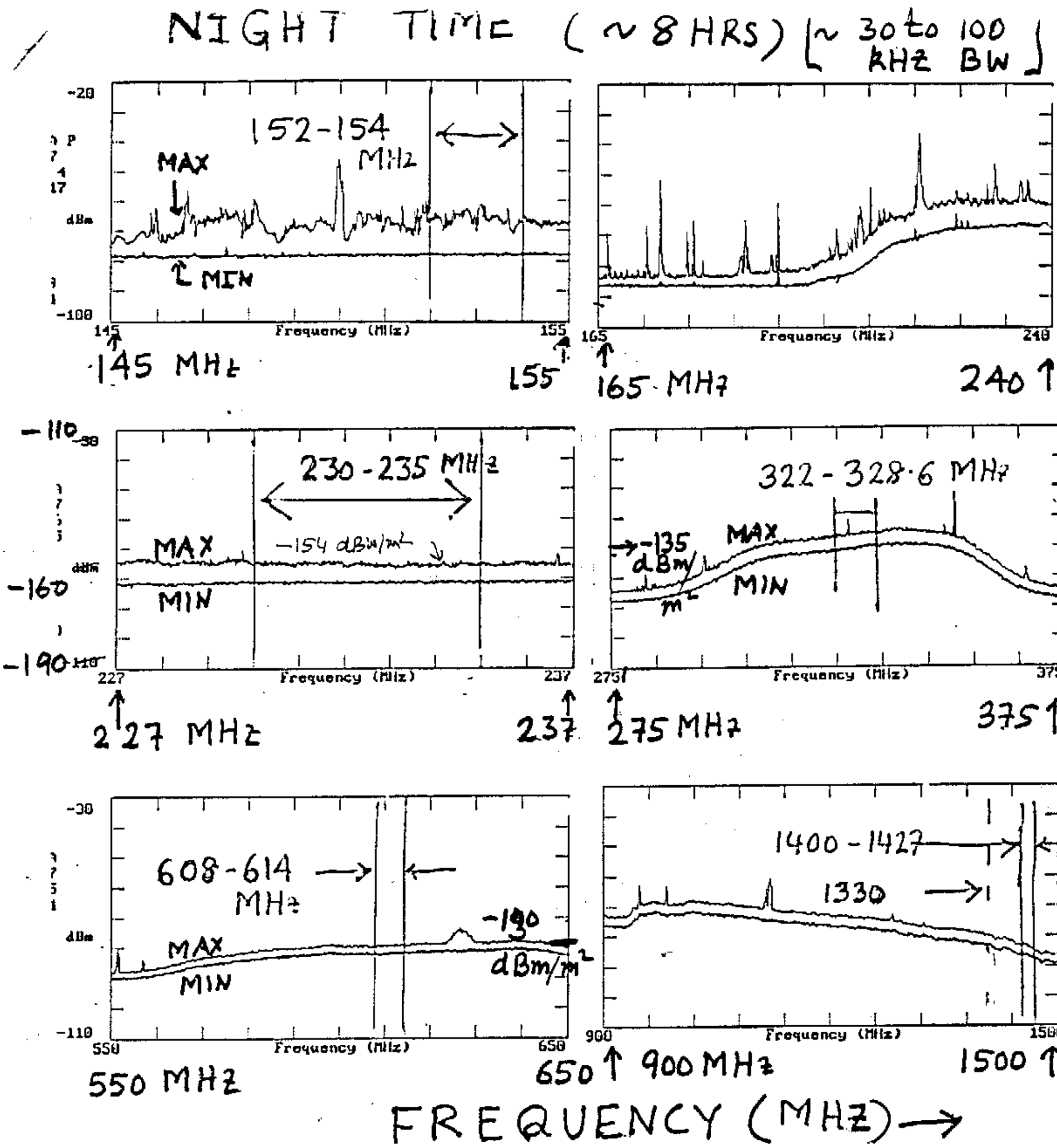


Fig 7(b)

RFI AT THE GMRT SITE IN AND NEAR RADIO ASTRONOMY BANDS ~ 150 MHz to 1500 MHz

7(b)
(40)

FIG. 7(c) : shows some typical RFI plots made by T.L. Venkatasubramani for several hours during the month of July 1999. Hatched portions show the bands 152-154 MHz protected for operation of GMRT. The difference between Maximum & Minimum shows Very High (VH), high (H) or relatively low (L) levels of RFI. (125 - 175 MHz)

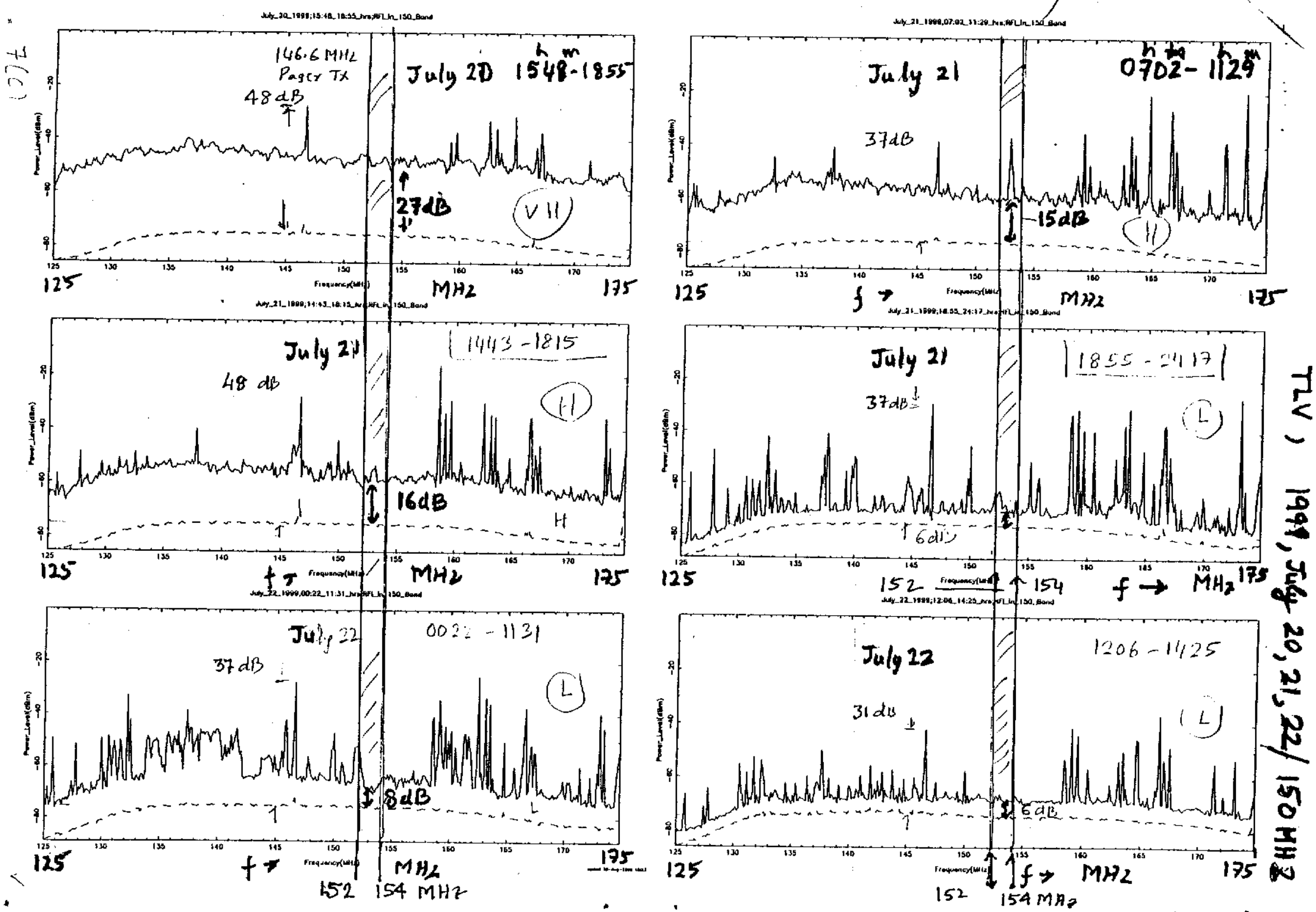


Fig 7(c)

FIG. 7(d) : shows some typical RFI plots made by Venkatasubramani in July 1999 in the bands near 210-260 MHz and 570-650 MHz. Hatched portions show the protected bands for GMRT.

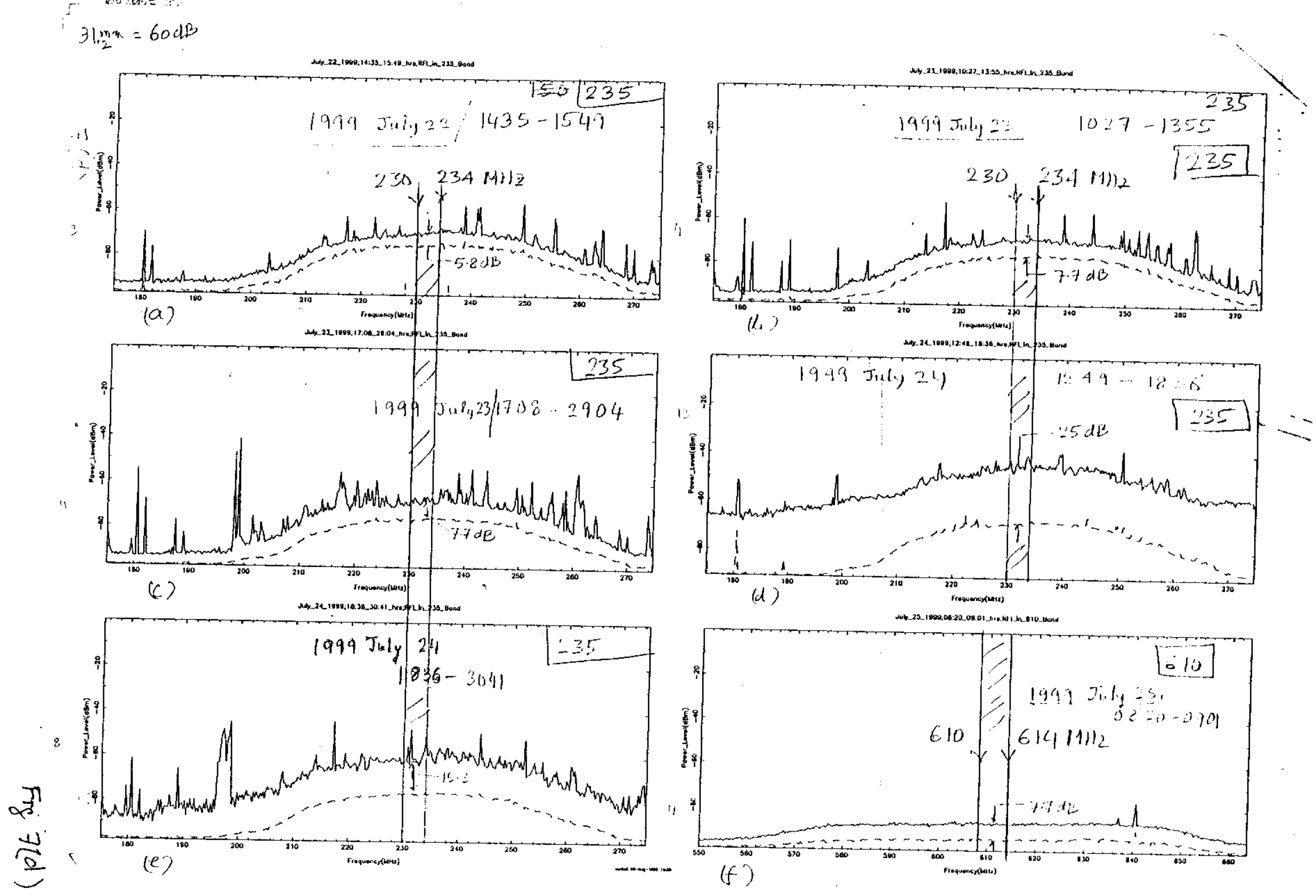


FIG. 8 : RFI MEASUREMENTS MADE IN THE BAND 150.5-155.5 MHz AT SEVERAL LOCATIONS FROM SANGAMNEER TO LONAVALA

Fig. 8(a) to 8(j) : shows Spectrum Analyzer outputs of RFI either in the frequency band 150.5 to 155.5 MHz or in the band 151 to 155 MHz which were made at Sangamneer, Kandali, Kukdi, Junnar, Pune (NCRA), Lonavala and Khandala. Measurements were made using (a) Log Periodic antenna with a bow-tie, (b) 60 dB amplifier (c) Spectrum Analyzer (see Appendix-A).

Measurements at all the above places except Pune were made with the Log Periodic antenna mounted on a jeep at a height of about 2.5 to 3 Mtrs. At Pune(NCRA) the Log Periodic antenna was mounted on a pole above the water tank on the second floor of NCRA building, such that the height of the Log Periodic antenna was about 10 Mtrs. Antenna was rotated in four directions viz. South, West, North & East. and plots in the four directions are Xeroxed on page No.1 for each of the locations. The following may be noted for RFI observations made at the above location in the protected GMRT band viz. 152-154 MHz.

i) RFI was noted near the band 152.06 MHz at Sangamneer, Pune and Lonavala. In particular, the RFI near the band 152.06 or 152.14 was quite strong at Pune & Lonavala. RFI at these frequencies is also quite prominent towards the Southern direction as seen in the surveys made with the GMRT antenna feeds.

ii) Strong RFI is observed in the band 152.25. Strong RFI is also observed at Junnar in the band 153.98 MHz. RFI is observed at Pune (NCRA) at the frequency 152.06-152.14 MHz, 152.25, 152.76, 153.76, 153.86 and 154.0 MHz. Only a few of the plots obtained at NCRA, Pune are produced in Fig. 8(a) to 8(f). In particular, we may note the presence of strong RFI in the frequency 152.06, 152.14, 152.69 & 153.53. The RFI in the frequency range of 152.69, 153.53 and 153.73 MHz was also observed at Khandala.

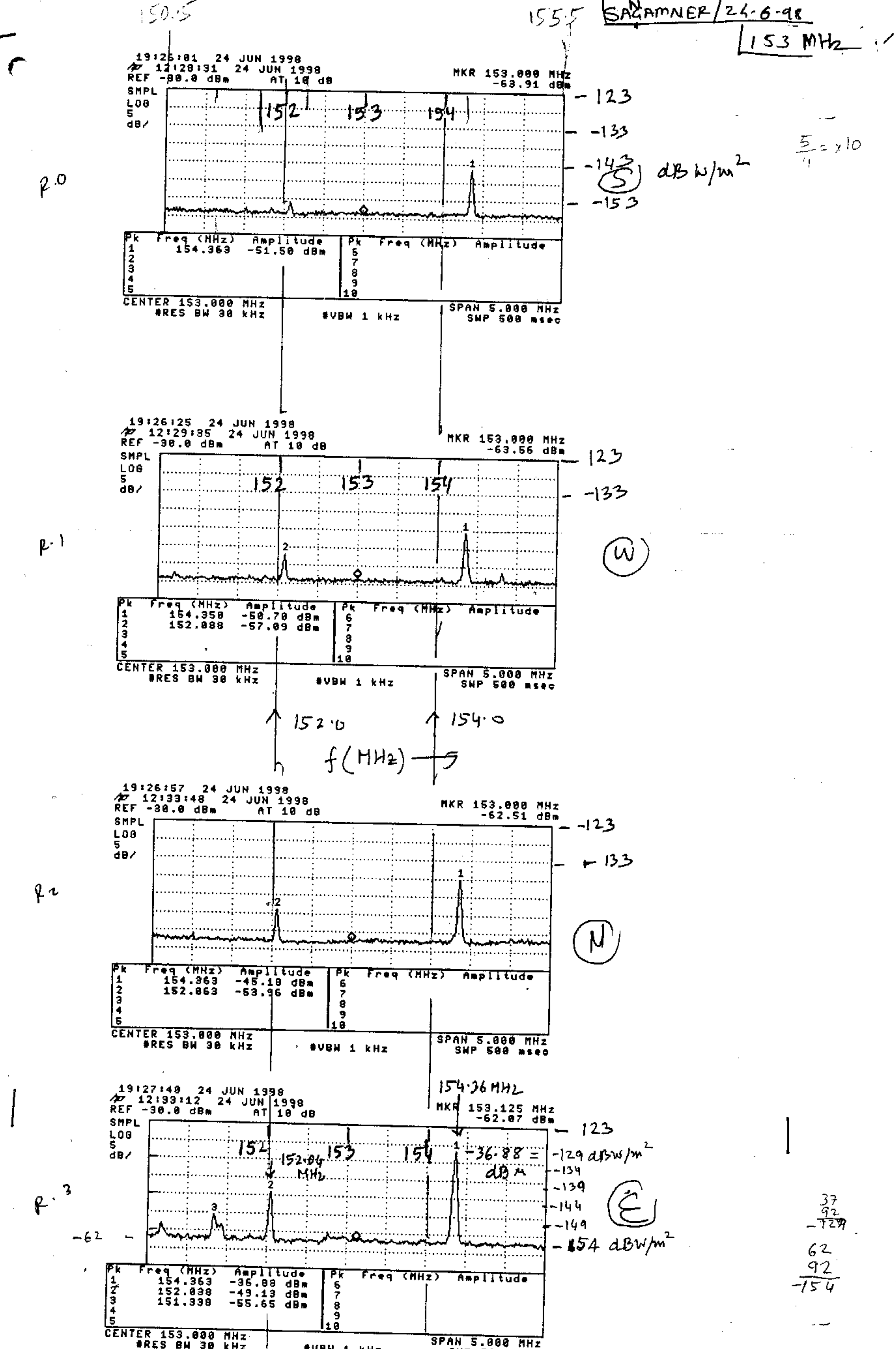
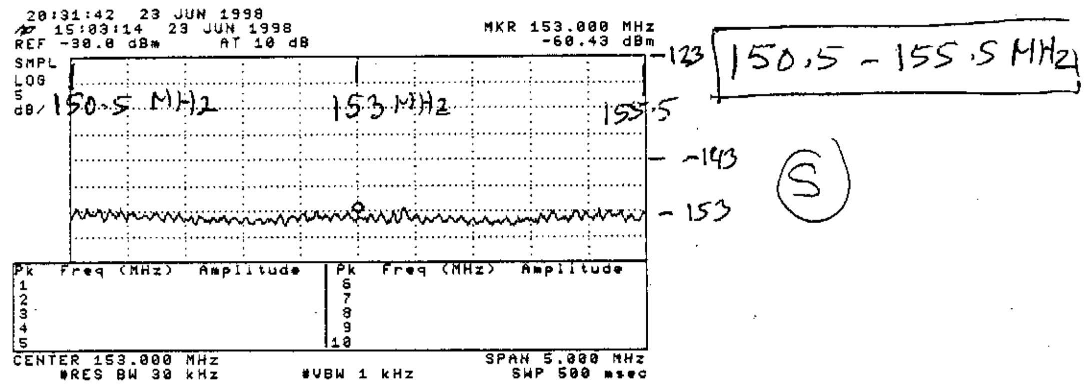
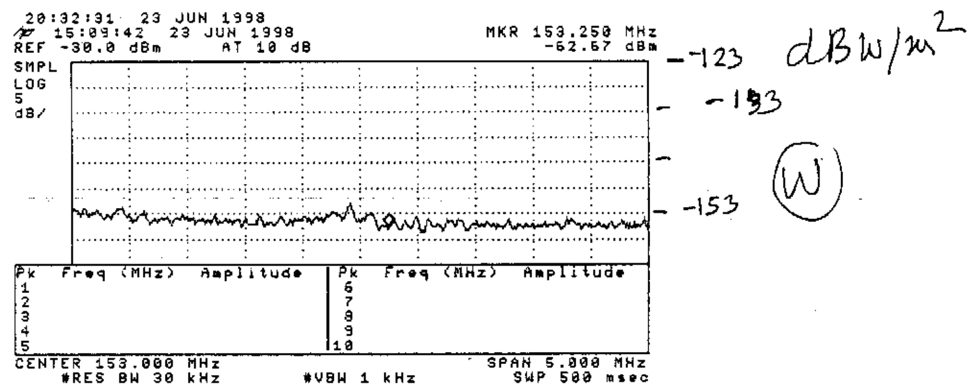
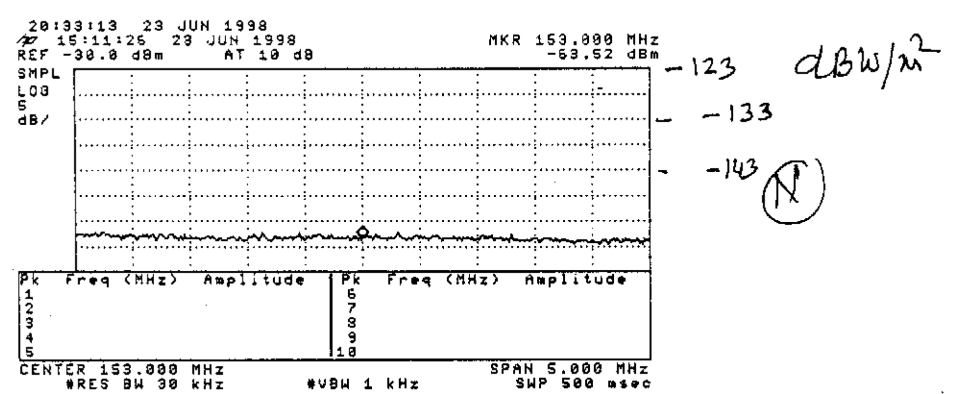


FIG. 8(a): RFI measurements made in the band around 150.5 to 155.5 MHz at Sangamneer.

Kandali Industrial Estate 23-6-98







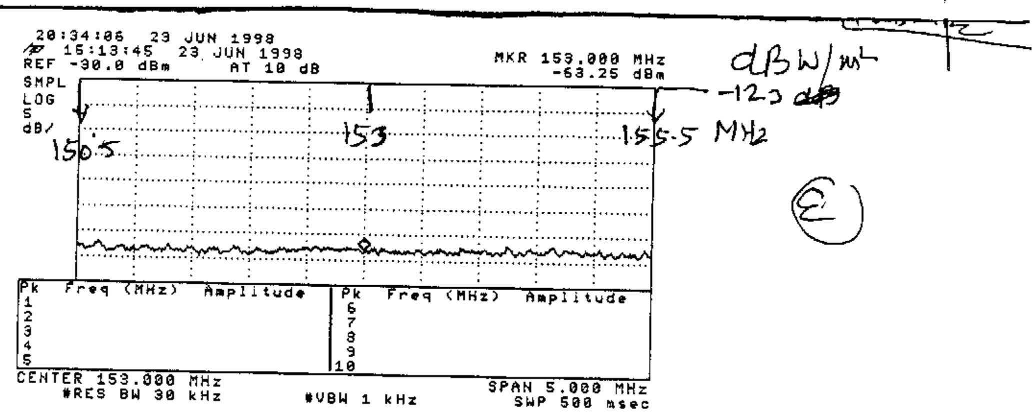


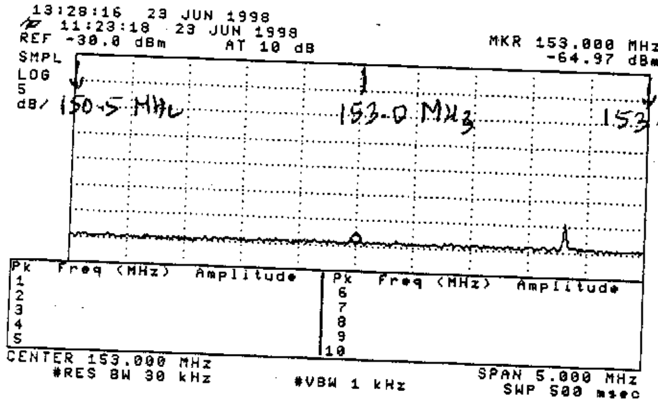
FIG. 8(b): RFI measurements in the band 151 to 155 MHz near Kandali (close to Industrial Estate few km north of W3 antenna.

Amp SET B.

Jambut Phata/23/6-98
153 MHz

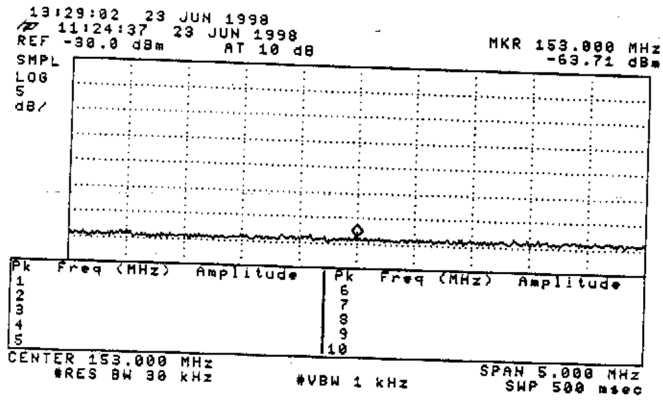
150.5 - 155.5 MHz

R-0



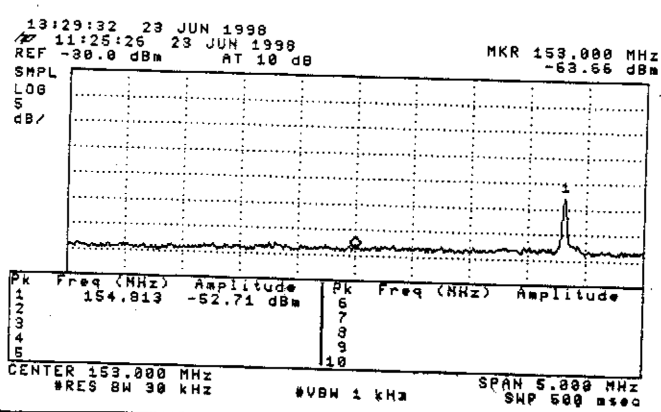
S

R-1



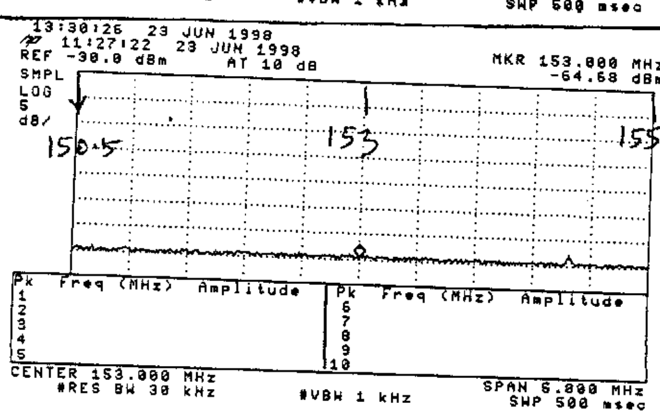
W

R-2



N

R-3



E

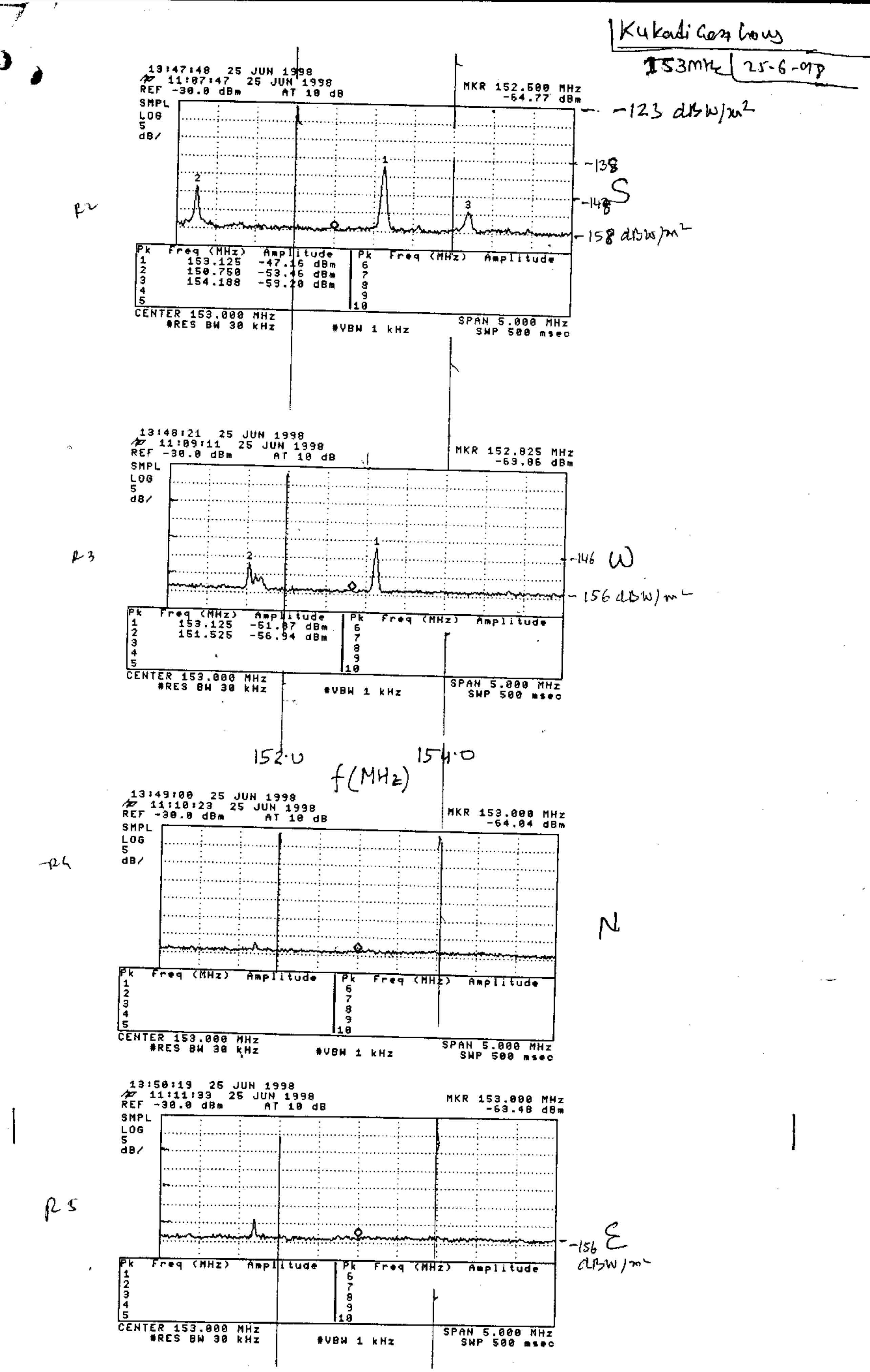


FIG. 8(c): RFI measurements made in the band around 150.5 to 155.5 MHz at Kukdi.

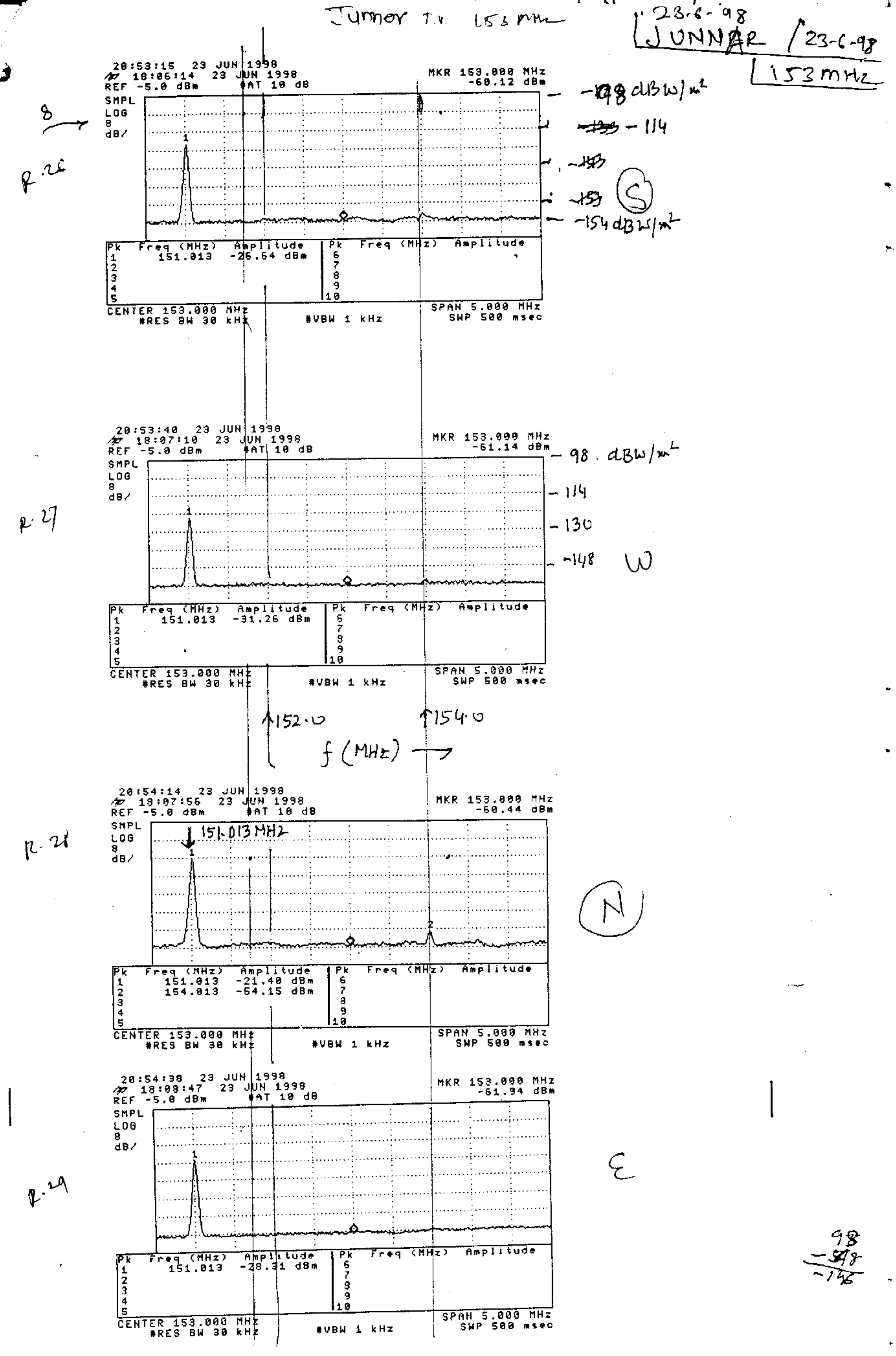


FIG. 8(d): RFI measurements made in the band around 150.5 to 155.5 MHz at Junnar.

Junnar
23-6-98
151 MHz
151-155 MHz

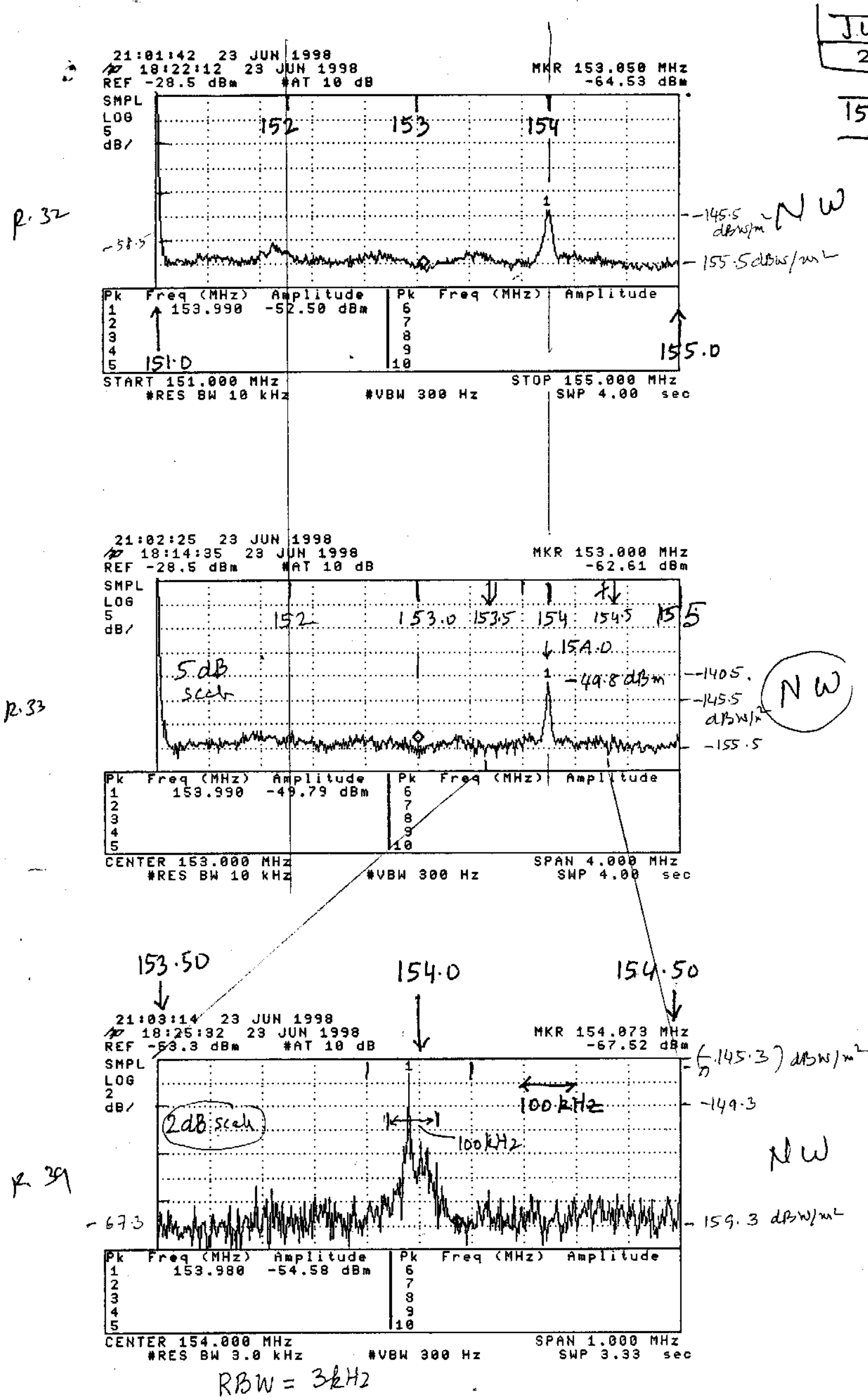


FIG. 8(e): RFI measurements made in the band around 151-155 MHz at Junnar.

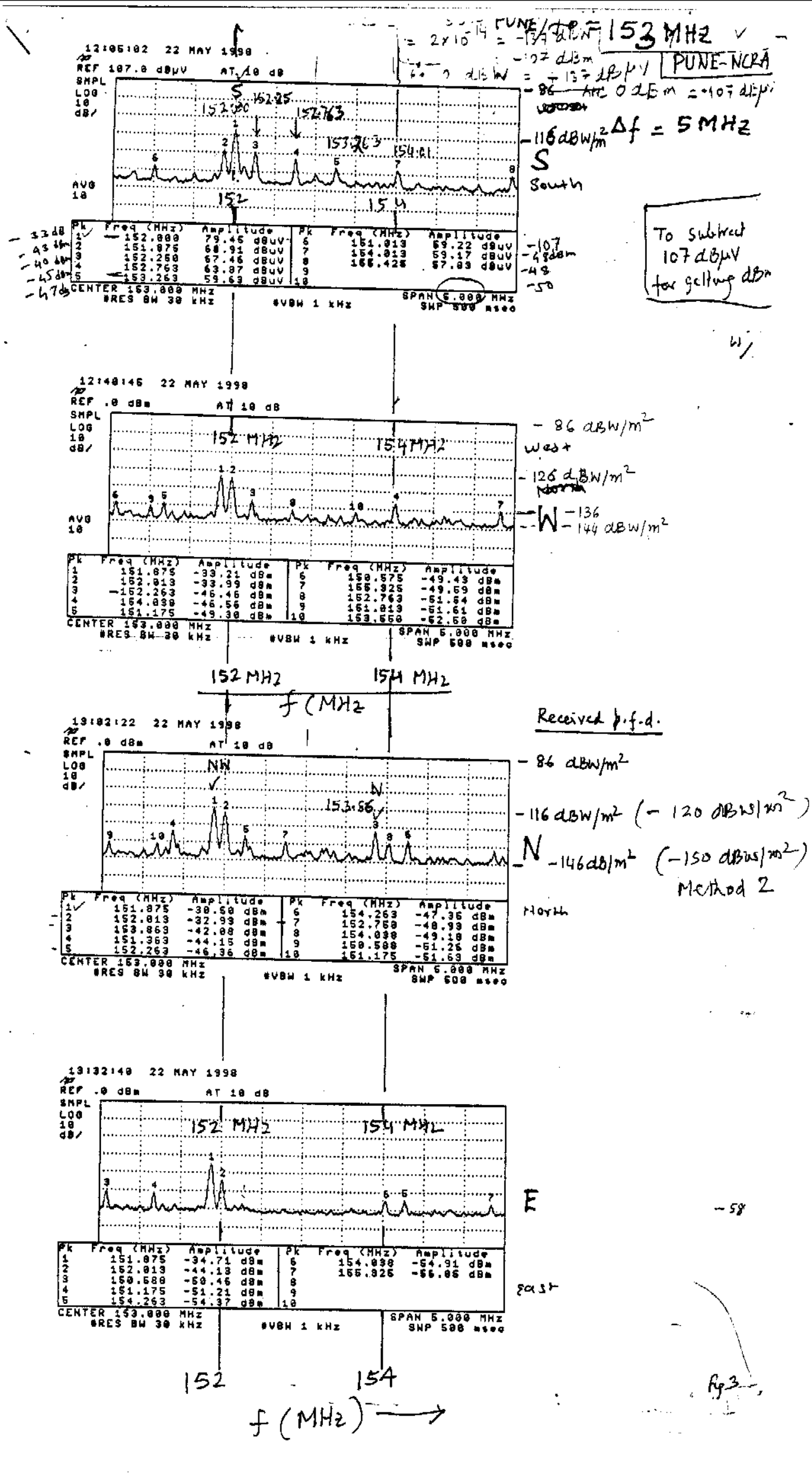


FIG. 8(f): RFI measurements made in the band around 150.5 to 155.5 MHz at Pune (NCRA) on 22nd May 1998.

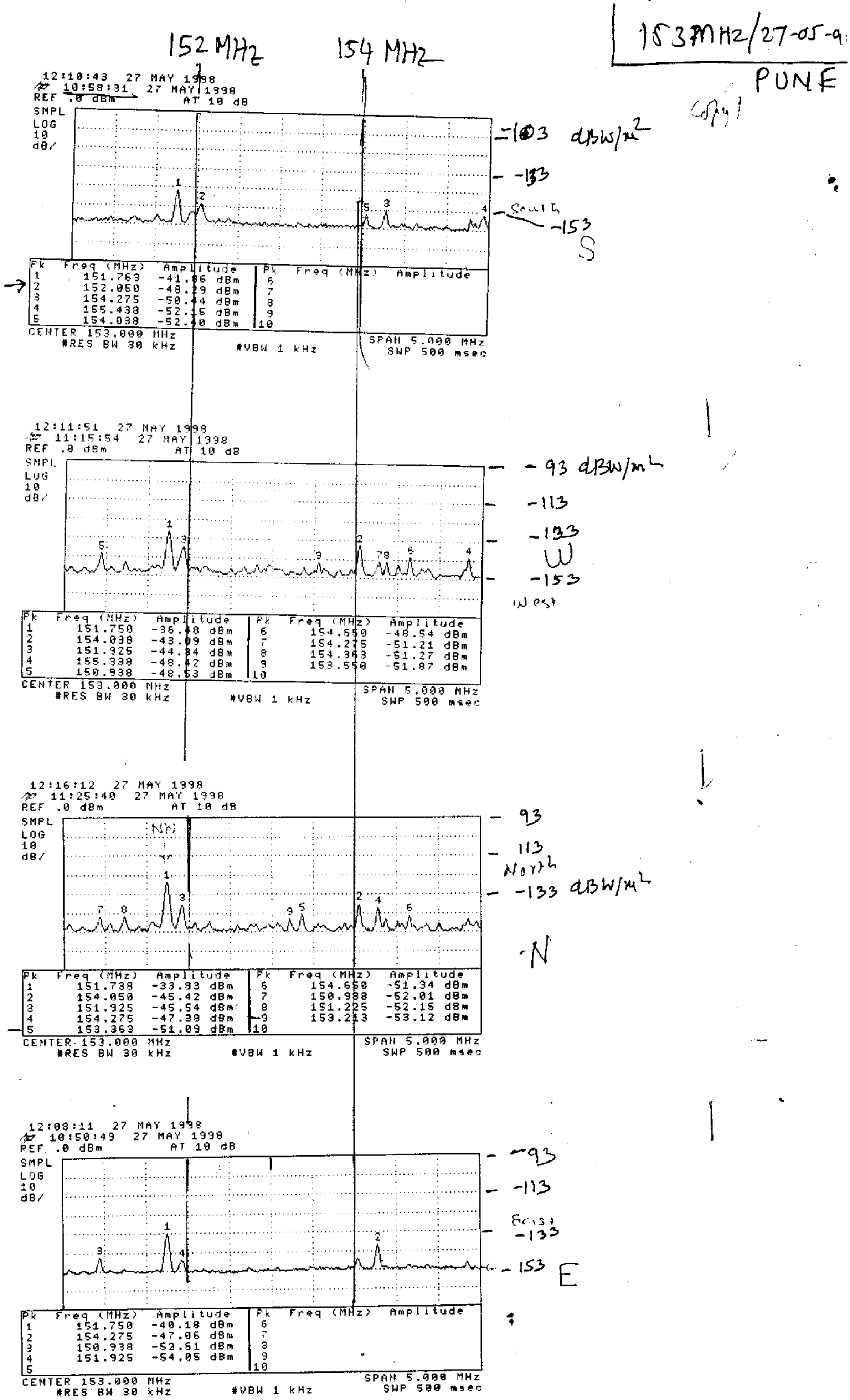


FIG. 8(g): RFI measurements made in the band around 150.5 to 155.5 MHz at Pune (NCRA).

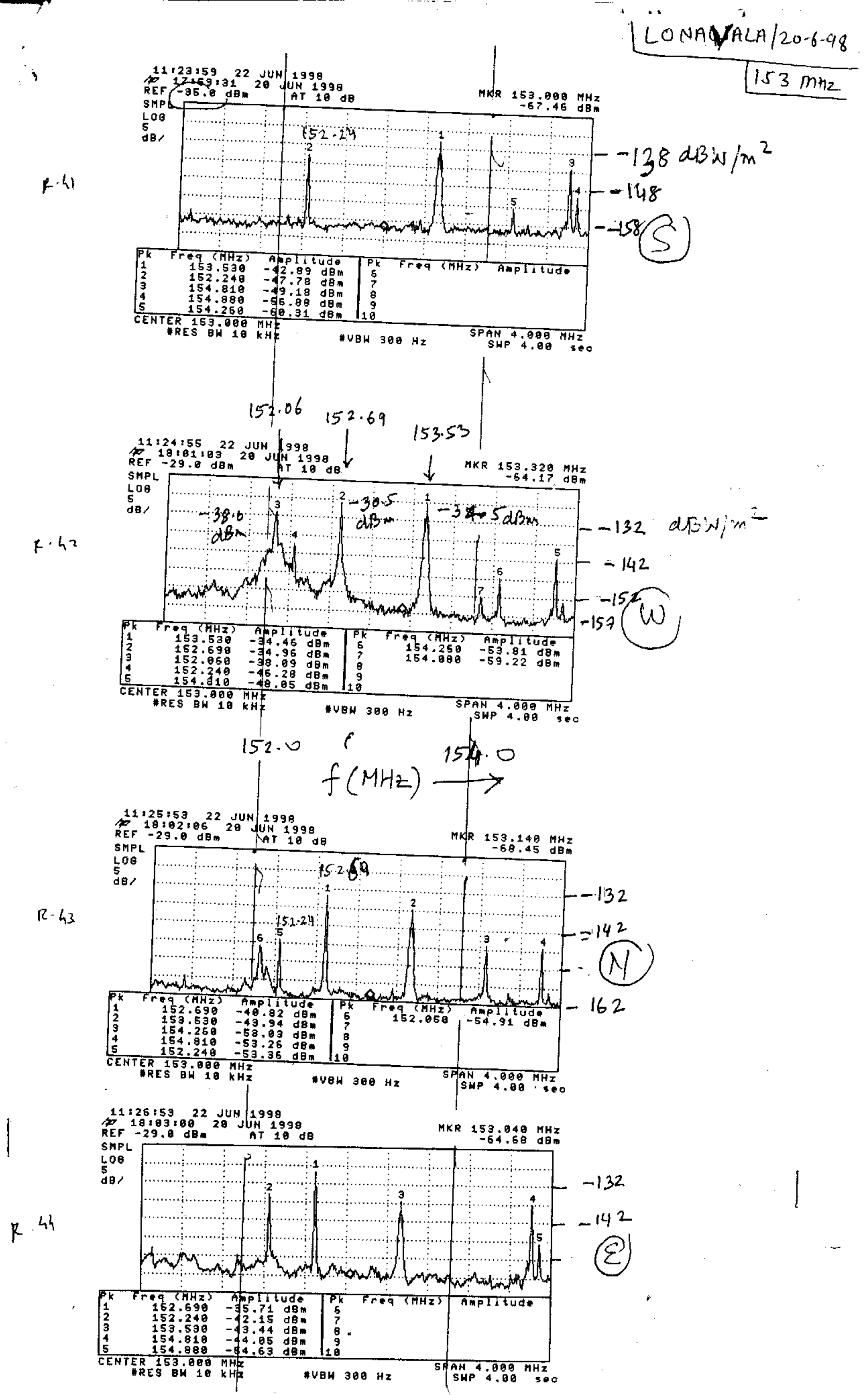


FIG. 8(h): RFI measurements made in the band around 151-155 MHz at Lonavala on 20th June 1998

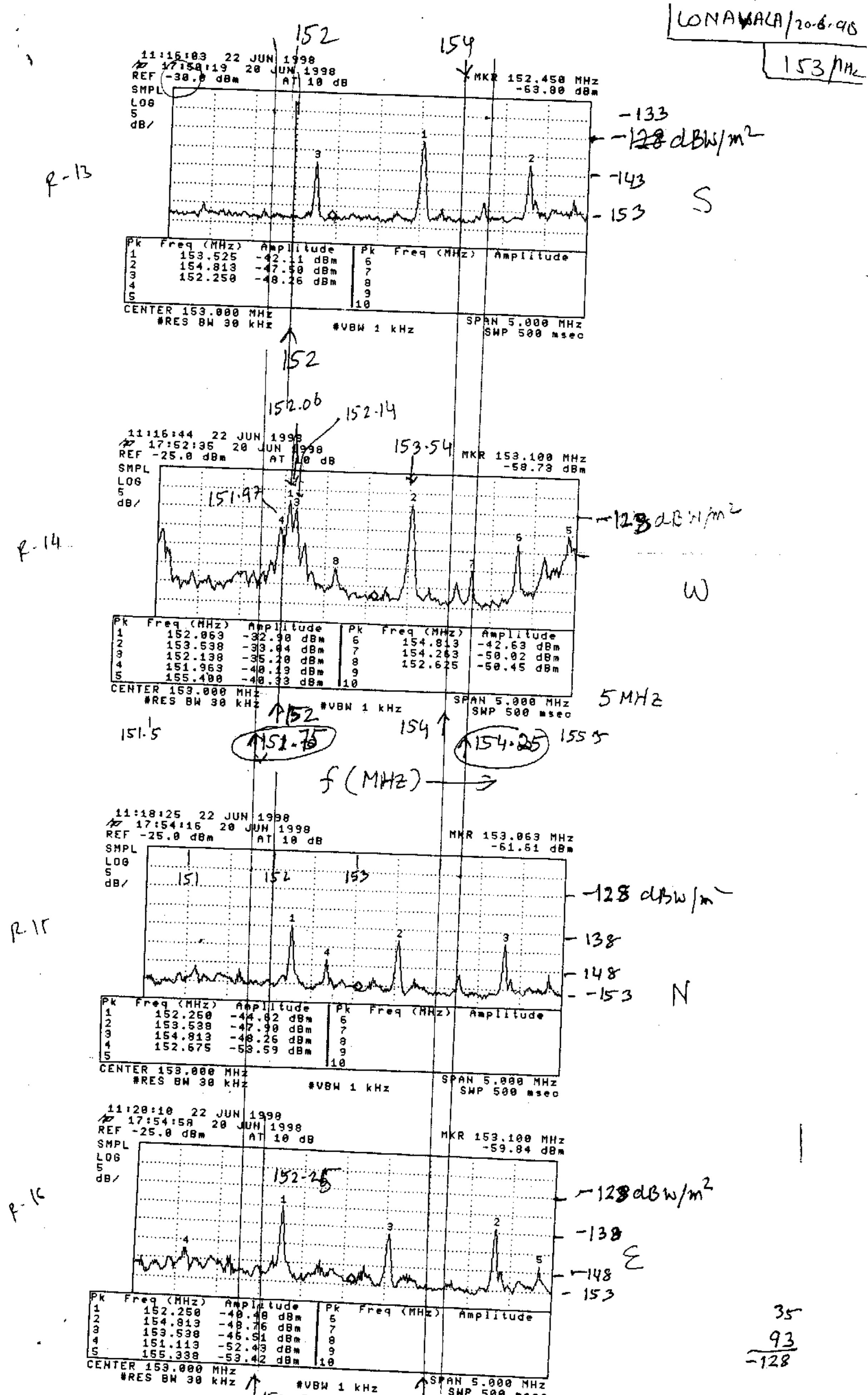


FIG. 8(i): RFI measurements made in the band around 150-155 MHz at Lonavala on 20th June 1998.

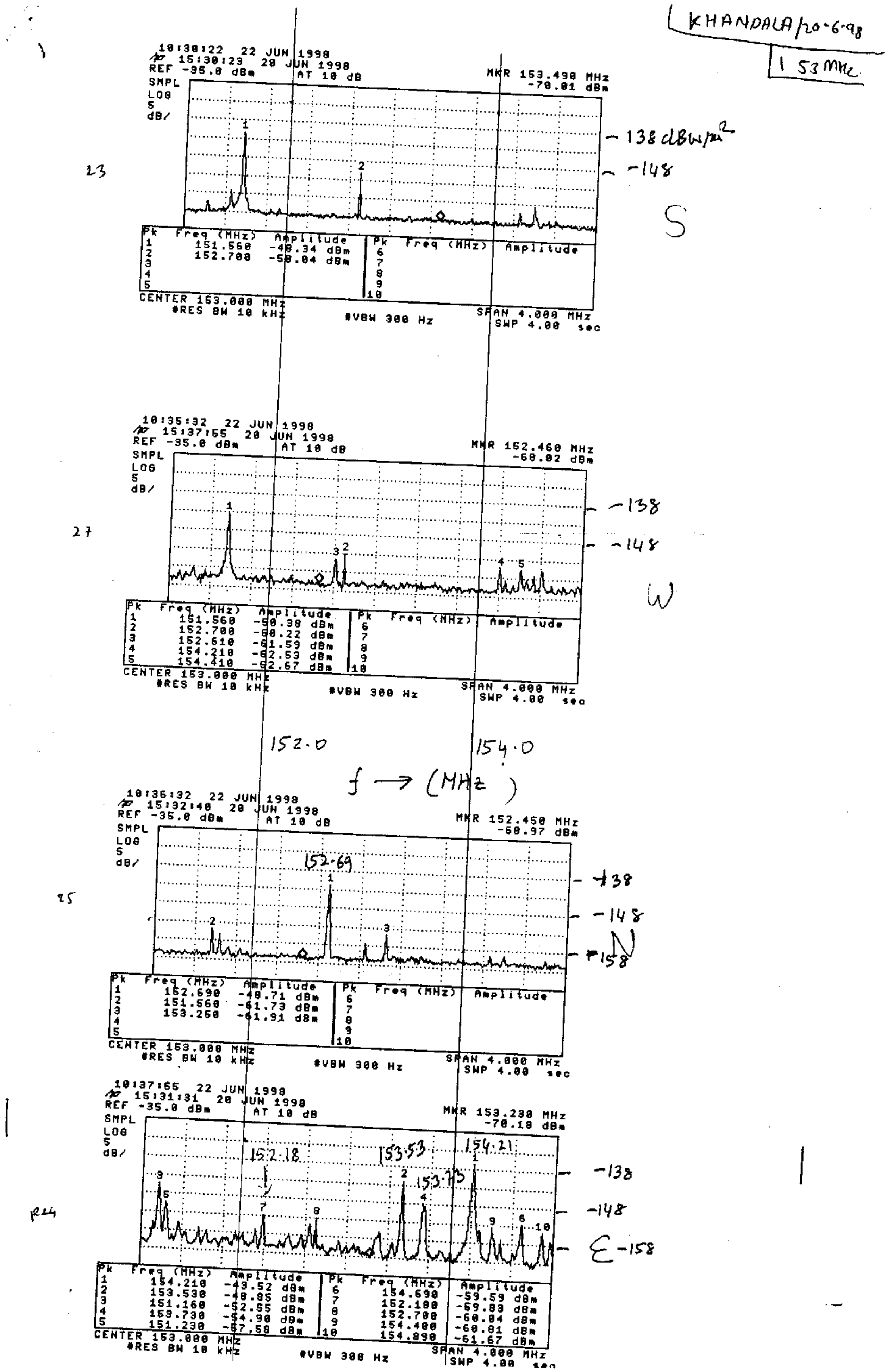


FIG. 8(j): RFI measurements made in the band around 151 to 155.5 MHz at Khandala on 20th June 1998.

FIG. 9 : RFI IN THE BAND 229.5 TO 234.5 MHz AT SEVERAL LOCATIONS AROUND GMRT AND PUNE, LONAVALA & KHANDALA

FIG. 9(a) to 9(k) : shows Spectrum Analyzer outputs of RFI either in the frequency band 230 to 234 MHz or in the band 229.5 to 234.5 MHz which were made at Alephata, Jambul-phata, Kandali, Junnar, Pune (NCRA), Lonavala and Khandala.

Measurements at all the above places except Pune were made with the Log Periodic antenna mounted on a jeep at a height of about 2.5 to 3 Mtrs. At Pune(NCRA) the Log Periodic antenna was mounted on a pole above the water tank on the second floor of NCRA building, such that the height of the Log Periodic antenna was about 10 Mtrs. Antenna was rotated in four directions viz. South, West, North & East. and plots in the four directions are Xeroxed on page No.1 for each of the locations. The following may be noted for RFI observations made at the above location in the protected GMRT band viz. 230-234 MHz.

i) Strong RFI was observed at Alephata at 230.90 MHz and at Junnar near the band 229.5-234.5 MHz.

ii) At Pune (NCRA) number of RFI signals were noted in near the band 229.5-234 MHz as shown in the figure 9(e) and 9(f). RFI seems to arise from North-West and South-West directions. Strong signals were noted at several frequencies in the band 230.93; 231.25; 231.80; 232.0; 232.71 and 233.34 MHz).

iii) At Lonavala & Khandala strong RFI signals were observed at 230.99 and 231.53 MHz and weaker at 232.13 and 233.63 MHz.

FIG. 9(a) RFI measurements made in the band 229.5-234.5 MHz near Sangamneer.

FIG. 9(b): RFI measurements made in the band 230 to 234 MHz at Alephata.

FIG. 9(c): RFI measurements made in the band 230 to 234 MHz at Jambul-phata.

FIG. 9(d): RFI measurements made in the band 230 to 234 MHz at Kandali

FIG. 9(e): RFI measurements made in the band 229.5 to 234.5 MHz at Junnar.

FIG. 9(f): RFI measurements made in the band around 229.5 to 234 MHz at Pune (NCRA).

FIG. 9(g): RFI measurements made in the band around 229.5-234 MHz at Pune (NCRA).

FIG. 9(h): RFI measurements made in the band around 230-234 MHz at Lonavala.

FIG. 9(i): RFI measurements made in the band around 229.5-234.5 MHz at Lonavala.

FIG. 9(j): RFI measurements made in the band around 230-234 MHz at Khandala.

FIG. 9(k): RFI measurements made in the band around 229.5-234 MHz at Khandala.

SAGAMNER / 24-6-98
231 MHz

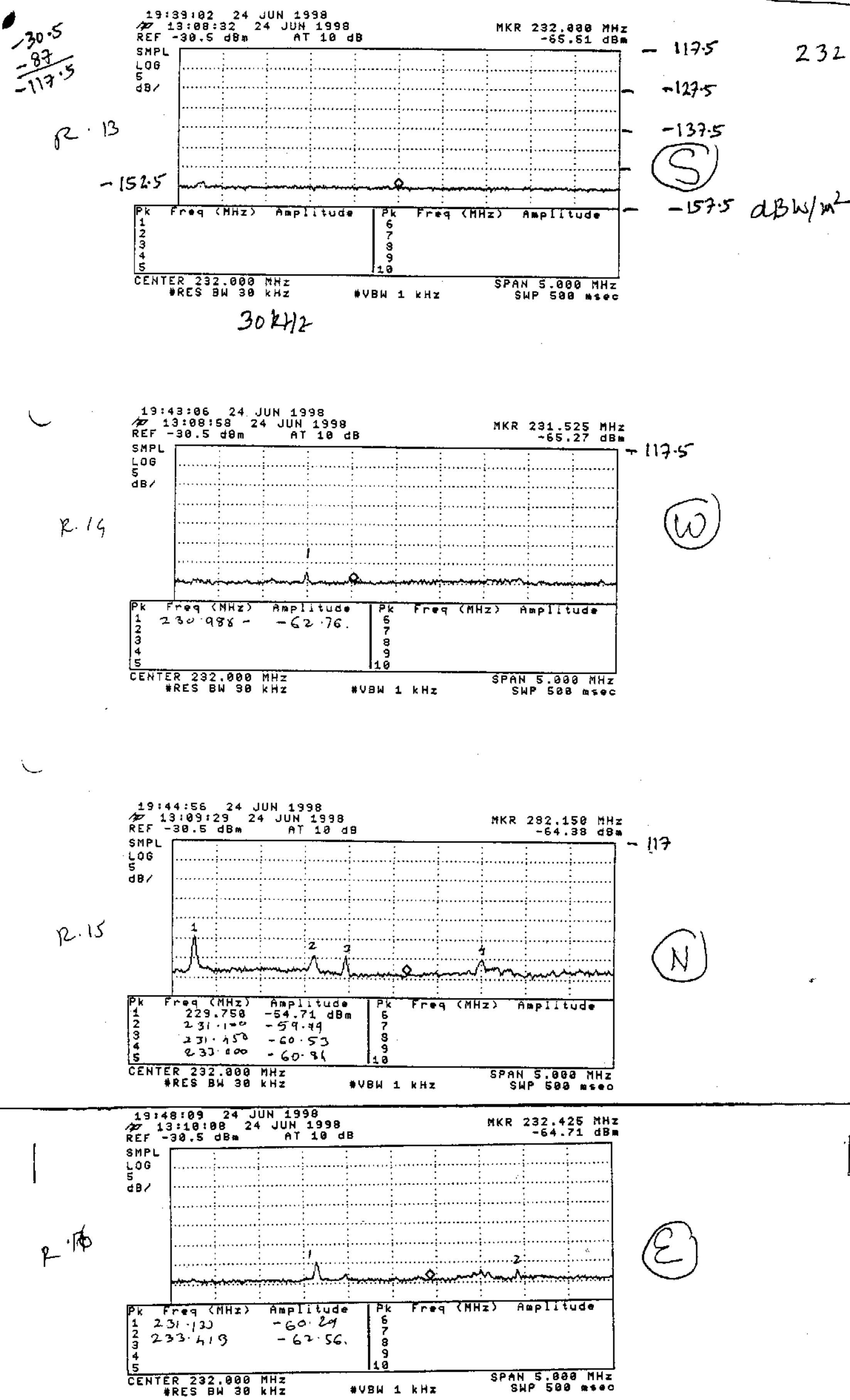


FIG. 9(a) RFI measurements made in the band 229.5-234.5 MHz near Sangamneer.

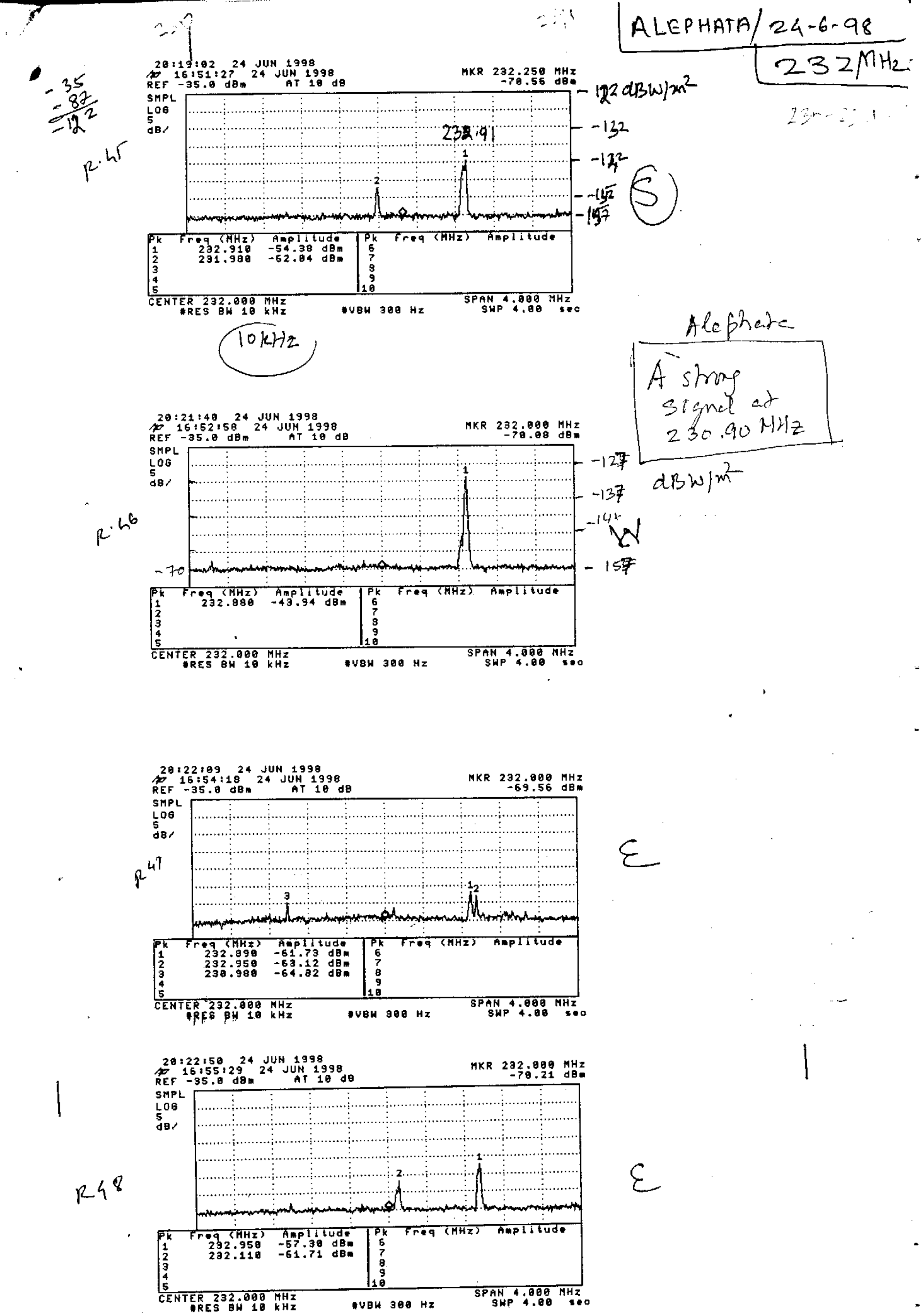
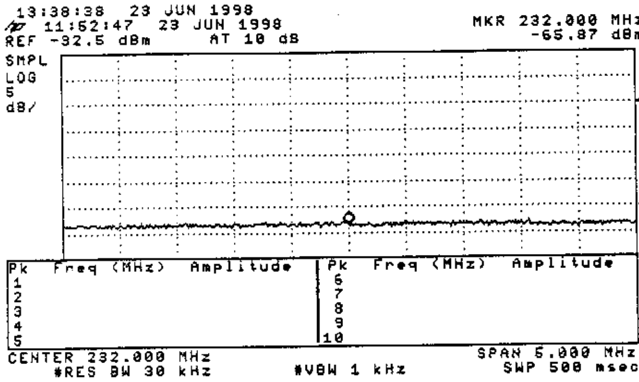


FIG. 9(b): RFI measurements made in the band 230 to 234 MHz at Alephata.

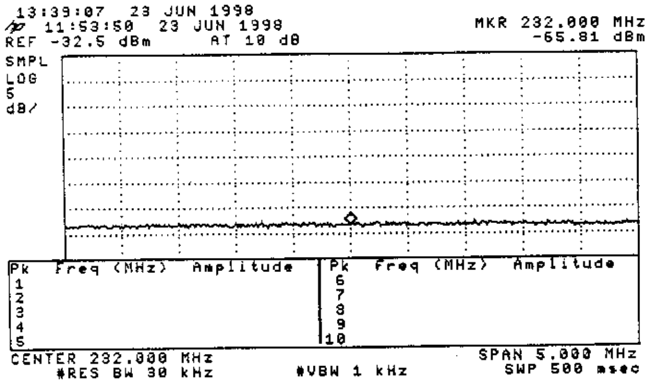
JAMBUT PHATA
232 MHz 23-6-98

R-14



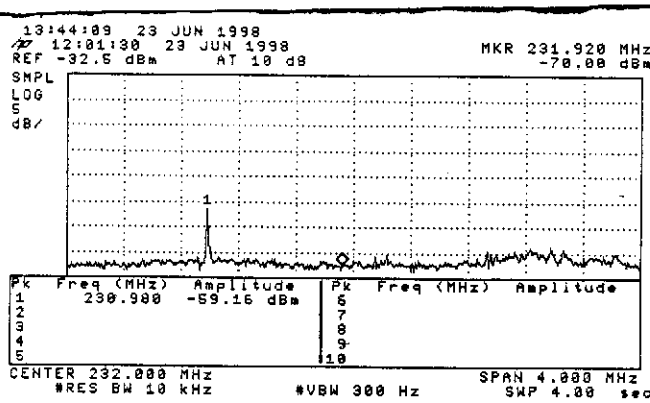
30 kHz

R-15



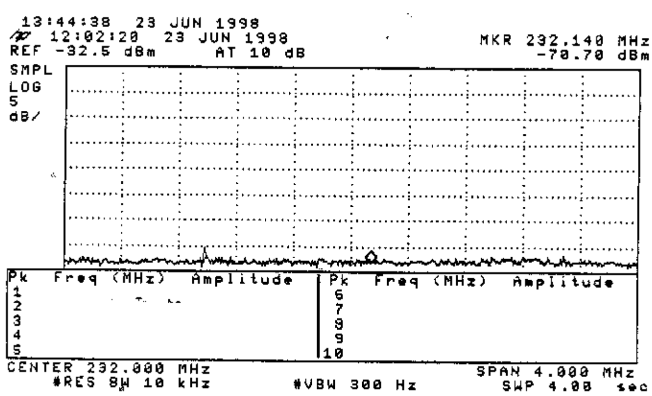
W

R-21



N

R-22



E

FIG. 9(c): RFI measurements made in the band 230 to 234 MHz at Jambul-phata.

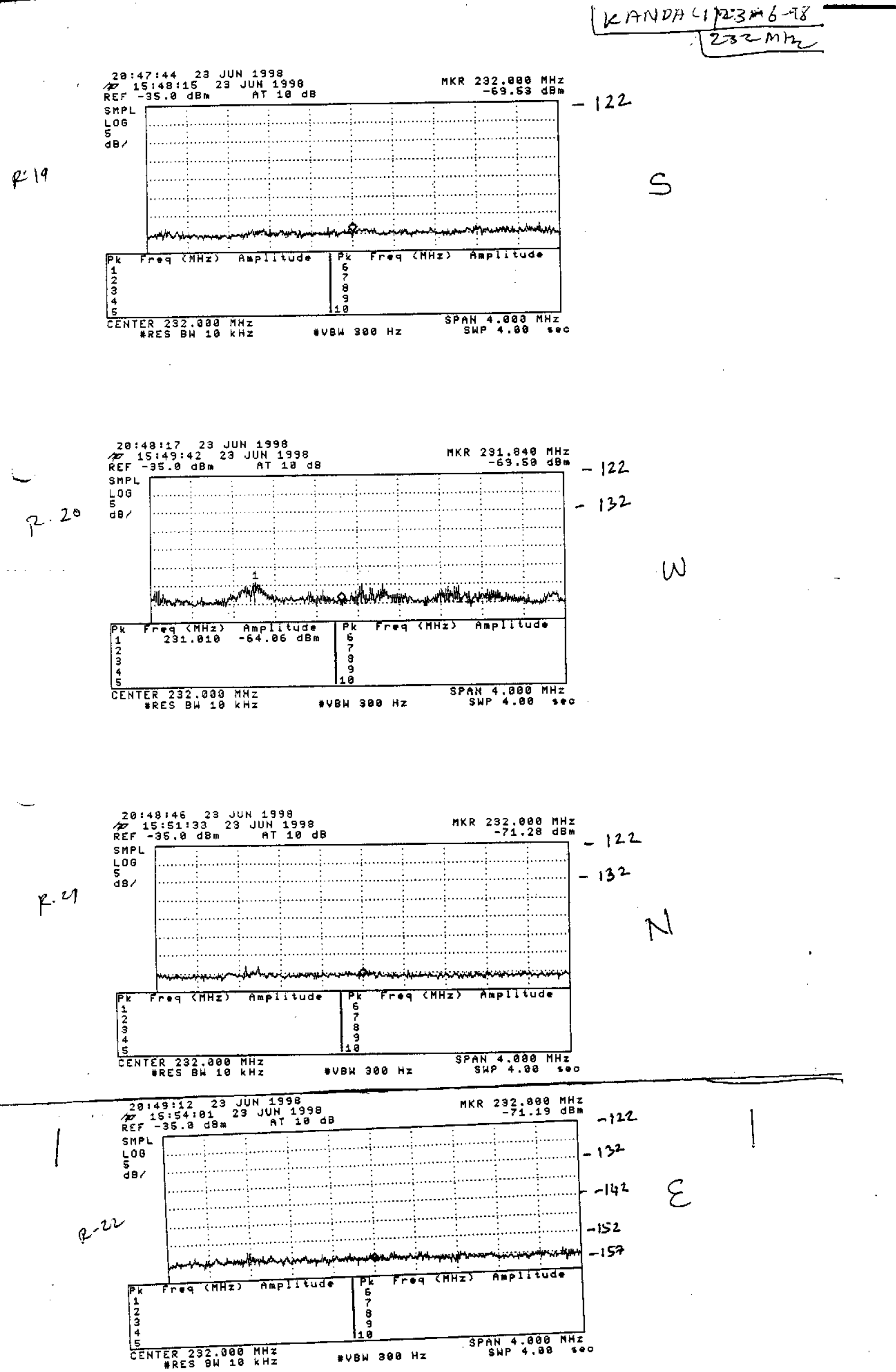


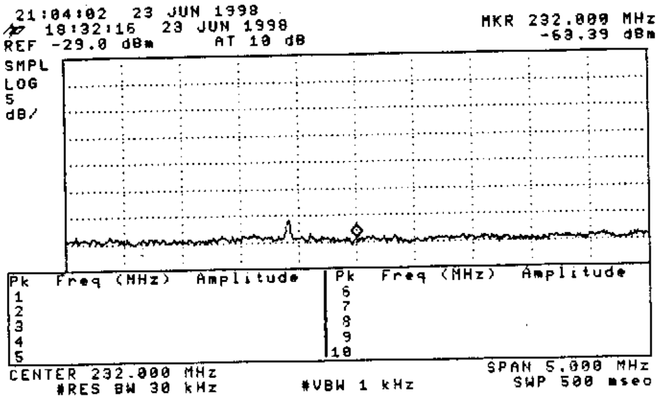
FIG. 9(d): RFI measurements made in the band 230 to 234 MHz at Kandali

229.5

Junner Tx. 233MHz 23-6-98

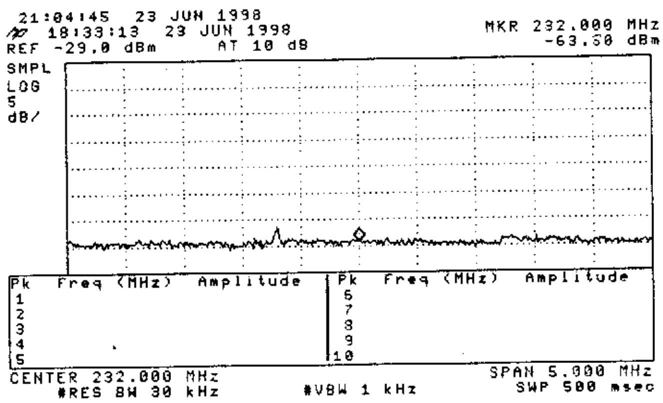
JUNNAR/233MHz

R.40



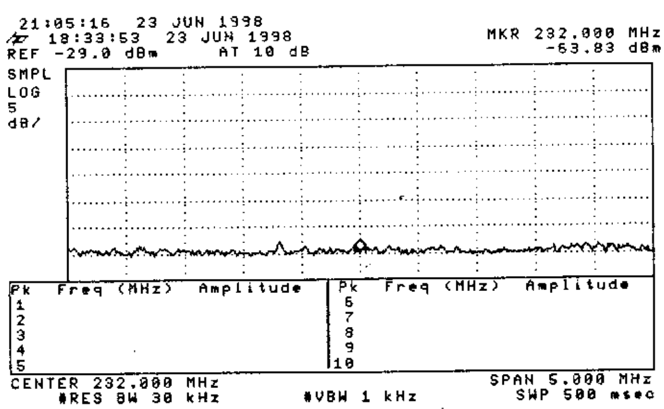
S

R.41



W

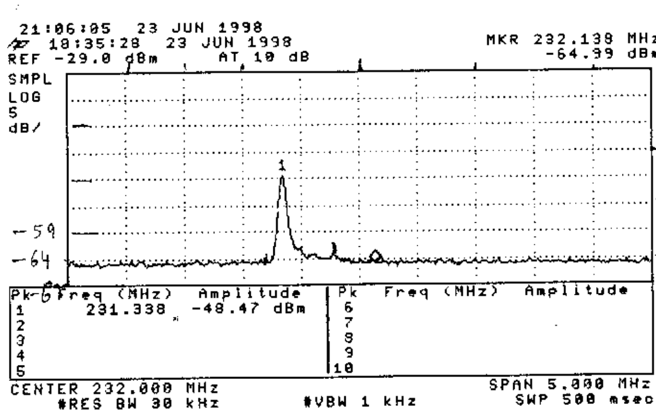
R.42



N

231.34

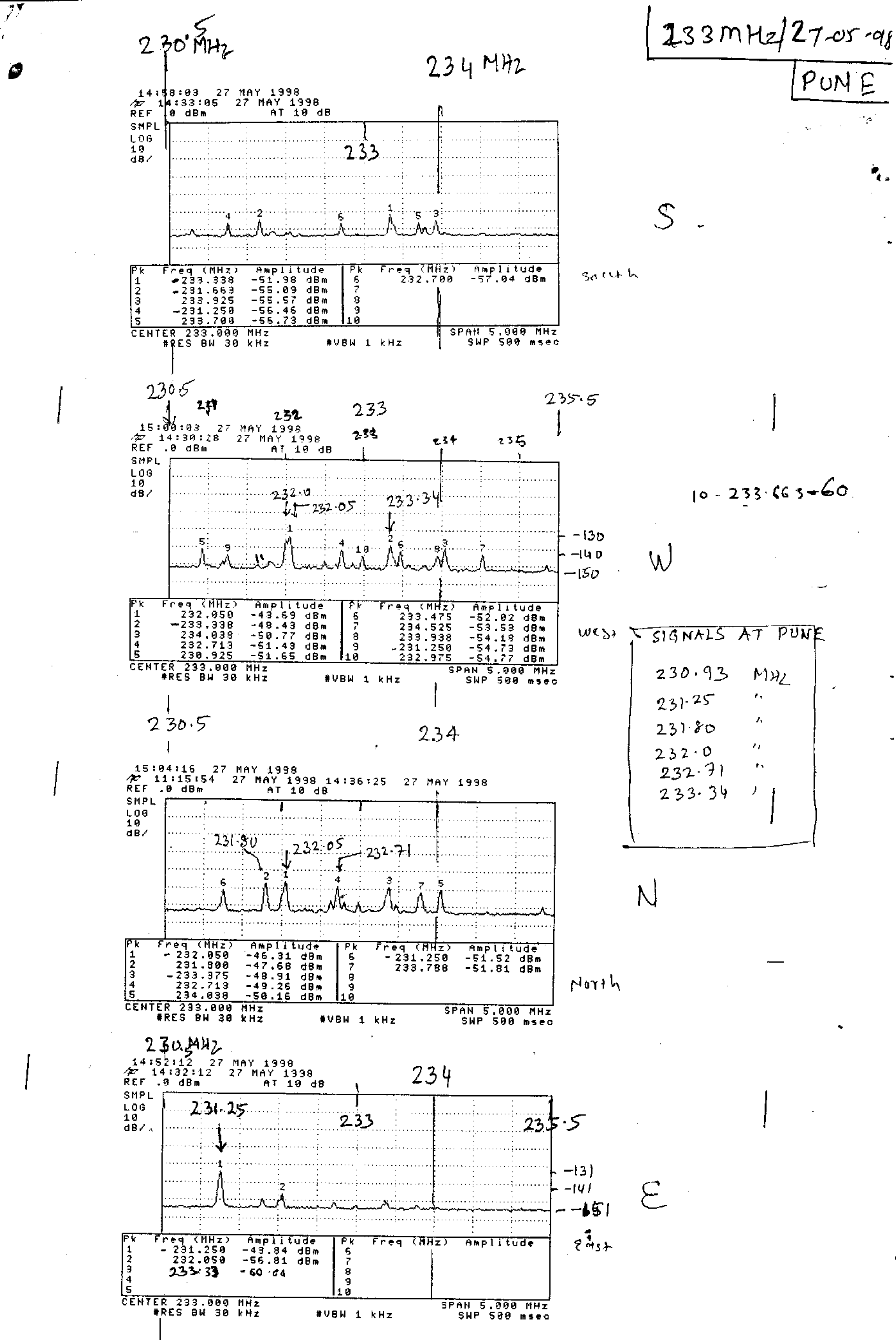
R.43



E

-65
-87
-152

FIG. 9(e): RFI measurements made in the band 229.5 to 234.5 MHz at Junnar.



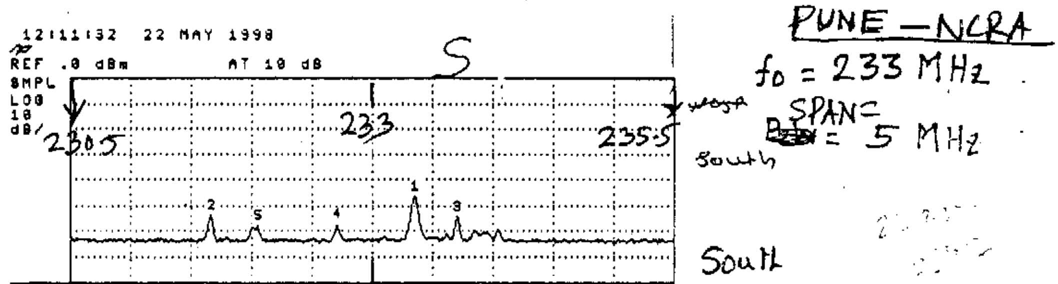
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	233.338	-51.98 dBm	6	232.700	-57.04 dBm
2	231.663	-55.09 dBm	7		
3	233.925	-55.57 dBm	8		
4	231.250	-56.46 dBm	9		
5	233.700	-55.73 dBm	10		

Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.050	-43.59 dBm	6	233.475	-52.02 dBm
2	233.338	-48.43 dBm	7	234.525	-53.53 dBm
3	234.038	-50.77 dBm	8	233.938	-54.18 dBm
4	232.713	-51.43 dBm	9	231.250	-54.73 dBm
5	230.925	-51.65 dBm	10	232.975	-54.77 dBm

Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.050	-46.31 dBm	6	231.250	-51.52 dBm
2	231.800	-47.68 dBm	7	233.788	-51.81 dBm
3	233.375	-48.91 dBm	8		
4	232.713	-49.26 dBm	9		
5	234.038	-50.16 dBm	10		

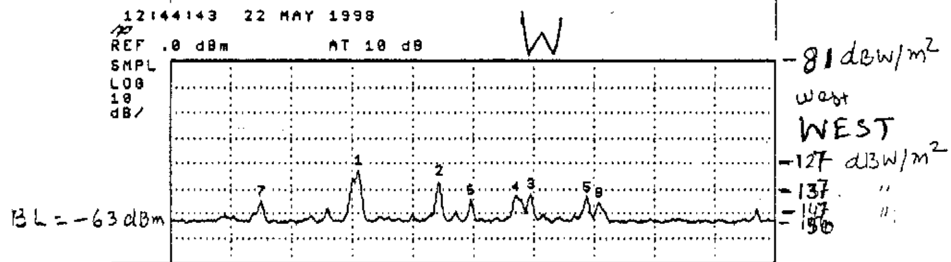
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	231.250	-43.84 dBm	6		
2	232.050	-56.81 dBm	7		
3	233.33	-60 d4	8		
4			9		
5			10		

FIG. 9(f): RFI measurements made in the band around 229.5 to 234 MHz at Pune (NCRA).



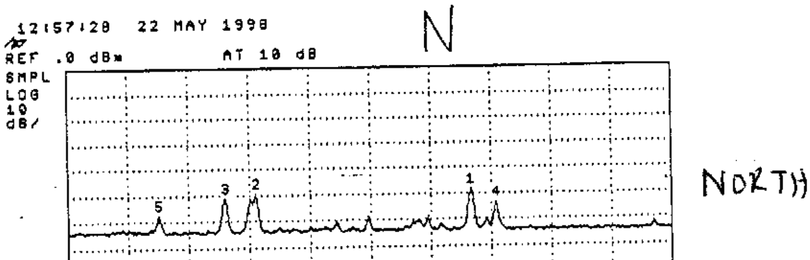
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	233.350	-46.92 dBm	6		
2	231.663	-53.73 dBm	7		
3	233.700	-54.38 dBm	8		
4	232.700	-57.42 dBm	9		
5	232.050	-57.53 dBm	10		

CENTER 233.000 MHz SPAN 5.000 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 500 msec



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.050	-42.75 dBm	6	232.975	-54.48 dBm
2	232.713	-47.13 dBm	7	231.250	-54.91 dBm
3	233.475	-51.74 dBm	8	234.038	-56.32 dBm
4	233.350	-53.03 dBm	9		
5	233.938	-53.18 dBm	10		

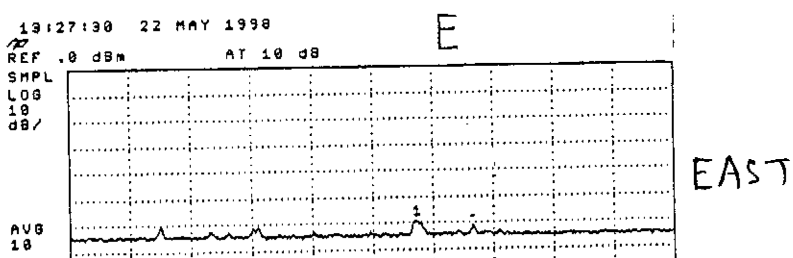
CENTER 233.000 MHz SPAN 5.000 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 500 msec



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	233.825	-48.62 dBm	6		
2	232.050	-49.48 dBm	7		
3	231.800	-51.53 dBm	8		
4	234.038	-53.62 dBm	9		
5	231.250	-57.80 dBm	10		

North

CENTER 233.000 MHz SPAN 5.000 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 500 msec



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	233.963	-59.50 dBm	6		
2			7		
3			8		
4			9		
5			10		

East

CENTER 233.000 MHz SPAN 5.000 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 500 msec

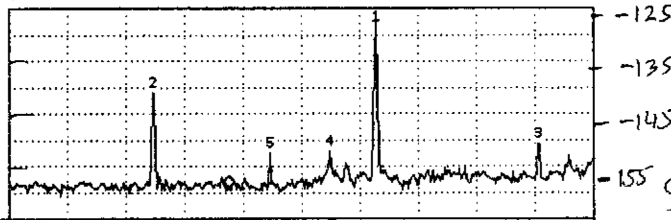
FIG. 9(g): RFI measurements made in the band around 229.5-234 MHz at Pune (NCRA).

20-6-98 / LONAVALA

232 MHz

P-6

11:08:54 22 JUN 1998
15:41:43 20 JUN 1998 17:3E
REF -35.0 dBm AT 10 dB
MKR 231.500 MHz
-69.27 dBm
SMPL
LOG
5
dB/

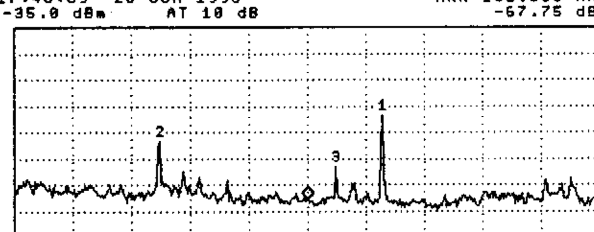


Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.510	-37.65 dBm	6		
2	230.980	-50.91 dBm	7		
3	233.620	-60.69 dBm	8		
4	232.190	-62.08 dBm	9		
5	231.780	-62.39 dBm	10		

CENTER 232.000 MHz SPAN 4.000 MHz
#RES BW 10 kHz #VBW 300 Hz SWP 4.00 sec

P.7

11:09:52 22 JUN 1998
17:40:09 20 JUN 1998
REF -35.0 dBm AT 10 dB
MKR 232.000 MHz
-67.75 dBm
SMPL
LOG
5
dB/

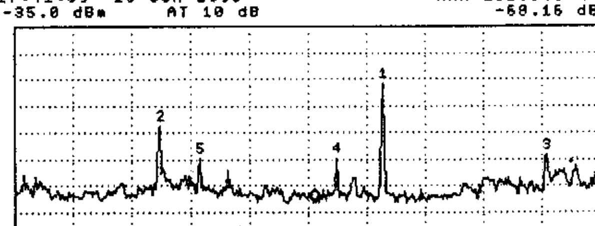


Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.510	-51.74 dBm	6		
2	230.990	-56.85 dBm	7		
3	232.190	-61.47 dBm	8		
4			9		
5			10		

CENTER 232.000 MHz SPAN 4.000 MHz
#RES BW 10 kHz #VBW 300 Hz SWP 4.00 sec

P.8

11:10:38 22 JUN 1998
17:41:09 20 JUN 1998
REF -35.0 dBm AT 10 dB
MKR 232.040 MHz
-68.16 dBm
SMPL
LOG
5
dB/



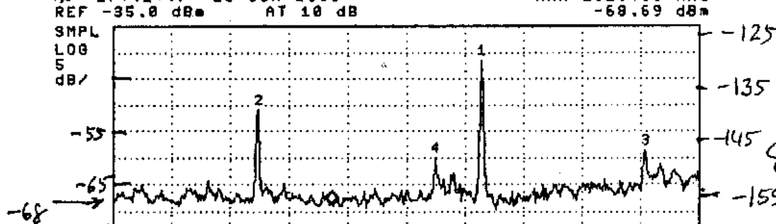
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.510	-45.78 dBm	6		
2	230.990	-58.85 dBm	7		
3	233.630	-59.21 dBm	8		
4	232.190	-59.80 dBm	9		
5	231.260	-59.89 dBm	10		

CENTER 232.000 MHz SPAN 4.000 MHz
#RES BW 10 kHz #VBW 300 Hz SWP 4.00 sec

* 230.99 strong
232.13 weak
* 232.51 v. strong
233.63 weak

R-9

11:12:24 22 JUN 1998
17:42:47 20 JUN 1998
REF -35.0 dBm AT 10 dB
MKR 231.490 MHz
-68.69 dBm
SMPL
LOG
5
dB/



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	232.510	-41.53 dBm	6		
2	230.990	-51.09 dBm	7		
3	233.630	-58.62 dBm	8		
4	232.190	-60.24 dBm	9		
5			10		

CENTER 232.000 MHz SPAN 4.000 MHz
#RES BW 10 kHz #VBW 300 Hz SWP 4.00 sec

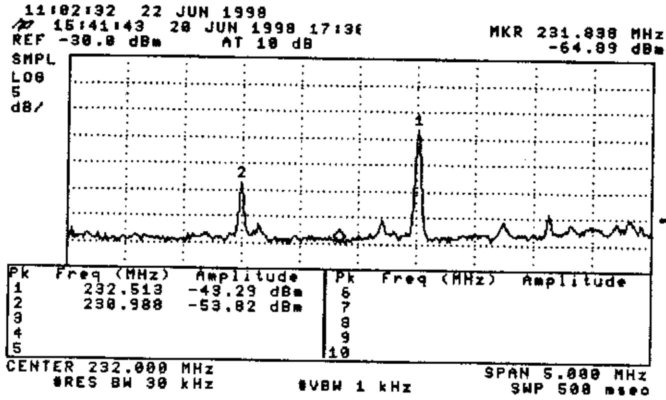
- 68
- 87
-155

FIG. 9(h): RFI measurements made in the band around 230-234 MHz at Lonavala.

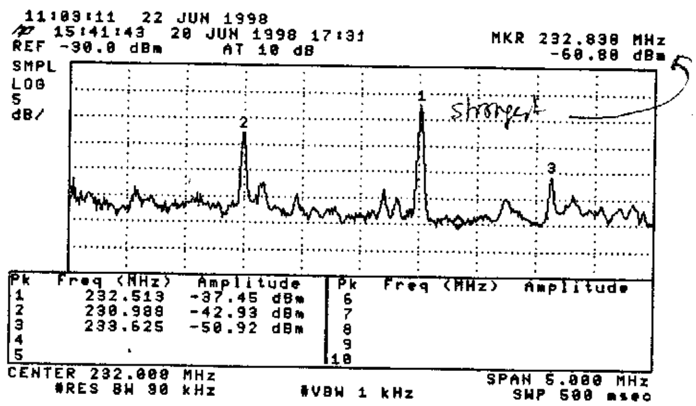
LONAWALA/20-6-98

232 MHz

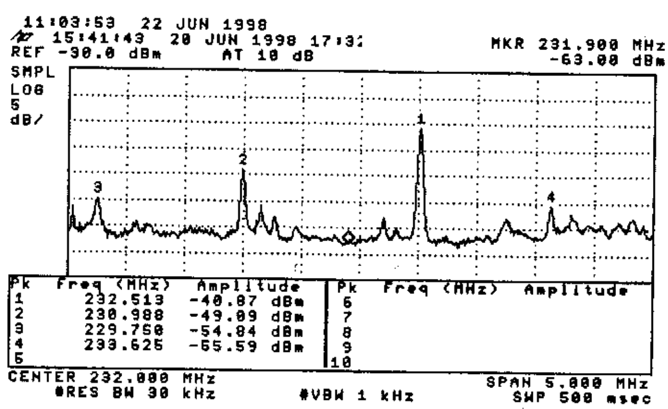
R.0



R.1



R.2



R.4

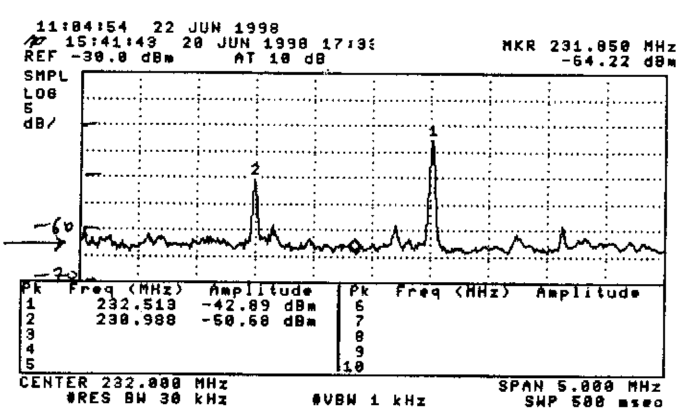
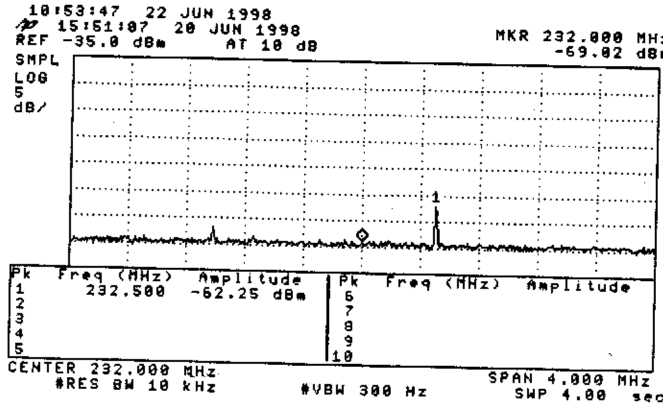


FIG. 9(i): RFI measurements made in the band around 229.5-234.5 MHz at Lonavala.

KHANDALA / 20-6-98

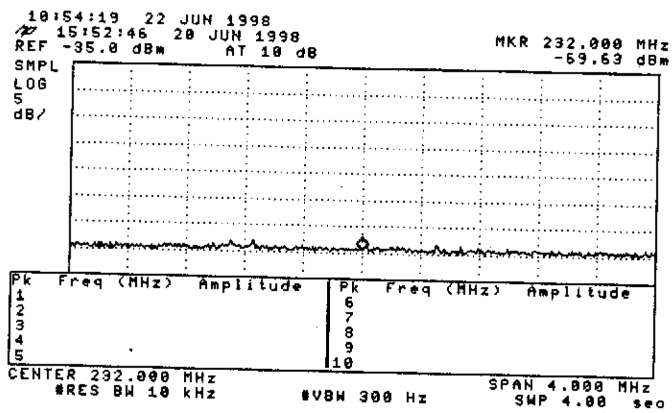
232 MHz

R.35



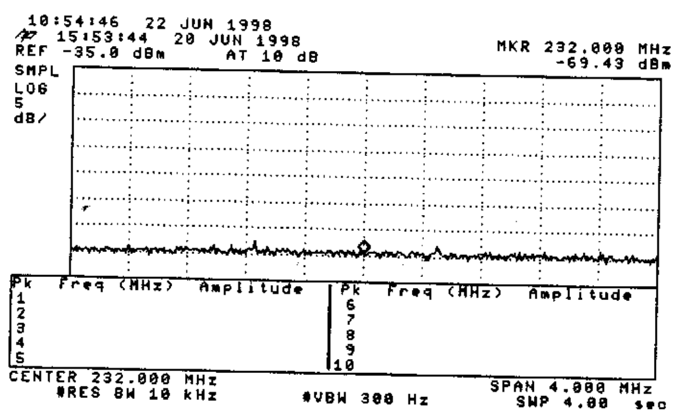
S

R.35



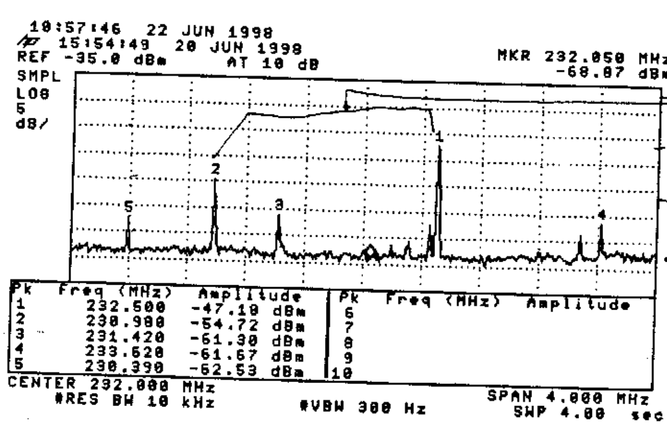
W

R.36



N

R.37



seen both at Khandala & Lonavela

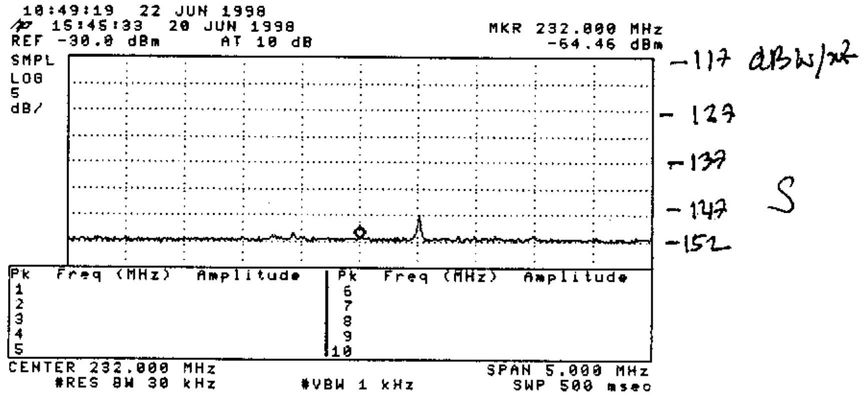
E

FIG. 9(j): RFI measurements made in the band around 230-234 MHz at Khandala.

KHANDALA/20-6-98

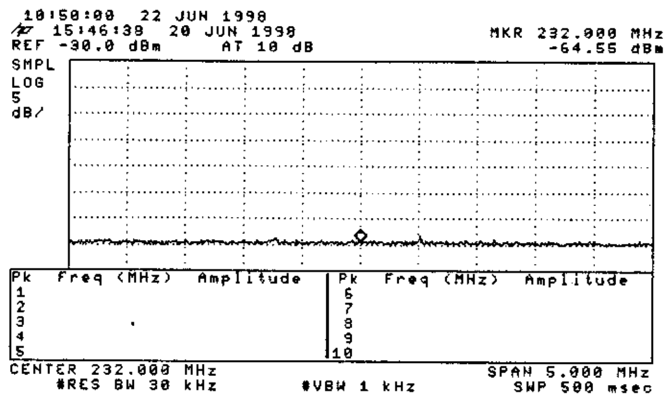
232 MHz

R.29



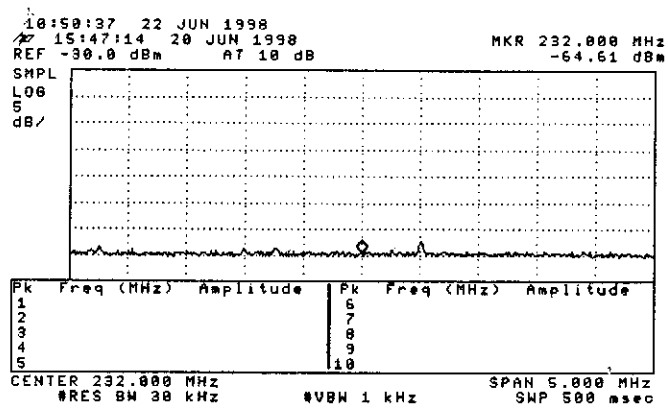
S

R.30



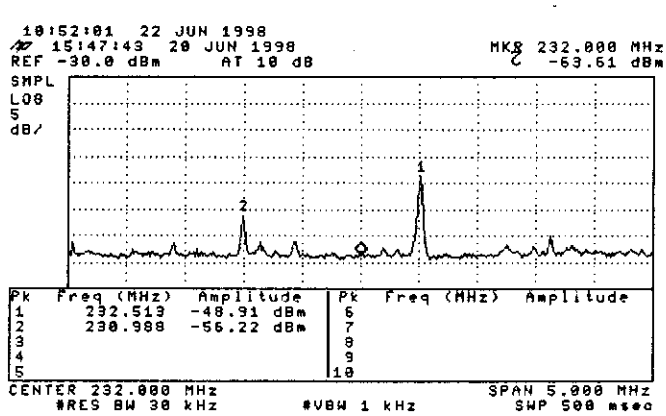
W

R.31



N

R.32



E

FIG. 9(k): RFI measurements made in the band around 229.5-234 MHz at Khandala.

Fig. 10 : A summary plot of RFI measurements in the GMRT Band of 152-154 MHz based on observations made at Sangamneer, Kukdi, GMRT site, (Pulsar Rx : see text), Pune, Lonavala and Khandala Ticks are marked on the GMRT site data for those frequencies for which there seems to be some correlation between RFI at (a) the GMRT site and (b) Pune, Lonavala and Khandala.

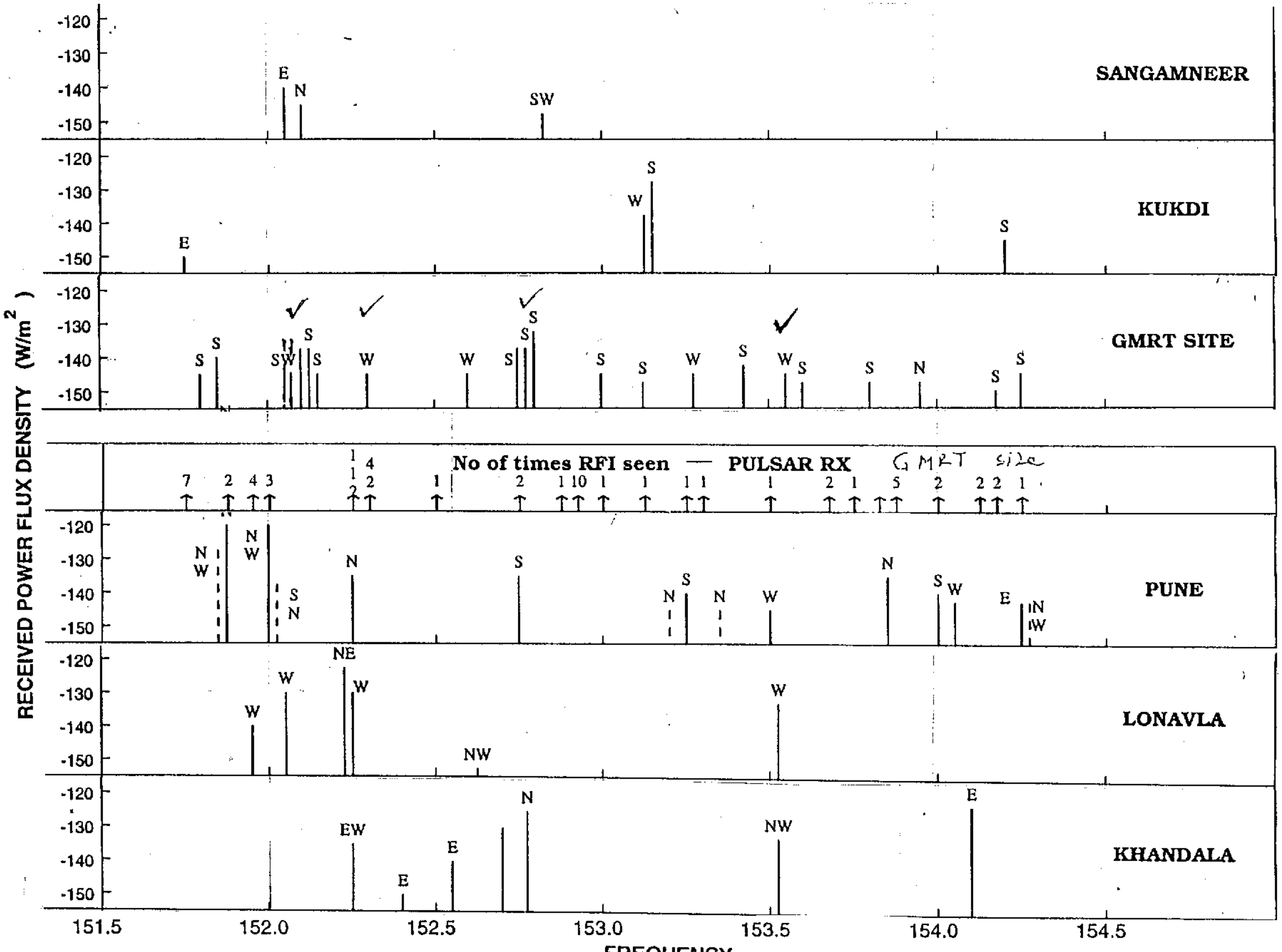


Fig. 10 : A summary plot of RFI measurements in the GMRT Band of 152-154 MHz based on observations made at Sangamneer, Kukdi, GMRT site, (Pulsar Rx : see text), Pune, Lonavala and Khandala Ticks are marked on the GMRT site data for those frequencies for which there seems to be some correlation between RFI at (a) the GMRT site and (b) Pune, Lonavla and Khandala

Fig. 11 : RFI measurements in the GMRT Band of 230-234 MHz at (a) Alephata (b) the GMRT site, (c) Junnar, (d) NCRA-Pune, (e) Lonavala and (f) Khandala.

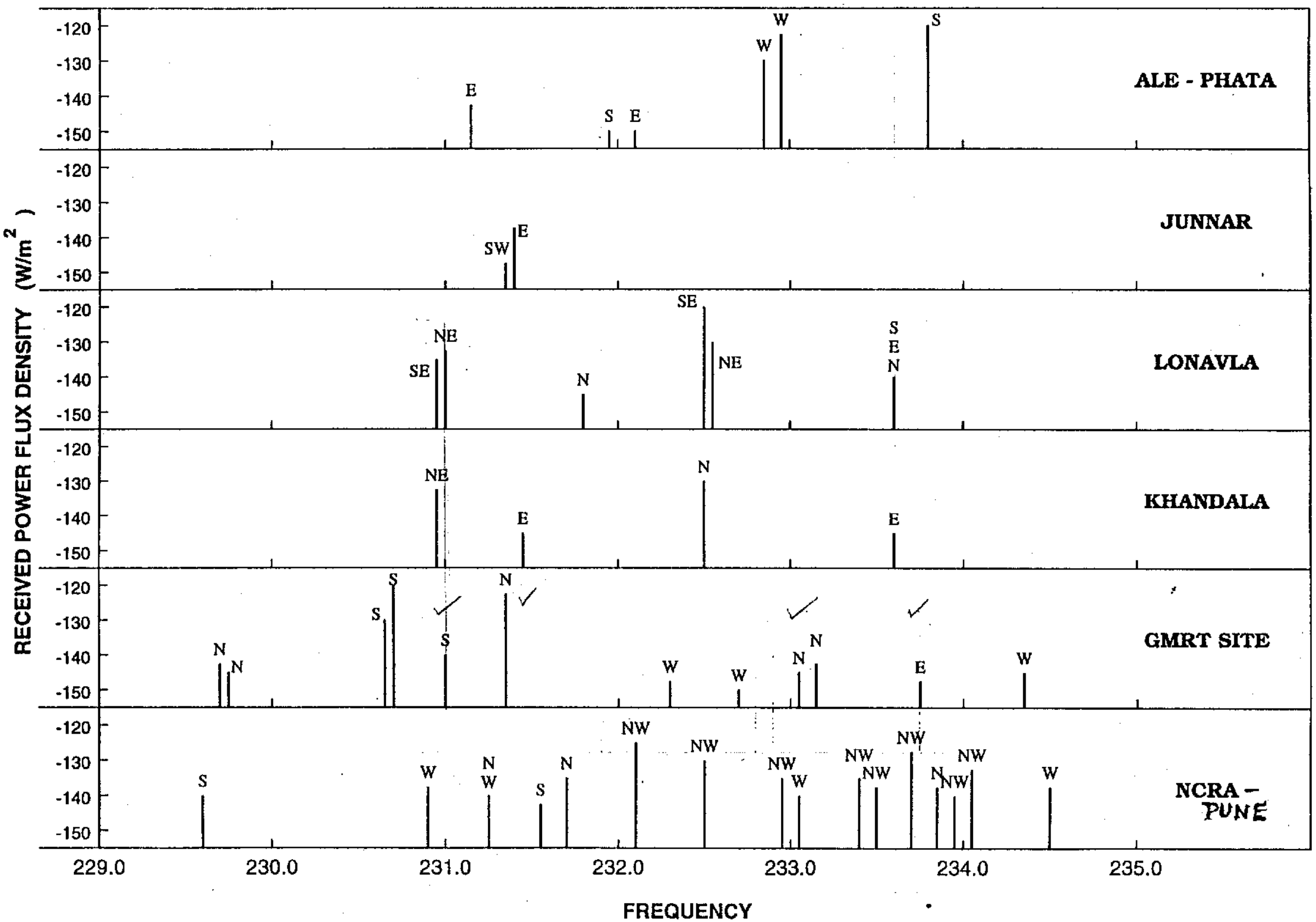


Fig. 11 : RFI measurements in the GMRT Band of 230-234 MHz at (a) Alephata (b) the GMRT site, (c) Junnar, (d) NCRA-Pune, (e) Lonavala and (f) Khandala.

(11)

Fig. 12 : Radio Frequency Spectrum (RFS) at Pune, Lonavala and Khandala

Fig. 12(a), 12(b) and 12(c) show RFI measurements made in the frequency band of 300-350 MHz at Lonavala, Khandala and Pune respectively. It is seen that the signals received are much larger at Khandala compared to Lonavala or Pune. In Fig. 12(d) is shown measurements made at NCRA-Pune in the bands 315-335 MHz, 140-160 MHz and 225-245 MHz. All measurements were made using method 2 of Appendix-B. It is clear that the Radio Frequency Spectrum is much quieter near the 325 MHz band than near the bands 150 and 233 MHz.

Fig. 12 (a) : RFI measurements in the band 300-350 MHz near Lonavala.

Fig. 12 (b) : RFS measurements in the band 300-350 MHz near Khandala.

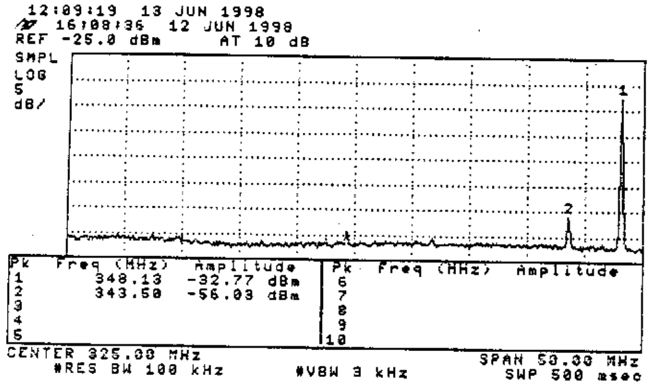
Fig. 12 (c) : RFS measurements in the band 300-350 MHz at NCRA-Pune.

Fig. 12(d) RFS measurements in bands 315-335 MHz, 140-160 MHz and 225-245 MHz at NCRA-Pune.

325MHz | LONAWALA
12-06-98

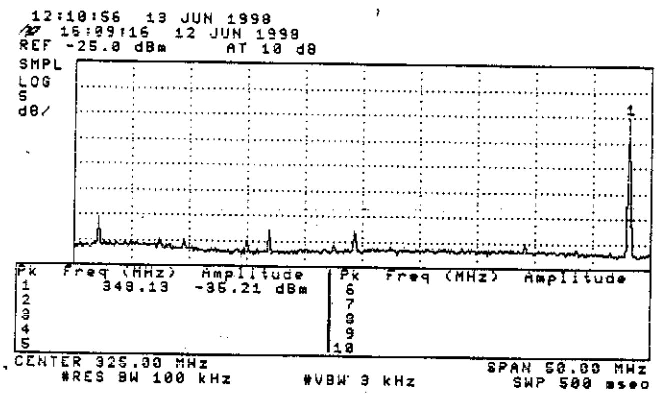
LONAVALA
325MHz
N
± 25MHz

25



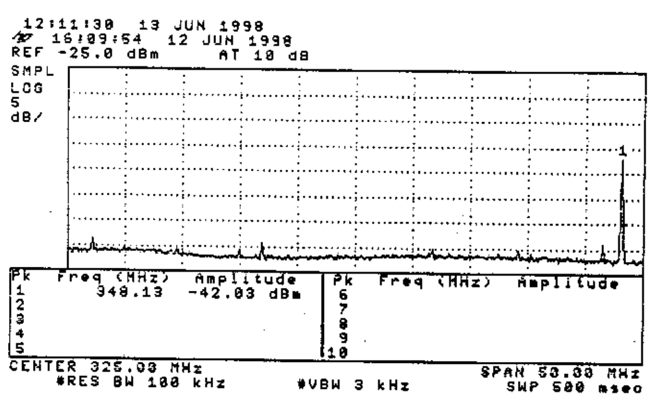
26

E



27

S



28

W

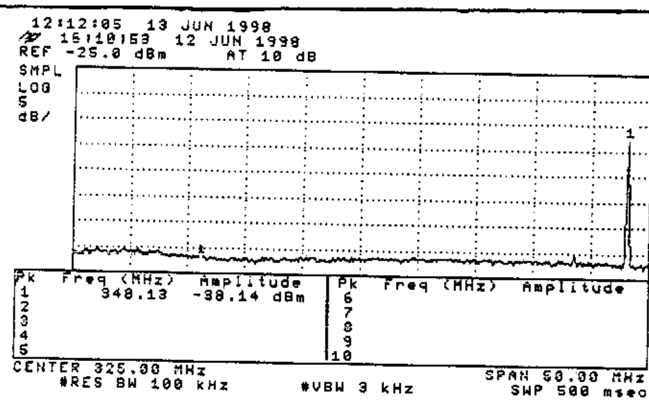


Fig. 12 (a) : RFI measurements in the band 300-350 MHz near Lonavala.

325 MHz/ Khandala

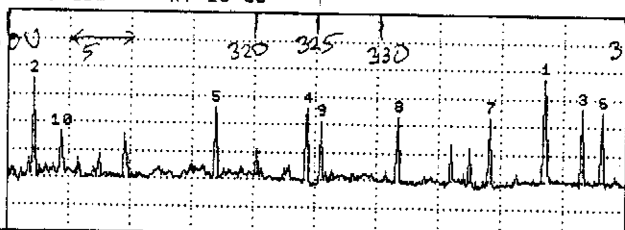
12-06-98

KHANDALA

325.0 ± 25 MHz

Req 10

11:30:18 13 JUN 1998
14:46:13 12 JUN 1998
REF -30.0 dBm AT 10 dB
SMPL
LOG
5
dB/



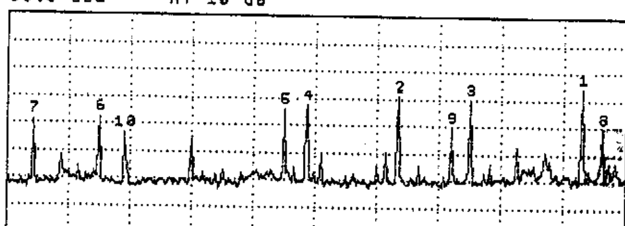
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	343.50	-41.34 dBm	6	348.13	-47.55 dBm
2	302.13	-42.30 dBm	7	339.13	-48.46 dBm
3	346.50	-46.93 dBm	8	331.75	-48.53 dBm
4	324.38	-47.18 dBm	9	325.50	-49.42 dBm
5	316.88	-47.19 dBm	10	304.38	-51.74 dBm

CENTER 325.00 MHz SPAN 50.00 MHz
#RES BW 100 kHz #VBW 3 kHz SWP 500 msec

Req 11

E

11:30:46 13 JUN 1998
14:47:24 12 JUN 1998
REF -30.0 dBm AT 10 dB
SMPL
LOG
5
dB/



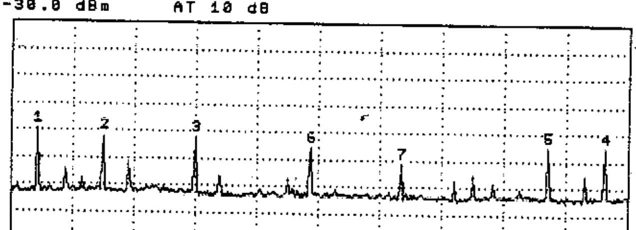
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	346.50	-42.78 dBm	6	307.50	-48.94 dBm
2	331.75	-44.57 dBm	7	302.13	-49.56 dBm
3	337.50	-45.19 dBm	8	348.13	-50.19 dBm
4	324.38	-46.16 dBm	9	336.00	-50.23 dBm
5	322.50	-47.22 dBm	10	309.50	-51.70 dBm

CENTER 325.00 MHz SPAN 50.00 MHz
#RES BW 100 kHz #VBW 3 kHz SWP 500 msec

Req 12

S

11:31:11 13 JUN 1998
14:48:21 12 JUN 1998
REF -30.0 dBm AT 10 dB
SMPL
LOG
5
dB/



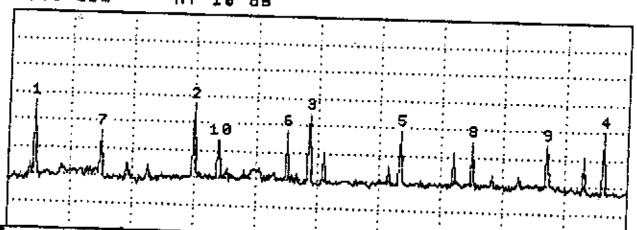
Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	302.13	-49.66 dBm	6	324.38	-52.75 dBm
2	307.50	-51.00 dBm	7	331.75	-55.78 dBm
3	315.00	-51.08 dBm	8		
4	348.13	-52.45 dBm	9		
5	343.50	-52.53 dBm	10		

CENTER 325.00 MHz SPAN 50.00 MHz
#RES BW 100 kHz #VBW 3 kHz SWP 500 msec

Req 13

W

11:32:43 13 JUN 1998
14:49:18 12 JUN 1998
REF -30.0 dBm AT 10 dB
SMPL
LOG
5
dB/



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	302.13	-46.55 dBm	6	322.50	-51.03 dBm
2	315.00	-46.63 dBm	7	307.50	-52.08 dBm
3	324.38	-47.80 dBm	8	337.50	-52.18 dBm
4	348.13	-50.03 dBm	9	343.50	-52.50 dBm
5	331.75	-50.65 dBm	10	317.00	-53.08 dBm

CENTER 325.00 MHz SPAN 50.00 MHz
#RES BW 100 kHz #VBW 3 kHz SWP 500 msec

Fig. 12 (b) : RFS measurements in the band 300-350 MHz near Khandala.

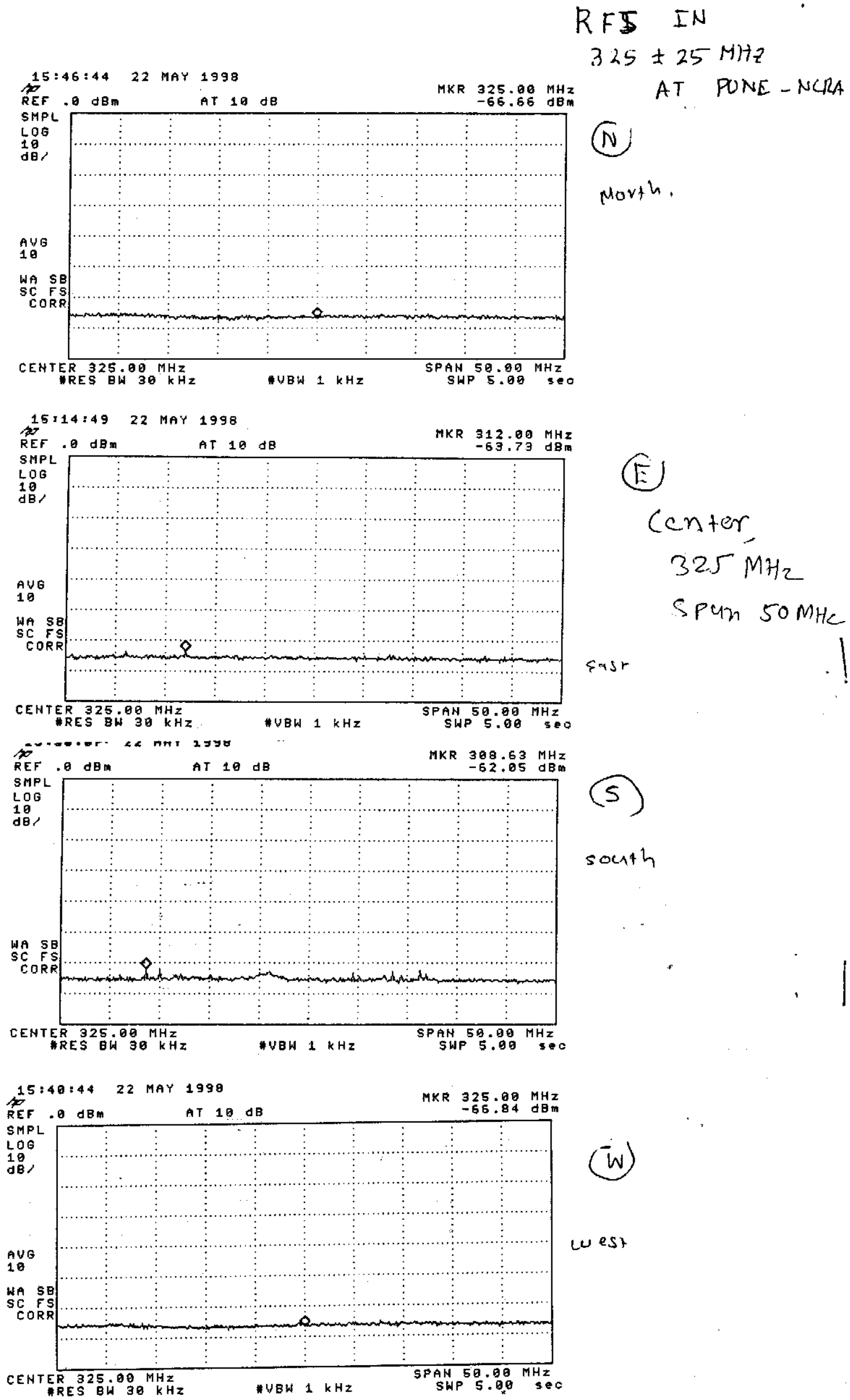
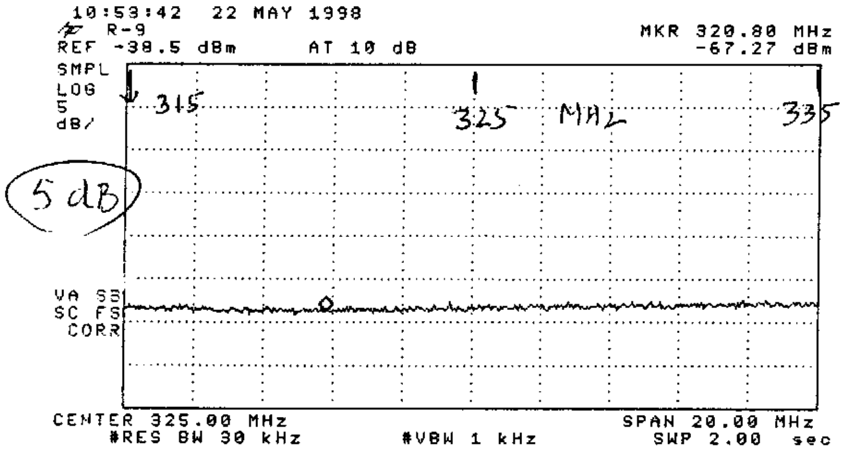


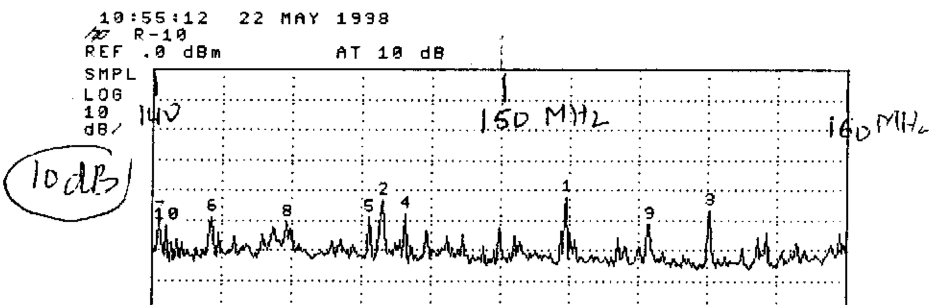
Fig. 12 (c) : RFS measurements in the band 300-350 MHz at NCRA-Pune.



Pune

(N)

325 ± 10 MHz

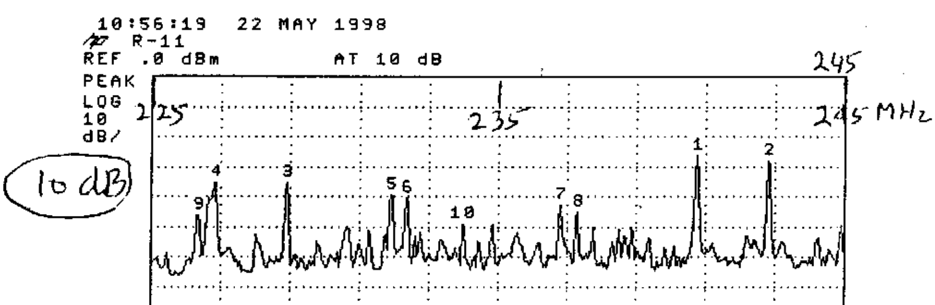


Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	151.90	-42.36 dBm	6	141.70	-49.08 dBm
2	146.60	-43.44 dBm	7	140.20	-49.80 dBm
3	156.05	-46.72 dBm	8	143.85	-51.08 dBm
4	147.25	-47.85 dBm	9	154.30	-51.36 dBm
5	146.20	-48.88 dBm	10	140.40	-51.72 dBm

CENTER 150.00 MHz SPAN 20.00 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 2.00 sec

N

150 ± 10 MHz



Pk	Freq (MHz)	Amplitude	Pk	Freq (MHz)	Amplitude
1	240.75	-26.50 dBm	6	232.35	-40.64 dBm
2	242.80	-28.13 dBm	7	236.80	-42.89 dBm
3	228.90	-35.32 dBm	8	237.30	-44.95 dBm
4	226.85	-35.35 dBm	9	226.35	-46.20 dBm
5	231.90	-39.36 dBm	10	233.95	-48.92 dBm

CENTER 235.00 MHz SPAN 20.00 MHz
#RES BW 30 kHz #VBW 1 kHz SWP 2.00 sec

N

235 ± 10 MHz

Fig. 12(d) RFS measurements in bands 315-335 MHz, 140-160 MHz and 225-245 MHz at NCRA-Pune.

FIG. 13 : Height path profile between Bombay and GMRT site.
The plots were made using survey of India maps along the line of site from the GMRT site to the central part of Bombay.

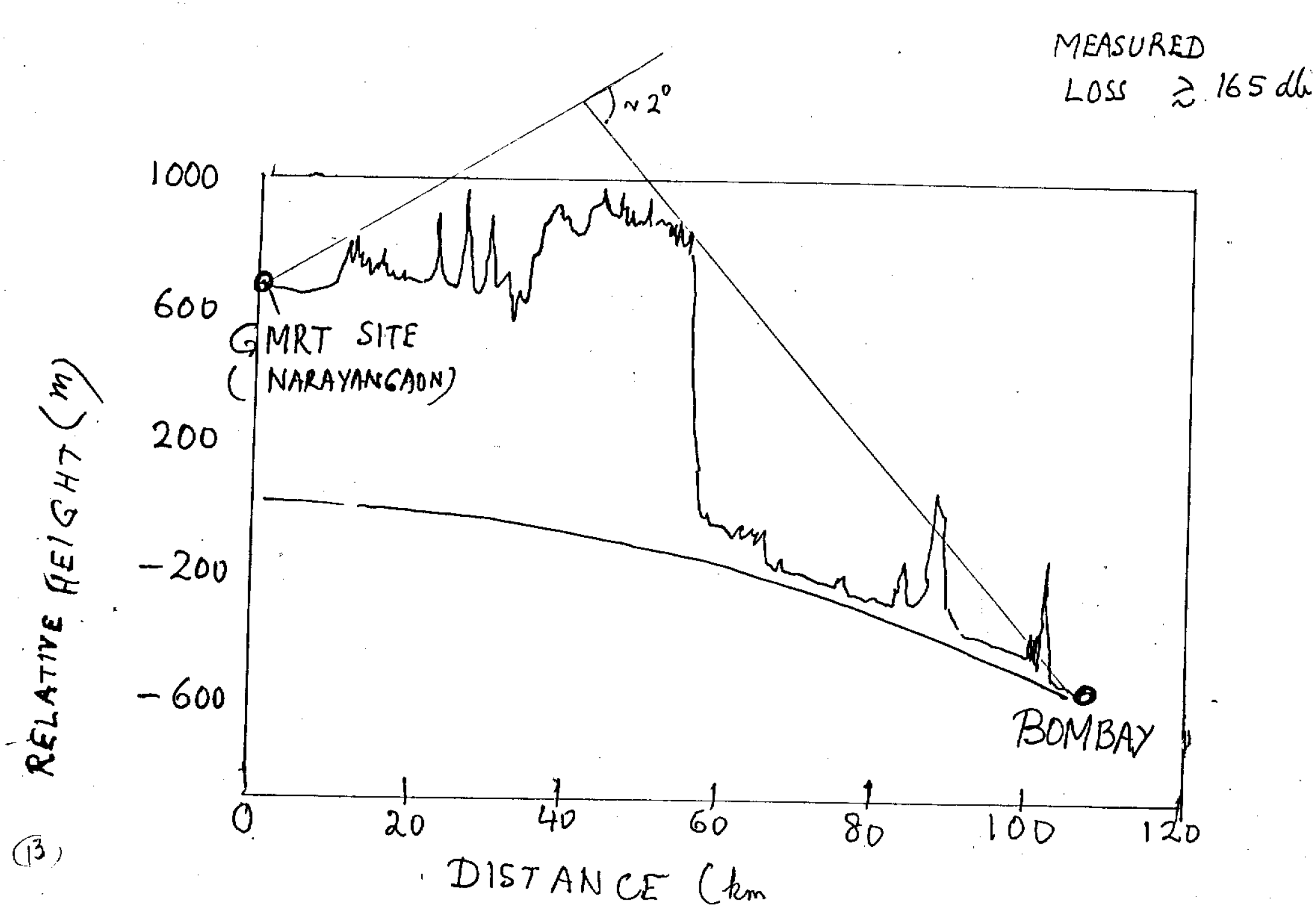


FIG. 13 : Height path profile between Bombay and GMRT site.
The plots were made using survey of India maps along the line of site from the GMRT site to the central part of Bombay.

2

FIG. 14: The calculations of Tropo-Scatter path as shown in Fig. 13 show transmission loss by NPL. The absissa percent of time ordinate exceeded at different values of losses. For e.g. it may be noted that 65% of the time ~~will be lost at the~~ [loss will exceed] 150 dB between Bombay and GMRT site.

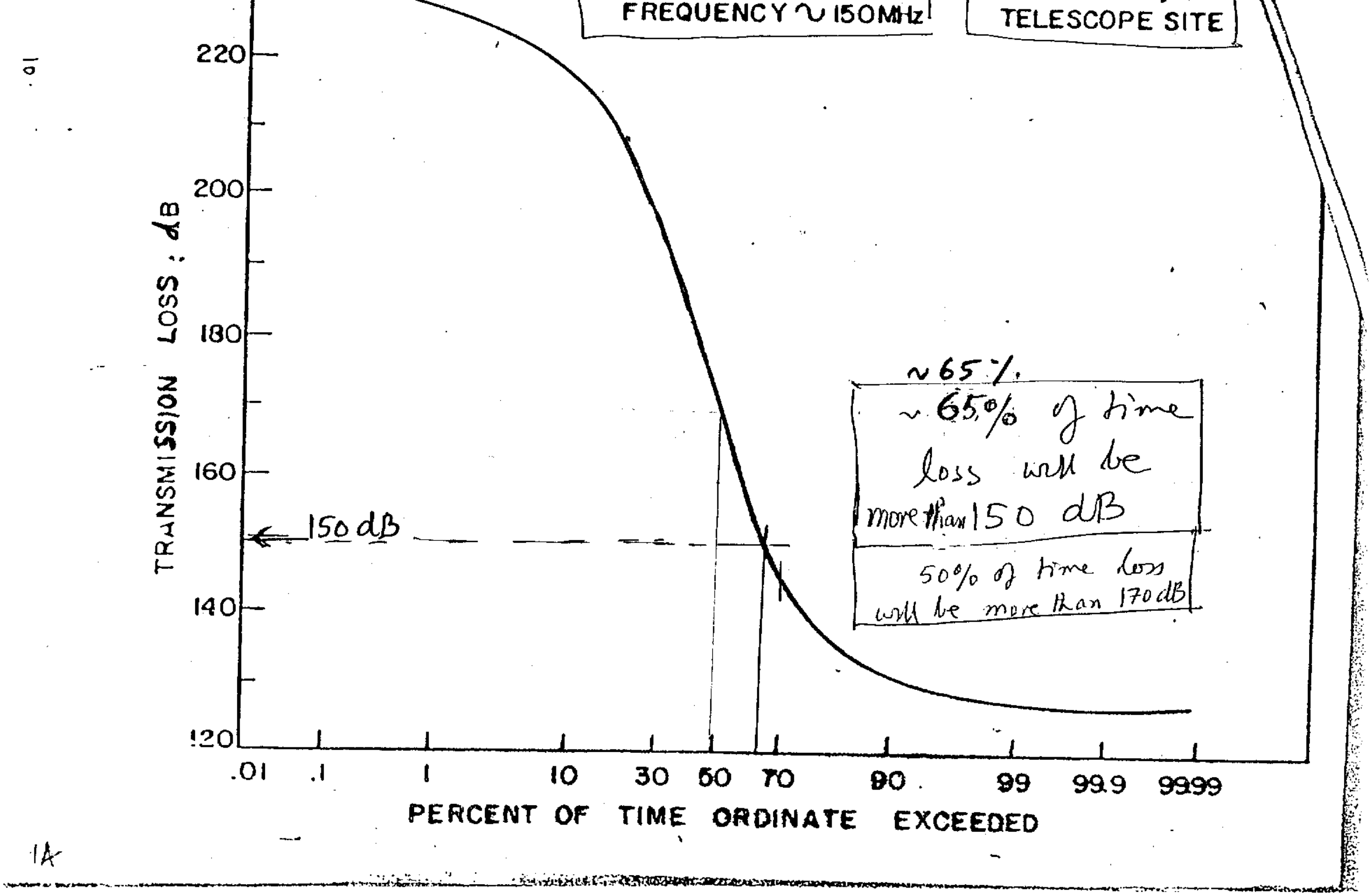


FIG. 14: The calculations of Tropo-Scatter path as shown in Fig. 13 show transmission loss by NPL. The absissa percent of time ordinate exceeded at different values of losses. For e.g. it may be noted that 65% of the time will be lost at the 150 dB between Bombay and GMRT site.

FIG. 15 : The percentage probability at Pune and GMRT site showing loss will exceed ~~will lost~~ at 150 dB for 17% of time.

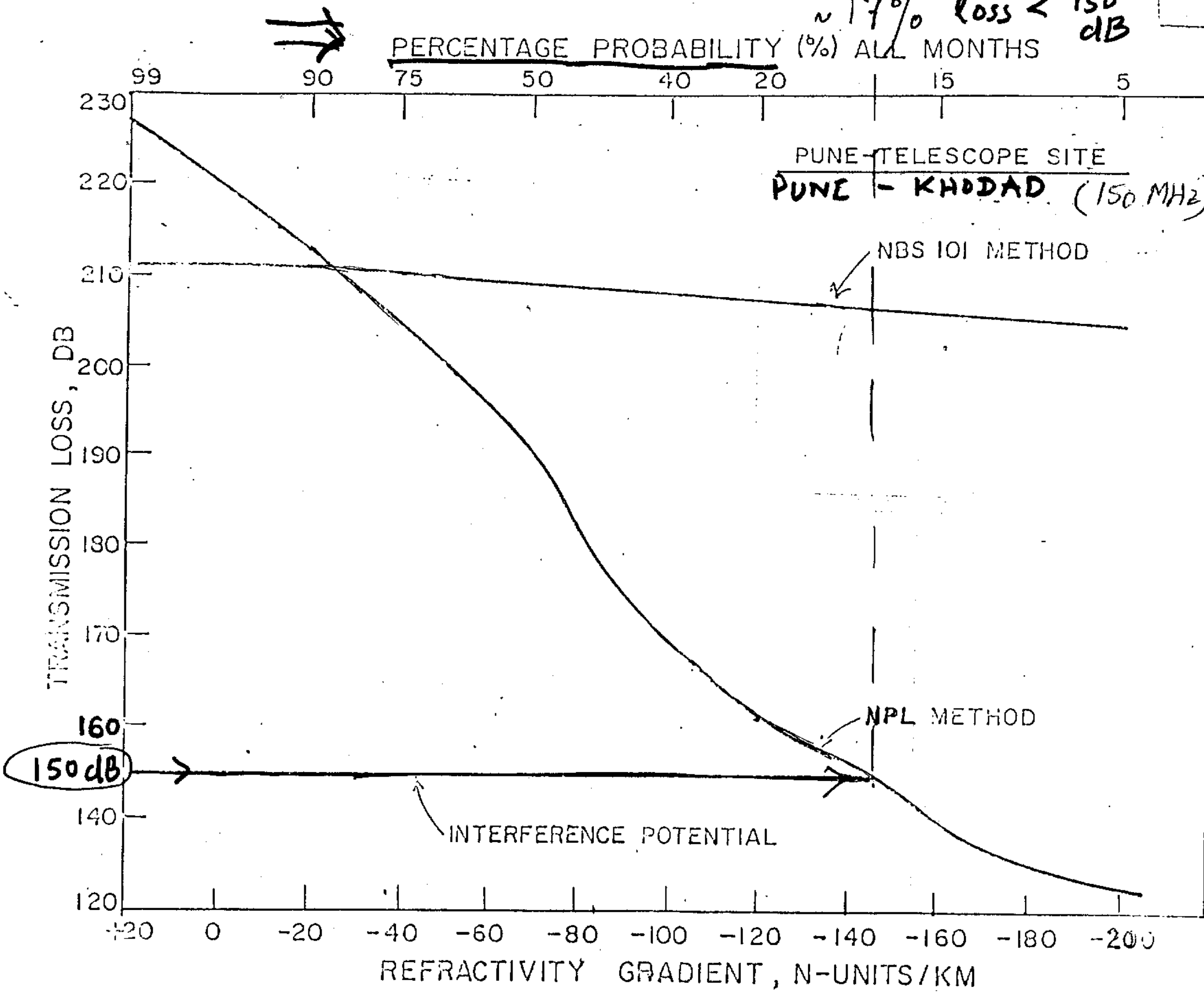


FIG. 15 : The percentage probability at Pune and GMRT site will lost at 150 dB for 17% of time.

FIG. 16 : Tropscatter loss estimated by T.L. Venkatasubramani from NBS Tech. Note 101, Vol. II (see RFI Report-Part XII)

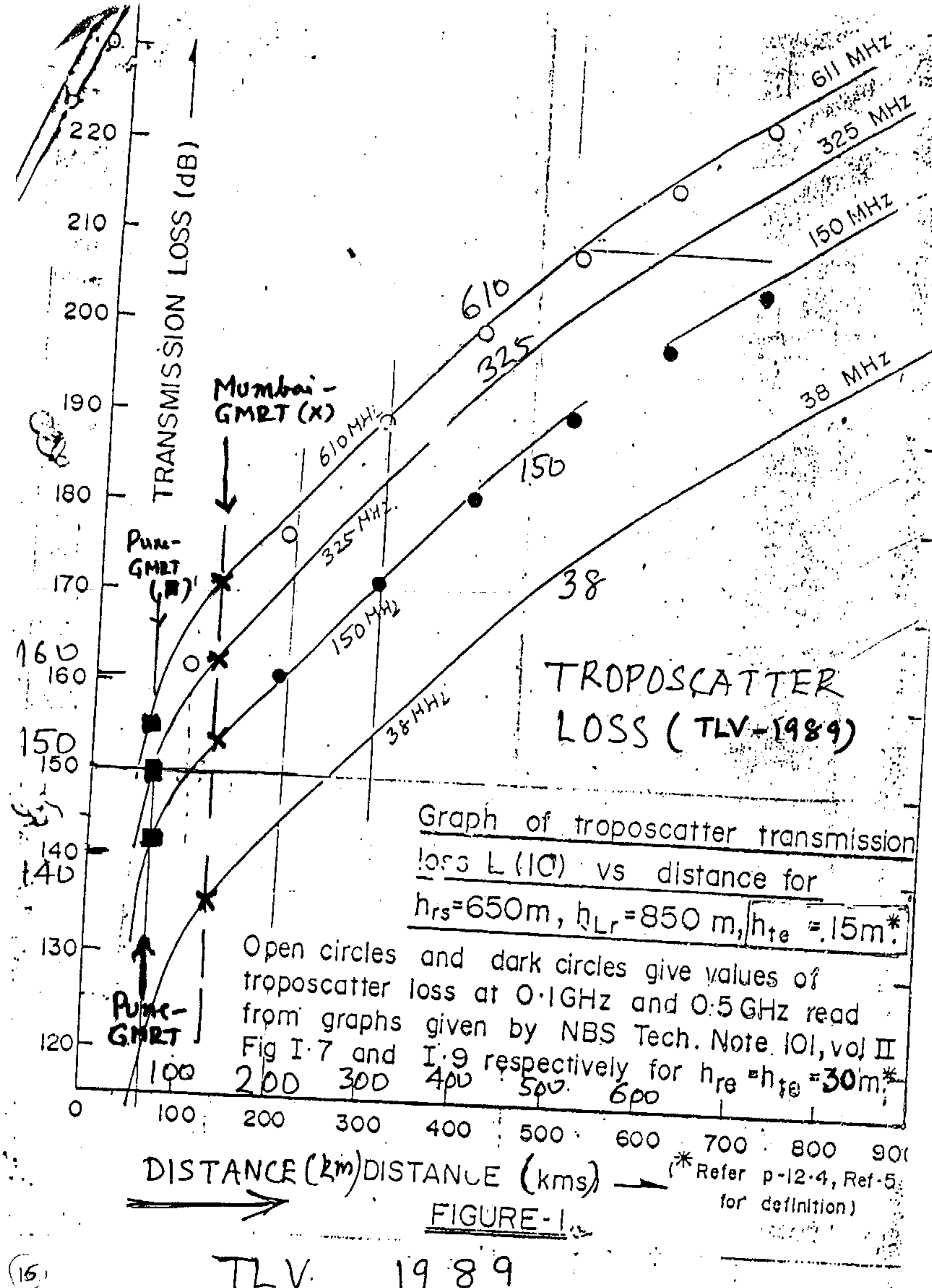


FIG. 16 : Tropscatter loss estimated by T.L. Venkatasubramani from NBS Tech. Note 101, Vol. II (see RFI Report-Part XII)

FIG. 17 : Circles given Protection Zones for GMRT on a map of Western India.

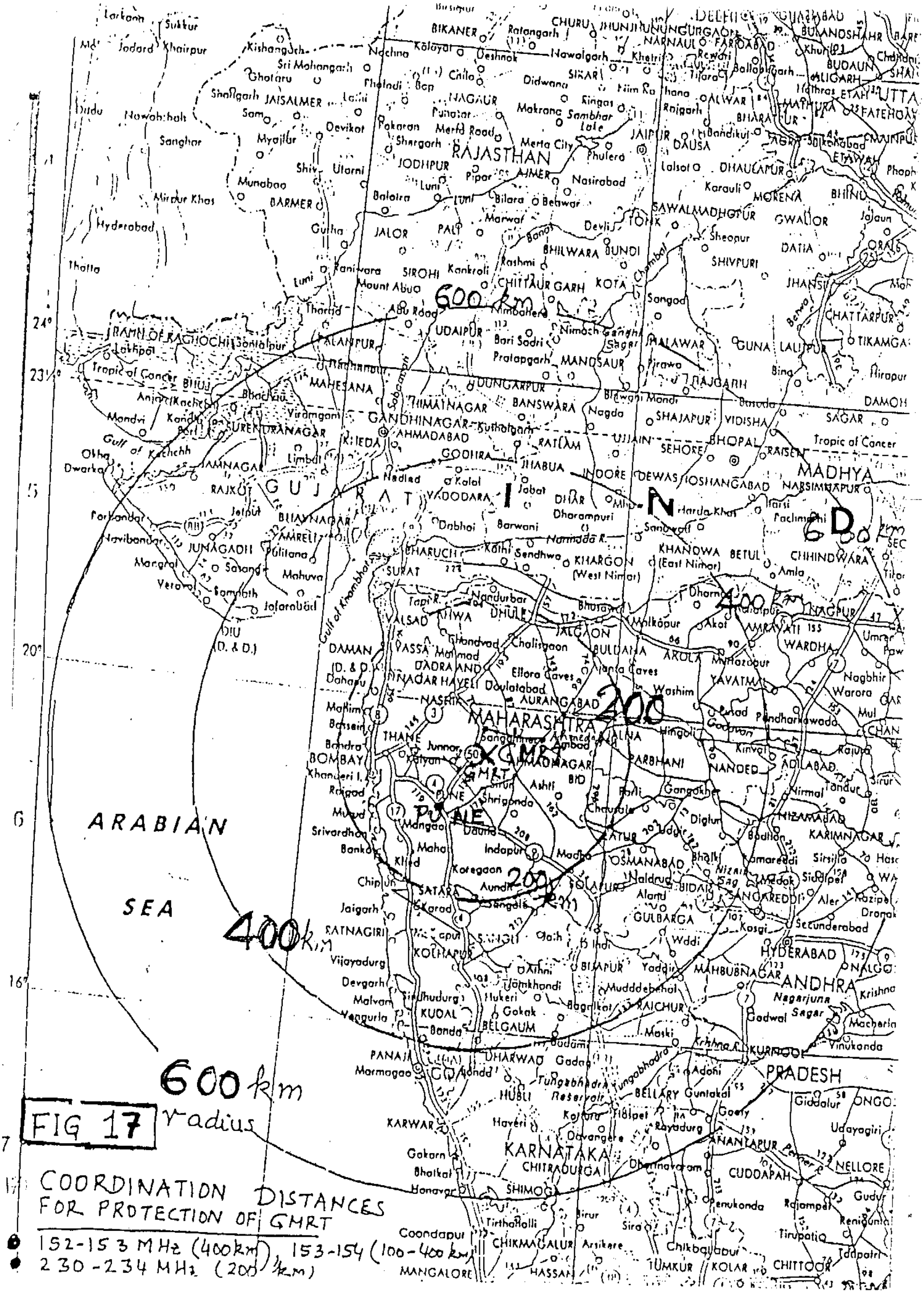


FIG. 17 : Circles given Protection Zones for GMRT on a map of Western India.

FIG. 18 :	Shows locations of sites where RFI measurements were made as given in Figs. 8 and 9.
Fig. 18 (a)	Shows locations where RFI measurements were made :
Fig. 18 (b)	Shows a sketch showing locations of the site near the Kandali Industrial Estate where RFI measurements were made.
Fig. 18 (c)	Shows location near Jambul-phata where RFI measurements were made.

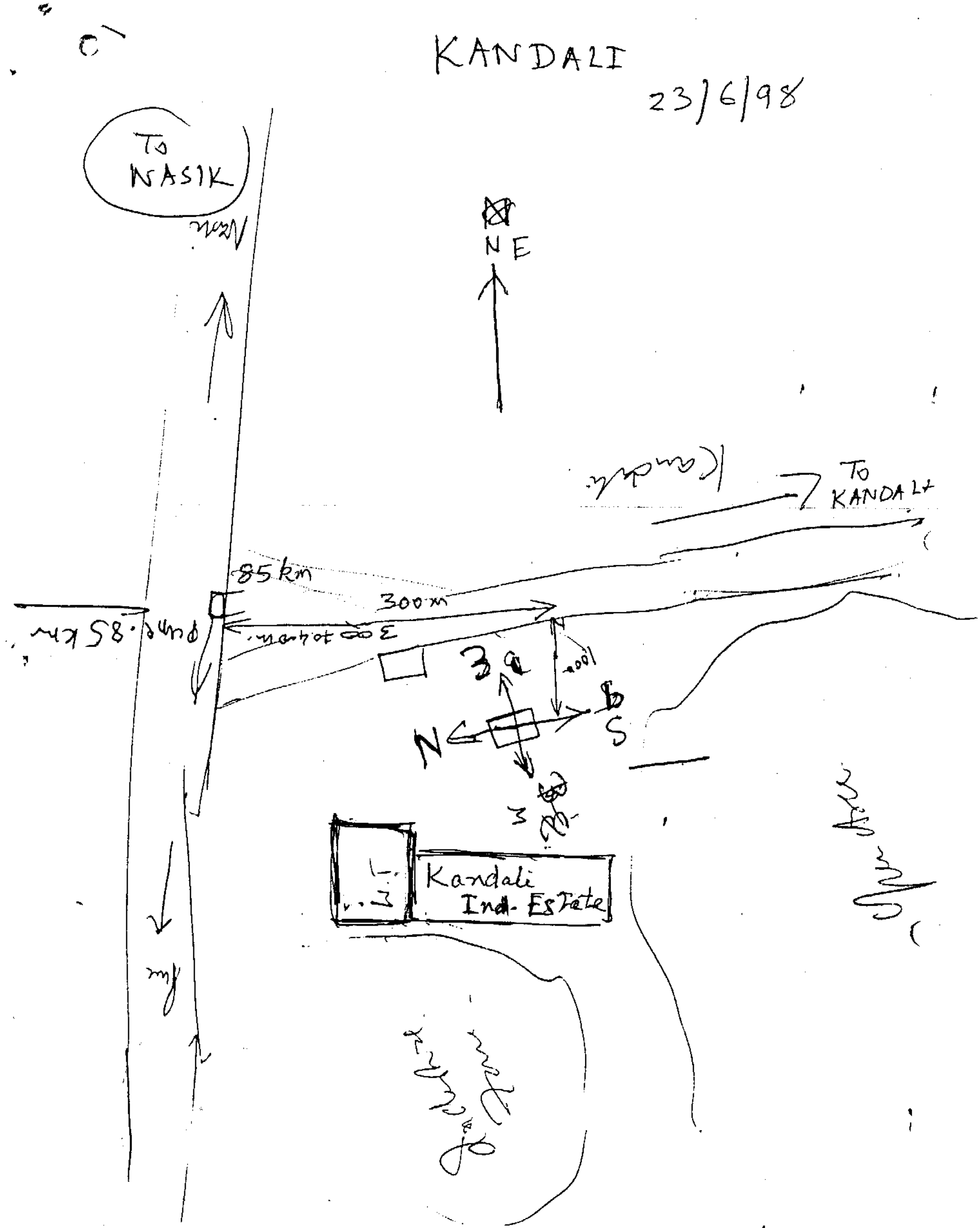


Fig. 18 (b) Shows a sketch showing locations of the site near the Kandali Industrial Estate where RFI measurements were made.

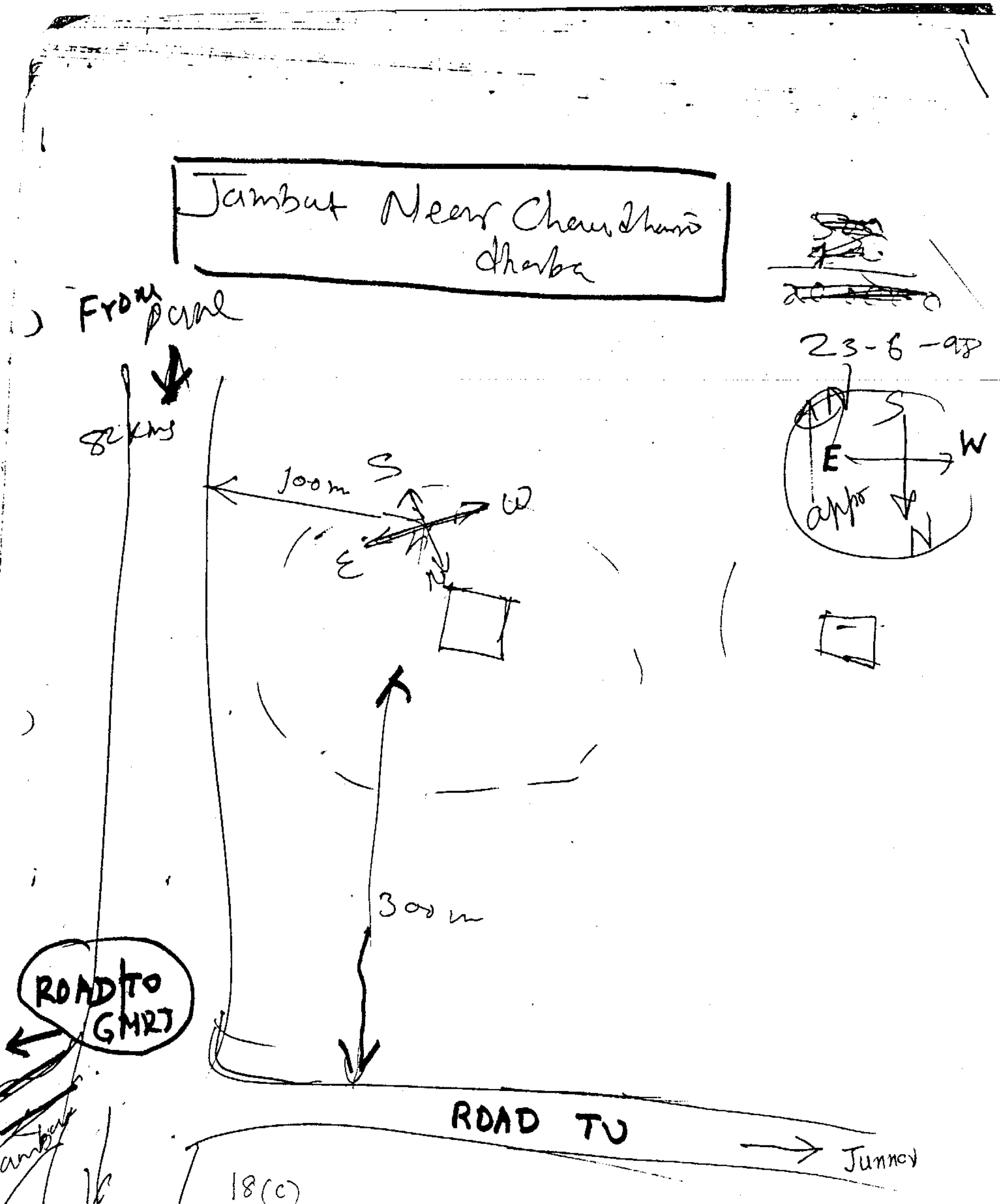


Fig. 18 (c) Shows location near Jambul-phata where RFI measurements were made.

APPENDIXES

Appendix-A : Methods used for RFI Surveys

Appendix-B : Sensitivity of a Radio Telescope

APPENDIX-A

METHODS USED FOR RFI SURVEYS

RFI surveys have been made at the GMRT site using signals received by the primary antenna feeds of 45-m dishes and also using a log periodic antenna. Various methods used are sketched in Fig. A-1. Most of the surveys made over the last few years have been made using Method-1 in which the primary antenna feeds are pointed towards the horizon. The Antenna feeds are nearly at a height of 40-m when the dish is pointed to zenith.

Surveys have also been made using a log-periodic antenna at a height of about 9-m as shown in Fig.A-2 (Method-2). Because of the lower height of only about 9-m used for placing the LPA, the sensitivity achieved may be about 10dB lower than that for the measurements made with the primary feeds of 45-m dishes pointed towards the horizon. Pulsar group have also made a survey near 150 MHz using the pulsar receiver connected to the GMRT antennas (Method-3). However, the feeds were pointed to the dish by the Pulsar group and hence their sensitivity will be about 8 dB lower. But, if they were to use 25 antennas, the sensitivity will be 5 times = 7 dB higher than for single dish. Methods 4 and 5 in which RFI measurements are made using the GMRT correlator are likely to be much more sensitive. Method 4 has been used for a few hours at 325 MHz and level of RFI seen was relatively low. In this Appendix, we discuss details of only the Methods 1 and 2 and also analysis procedure used for calculating the power flux density (dB watts/m^2) of the received signals.

METHOD-1 : SURVEY USING GMRT ANTENNA FEEDS

Using the Feed Position System (FPS); the primary feeds of the GMRT antennas are pointed towards the horizon and measurements are made at the IF in the receiver room using a HP spectrum analyzer. This is done conveniently by making the elevation of the antenna = 90° (zenith) and then pointing the required feed in a direction perpendicular to the dish (Note GTN/GS/Dec 98). Further, the antenna is rotated in Azimuth such that the feed points to either towards South (Pune), West (Mumbai), North (Nasik) or East (Ahmednagar). Feeds can also be pointed closely towards the horizon by making the elevation angle to be about 20°, and then observing with a feed which is opposite to the one pointed towards the dish. Since the 3 dB bandwidth of most of the feeds is about ± 30°, this procedure is also acceptable.

Measurements have also been made using a HP spectrum analyzer (SPA) at the base of the antenna, but I have preferred to make measurements in the Receiver Room in the central electronics building (CEB) at the out put of the monitoring point of the optical fibre system. This allows rapid measurements of RFI seen at different antennas of GMRT in the Central Array or Y-array.

In most cases, the bandwidth of the RFI signals is likely to be about few kHz for any CW spurious signals and 10 to 30 kHz for FM signals which is the method of modulation used generally at vhf and uhf range, for either voice or data transmissions. Of-course, the bandwidth of the TV signals in the frequency range of about 175 to 230 MHz is about 7 MHz. For TV, about 30 or 40% power is radiated at the video carrier frequency with a bandwidth of about 100 kHz (to be found) and 5 or 10 percent at the audio carrier. For RFI measurements, we have generally used a resolution bandwidth (RBW) of the SPA=10 or 30 kHz (in earlier meas. 100 kHz was also used), VBW about one tenth of RBW or it is set with auto value, no line trigger, sweep rate (auto) and averaging 10 or 20 times. Line trigger (50 Hz) is not used as the spectrum is affected by spark induced wide-band RFI from AC or DC power lines (see Parts VI and VII of this series). Averaging is also found quite useful for improving sensitivity and minimizing effects of power-line RFI. Longer averaging tends to decrease the measured values of RFI, if the amplitude of the received signals varies due to fading or due to variations in power of the signals (on-off). However, longer averaging, say 100 scans may give a higher s/n for steady signals such as leakages of TV cable signals or of oscillators in computer systems etc.

Analysis for Method-1 : The spectrum analyzer (SPA) measures the total power received in dBm (=Pspa) in the resolution bandwidth (RBW) used. IF the signal bandwidth is smaller than RBW, SPA will give the correct value of the power at its input. Otherwise the measured value will be smaller by the ratio Δf/RBW, where Δf is the signal bandwidth - this can be estimated from the SPA record, by making the SPAN range of only a few hundred kHz or only one or two MHz.

In order to assess the degree of RFI, we need to determine the value of the received power flux density (p.f.d.) or S in Watts/m^2. This is given by

$$S = 2\,(Pin/A)\ w.m^{-2}$$
$$= 2\,(Pspa/G_r.A)$$

where Pin is the received power at the input of the GMRT receiver , G_r is the gain of the receiver and A is the effective area of the primary antenna feed. The factor 2 in the numerator arises because GMRT feeds are circularly polarized but RFI is generally linearly polarized and hence an area of only A/2 is applicable. The value of A is given by

$$A = \lambda^2 G_a/4\pi$$

Where λ = (c/f) is the wavelength, c=velocity of light, f = frequency and G_a is the gain of the primary feed. The measured values of G_a and A for the GMRT feeds are given in Table-A1 (based on measurements by G. Sankarasubramanian for 150, 233 & 610 MHz feeds and RRI for the 21 cm feed).

Table-A1 : Effective Area of GMRT feeds

f (MHz)	λ (m)	G_a (dB)	G_a	A (m^2)	A (dB)
150	2.0	8.5	7.1	2.25	3.5
233	1.29	7.7	5.9	0.78	-1.1
325	0.92	5.4	3.5	0.23	-6.4
610	0.49	8.6	7.2	0.14	-8.5
1000	0.30	12.0	15.8	0.11	-9.6
1200	0.25	12.8	19.1	0.095	-10.2
1400	0.21	9.6	9.1	0.032	-15.0

The gain G_r of the receiver can be found by switching off the ALC at the ABR output and using Hi-CAL value of the noise generator in the RF box, for the case when measurements are made with the SPA in the Receiver Room. For measurements at the base of the antenna, one may use values of the Gain of the front ends given by the RF group or those found by characterization. Any case, it is advisable to use Noise-Generator calibration also in that case, if time permits (see Table A-6 and A-7)

However, for measurements made so far, we have not done noise generator calibration. Hence I have used the following method for calculating the values of S_H:

In that part of the spectrum, where no RFI is present which may call as base level, the power received by the SPA, P_{SBL} is given by the thermal noise of the receiver times its gain Hence,

$$P_{SBL} = G_r\ kT_s.\ RBW \qquad (1)$$

$$\text{or} \qquad G_r = P_{SBL} /(kT_s.RBW) \qquad (2)$$

Where G_r is the overall gain of the receiver upto the input of the SPA, Ts is the system temperature of the receiver including the antenna temperature for the case when the feed is pointed towards the horizon and RBW is the bandwidth of the spectrum analyzer, SPA.

The peak value of discrete signal or RFI observed in the spectral analyzer output, P_{SRFI} is the sum of the receiver thermal noise power, P_{BL}, and contributions by RFI signals, P_{RFI}.

$$P_{SRFI} = P_{RFI} + P_{SBL}$$

$$\text{Hence,} \qquad P_{RFI} = (P_{SRFI} - P_{SBL}) \qquad (3)$$

The power due to RFI at the input of the receiver is given by,

$$Pin\ (RFI) = P_{RFI} / G_r \qquad 4(a)$$

The power flux density, S_m, of the minimum sensitivity limit of the RFI survey is given by

$$S_m = 2\ P_{in}\ (RFI)/A \qquad 4(b)$$

Using equations (2), (3) and (4), we get

$$S_m = 2\ (P_{SRFI} - P_{SBL})/A\ .\ G_r$$

$$= 2\ (P_{SRFI} - P_{SBL})/(A.(P_{SBL}/kT_S.RBW))$$

$$= \{ 2\ (P_{SRFI} - P_{SBL})\ .\ (kT_S\ .\ RBW)\ \}/\{A.P_{SBL}\} \qquad (5)$$

It may be noted that for calculating the value of the term in the first bracket, we must take antilog of P_{SRFI} and P_{SBL} after dividing by 10, if measured in dBm. However, if P_{SRFI} is much greater then the base-line level, P_{SBL}, we may ignore P_{SBL} within the first bracket and hence

$$S_m\ (dBW/m^2) = \{P_{SRFI}\ (dBm) - P_{SBL}\ (dBm)\}$$

$$+ 10 \log (2\ kT_S.\ RBW/A) \qquad (6)$$

For the 150,235, 325 MHz feeds, T_S is expected to be approximately = 700, 500 and 300 K when the feeds are pointed towards the horizon (may be 2 or 3 dB higher due to the rural noise at Khodad) and A=3.5 dB, -1.1 dB and - 6.4 dB respectively, as seen from Table-A1. The Spectrum Analyzer gives the actual power of the signal if its bandwidth is less than Resolution Bandwidth (RBW) but if the signal width is longer than RBW, corresponding correction has to be made. As an example, if the weighted or equivalent width of the RFI signal is SW then S_m (corrected) = S_m x (SW/RBW).

Hence, for RBW = 10, 30 and 100 kHz, we get the following values for the log term in Equ. (6).

Values for the log term:

Table-A2 : Values of the log term : 10 log (2kTs.RBW/A)

f (MHz 1	RBW (kHz) 2	Ts (K) 3	A (m^2) 4	10 log (2kTs.RBW/A) (dBW/m^2)/10 kHz 5
150	10	700	2.25	-161
	30			-156
	100			-151
233	10	500	0.78	-158
	30			-154
	100			-158
325	10	300	0.23	-154
	30			-150
	100			-144
610	10	300	0.14	- 152
	30			- 148
	100			- 142
1000	10	300	0.11	- 151
	30			- 147
	100			- 141

Therefore, using Eq. (6), the value of the received power flux density, S_m (W/m^2) of the RFI or other discrete signals at the GMRT antenna feeds can be determined simply by adding values given in Col.5 of the above Table to the difference of the values of the RFI peak and Base Levels in dBm. If the peak value is only 3 dB higher then the Base level, the difference will be about 3 dB lower, if equation (6) is used rather than equation (5), as explained above.

METHOD-2 : RADIO SURVEYS CARRIED OUT USING A LOG-PERIODIC ANTENNA

A log-periodic antenna (LPA) with a bow-tie was used for carrying out radio surveys at the GMRT site and several other locations as discussed in Section-2 of this Report (Part-IV).

The LPA was connected to amplifiers and a HP spectrum analyzer HP 8590 L. Initially 2 x MAR-6 amplifier followed by 2 x MAR-3 amplifiers were used as per SET-A shows in Table A-3. Since this set up was subject to intermodulation products when RFI level exceeded about - 70 dBm, we later used SET-B (see Table A-4) consisting of (1xMAR6 + 2xMAR-3) plus (1xMSA 1120 + 1 x MSA 520) which did not produce significant intermodulation products for input signals of less than -55 dBm (see Table-A5).

Gain of the overall receiver system, G_{ra}, at various frequencies, including loss of cables and filters, gain of amplifiers and further dividing by the gain of the antenna are given in Table-A3 for SET A and Table A-5 for Set B. The power flux density, S_H (W/m^2) of the RFI signals at the input of the LPA is given by

$$S_m = P_{SRFI} / G_{ra} \ (W.m^{-2})$$

In the last column of Tables A3 and A4 is given values to be subtracted from the measured values of P_{SFRI} in dBm using the set ups shown therein for obtaining the values of S_m in units of dBW m^{-2}.

The measured values of S_m at various frequencies are given in Tables 1 and 2 of the main report of Part-IV.

hck/gsrfi1.doc

TABLE A-3

MEASUREMENTS MADE USING THE LOG-PERIODIC ANTENNA WITH BOW-TIE AND SET A (AMPLIFIERS CONSISTING OF (2 x MAR 6) + (2 x MAR 3).

Sr.	f (MHz)	Loss Cable	Loss filters	GAIN Amplifiers	Total Gain	Area LPA	G_{ra}	(G_{ra} + 30 dB) *
1.	50	- 2.2	0	63.0	61	12.6	73.6	103
2.	153	- 3.8	- 0.9	63.4	58.9	3.0	61.9	92
3.	232	- 4.8	- 0.8	63.1	57.5	-0.8	56.7	87
4.	325	- 5.8	- 0.5	61.8	55.5	- 0.4	55.1	85

* Values to be subtracted from the values of P_{SRFI} (dBm) measured using the spectrum analyzer in order to obtain the values of the power flux density (W m^{-2}) of the RFI signal incident at the LPA.

TABLE A-4

MEASUREMENTS MADE USING THE LOG PERIODIC ANTENNA WITH BOW-TIE AND SET-B (AMPLIFIERS CONSISTING OF 1 x MAR 6 + 2 MAR-3 + 1 x MSA 1120 + 1 x MSA 1120 + 1 x MSA 520)

Sr.	f (MHz)	Loss Cable (dB)	Loss Filter (dB)	Gain Amplifier (dB)	Total Gain (dB)	Area LPA (dB)	G_{ra} (dB)	(G_{ra} + 30 dB) *
1.	50	-2.2	0	66.1	64	12.6	76.6	107
2.	153	-3.8	- 0.9	64.8	60.1	3.0	63.1	93
3.	232	- 4.8	- 0.8	64.1	58.5	- 0.8	57.7	88
4.	325	- 5.8	- 0.5	63.2	56.9	- 0.4	56.5	87

* Values to be subtracted from the values of P_{SRFI} (dBm)measured using the spectrum analyzer in order to obtain the values of the power flux density($W.m^{-2}$) of the RFI signal incident at the input of LPA.

TABLE A-5

Results : (1) No 3rd order Intermodulation for 2 input signals ≥ < −55 dBm and output less than 5.8 dBm

(2) For two input signals ≥ −50 dBm (output 10.7 dBm) 3rd order IM = −41 dB

(3) For 2 input signals ≥ −45 dBm [output = +15] 3rd order IM = −24

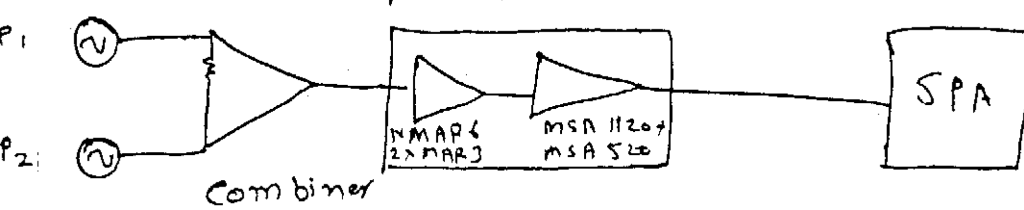
51 dBm

5.6.98 / SNS

To See Intermodulation Product of Amplifier. Pune:-

AMP. SET-B | 1x MAR6 + 2MAR3 + MSA 1120 + MSA 520

SET B



Power Input f_1, f_2	dBm output f_1, f_2	3rd ord. f_3, f_4	Ratio $P_{out}(f_3)/P_{out}(f_2)$
−55	+5.8	< −80	−85 dB
−50	+10.7	−41	−52
−45	+15	−24	−39

Signal Generator + Power combiner + Amplifier + SPA . AV = 10

Signal Generator INPUT →			← OUTPUT AT f_1 & f_2 (Spectrum Analyser)				3rd order intermod		3rd order	
P_1 dBm	f_2 MHz	P_2 dBm	f_1 MHz	P_1 dBm	f_2 MHz	P_2 dBm	f_3 MHz $(2f_1 - f_2)$	P_3 dBm	f_4 MHz $(2f_2 - f_1)$	P_4 dBm
−80	160	−80	155	−19.9	160	−19.0	–	–	–	–
−70	"	−70	155	−9.04	"	−9.05	–	–	–	–
−65	"	−65	"	−4.07	"	−4.12	–	–	–	–
−60	"	−60	"	+0.94	"	+0.82	< −80	< −80	< −80	< −80
−55	"	−55	"	+5.91	"	+5.74	< −80	< −80	< −80	< −80
−50	"	−50	"	+10.78	"	+10.71	150 MHz	−41.19	165.13	−40
−45	"	−45	"	+15.59	"	+14.44	−"−	−24.37	−"−	−23

GAIN = 61 dB

Table A-6 GMRT

SYSTEM TEMPERATURES

Sr. No.	Frequency band [MHz]	Input cable loss L' [dB]	Polarizer Loss L [dB]	LNA temp. T_{LNA}' [K]	Receiver Temp. (Includes cable losses) T_R [K]	Ground Temp. T_{Gnd} [K]	Sky Temp. T_{Sky} [K]	System Temp. T_{Sys} [K]	Bandwidth [MHz]
1	50	1.33[1]	0.80	895	1651	19	6500	8170	40
2	150	0.2	0.75[2]	150	260	12	308	580	40
3	235	0.55[3]	0.25	35	103	32	99	234	40
4	327	0.13	0.18	30	55	13	40	108	40
5	610	0.22[4]	0.15	30	59	32	10	101	40
6	1060	0.22[5]	—	35	53	25	5	83	120
7	1170	0.22[5]	—	32	49	24	4	77	120
8	1280	0.22[5]	—	30	47	23	4	74	120
9	1390	0.22[5]	—	28	45	23	4	72	120

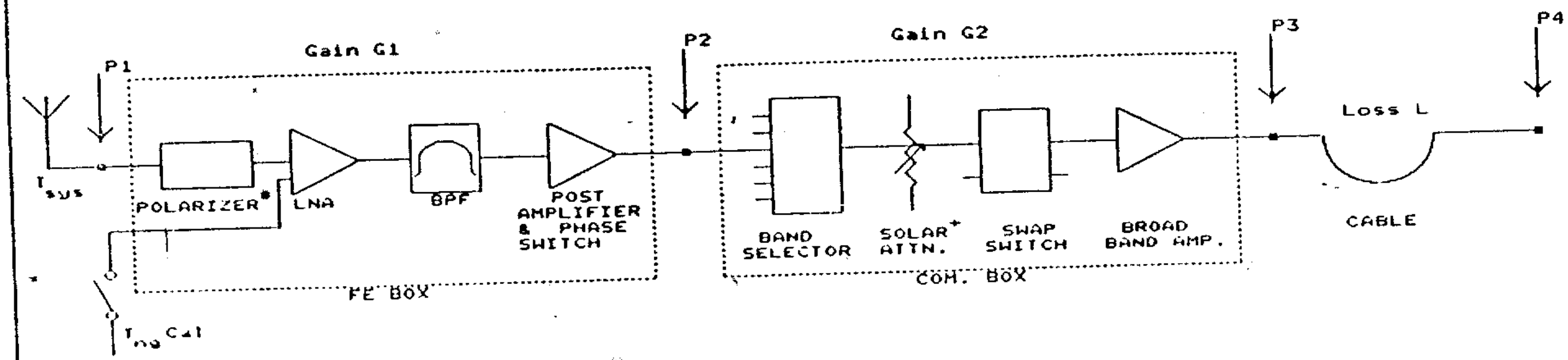
1 12 m of RG223 cable (estimated)
2 Includes 2-1 combiner insertion loss
3 Insertion loss of Balun & associated cbles.
4 Insertion loss of Balun & 20 cm 0.141" semirigid cable from Balun to Probe.
5 Contains loss of OMT & OMT to LNA input cable.

$$T_R = 10^{((L+L')/10)} T_{LNA} + [10^{((L+L')/10)} - 1] T \qquad T_0 = 300 \text{ K}$$

$$T_{Sys} = T_R + T_{Gnd} + T_{Sky}$$

APK/GSS/Srini/05/94

Table A7: LEVEL DIAGRAM [32 MHz BANDWIDTH]



Freq. Band [MHz]	T_{sys} [K]	P1 [dBm]	G1 [dB]	P2 [dBm]	G2* [dB]	P3 [dBm]	L [dB]	P4 [dBm]
150	580	-96	34	-62	28	-34	8	-42
233	234	-100	37	-63	27	-36	9	-45
327	108	-103	38	-65	27	-38	11	-49
610	101	-104	35	-69	26	-43	15	-58
1060	83	-104	50	-54	25	-29	22	-51
1170	77	-105	49	-56	24	-32	23	-55
1280	74	-105	49	-56	23	-33	24	-57
1390	72	-105	47	-58	23	-35	26	-61

Freq. Band [MHz]	T_{ng} Cal. steps [°K]			
	Extra Hi Cal	High Cal.	Medium Cal.	Low Cal.
150	800	400	80	40
233	800	200	80	20
327	400	100	40	10
610	400	100	40	10
1060	760	190	76	19
1170	720	180	72	18
1280	640	160	64	16
1390	600	150	60	15

'+' Solar attenuator setting: 0dB, 14dB, 30dB or 4[illegible]dB.

'*' For 0dB solar attenuator setting.

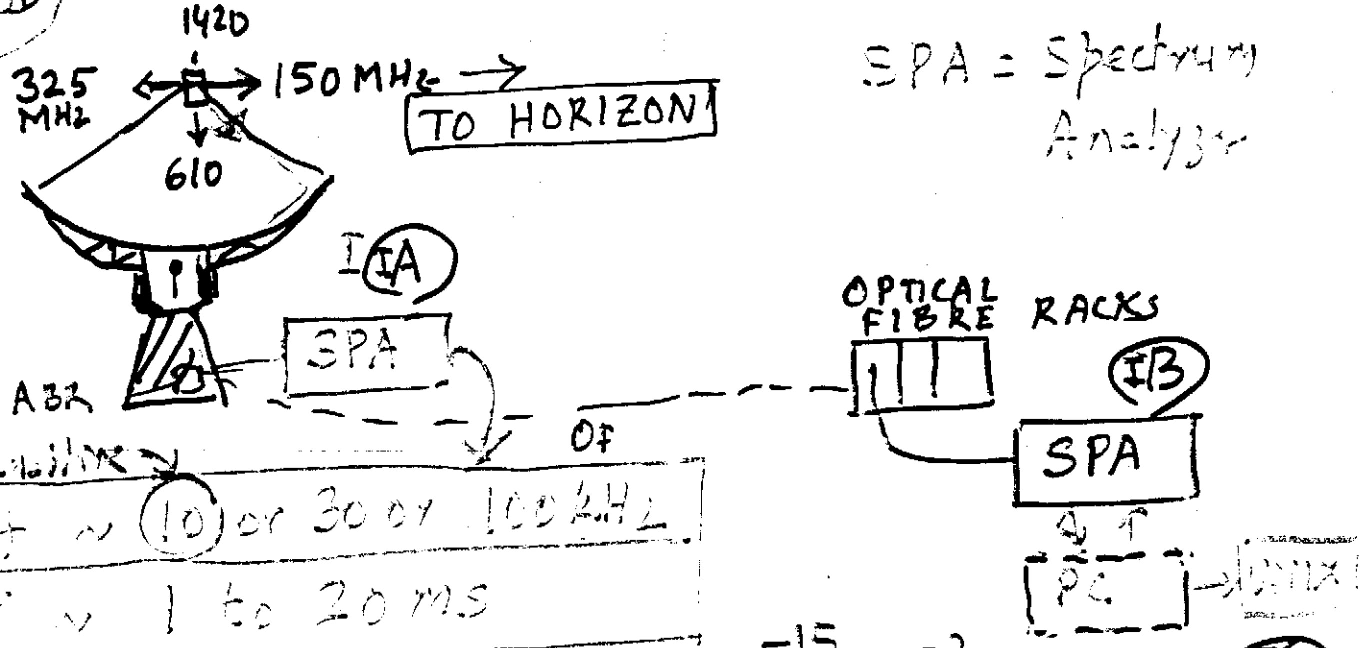
'*' The polarizer is incorporated after the LNA in the L-Band (1000 - 1450 MHz) receiver.

TIFR NCRA INDIA	GIANT METERWAVE RADIOTELESCOPE PROJECT		
	Title: FRONT END SYSTEM POWER LEVEL DIAGRAM		
	Size: A	Document Number	REV 7
Prep: Srinivas M.			
Aprvd: A.Praveen Kumar	Date: August 8, 1995	Sheet of	

RFI SURVEYS

METHOD I

SPA = Spectrum Analyzer



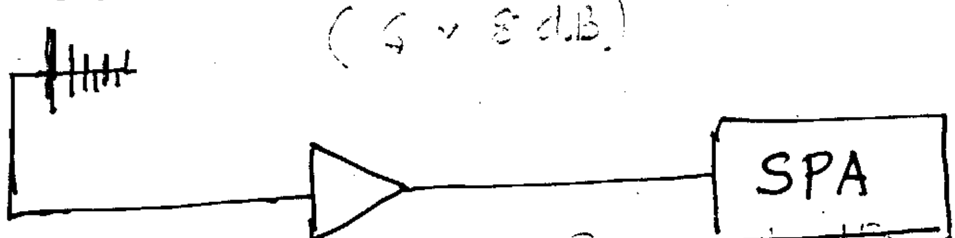
$\Delta f \sim 10$ or 30 or 100 kHz

$\tau \sim 1$ to 20 ms

SPA gives MIN. DETECTABLE RFI $\sim 10^{-15}$ W m^{-2}

METHOD II

LOG-PERIODIC ARRAY (LPA)
(G ~ 8 dB)



METHOD III

PULSAR RECEIVER

USED SO FAR

$\Delta f \sim 64$ kHz
$\tau \sim 4$ s

8 or 4 ant added incoherently

FUTURE

25 Ant, $\Delta f = 16$ or 32 kHz
$\tau \sim 100$ s

METHOD IV

2-ANT INTERFEROMETER × 4 different directions

METHOD V All interferometers to determine DIRECTION

APPENDIX - B

2. SENSITIVITY OF A RADIO TELESCOPE

As shown below, the sensitivity of a radio telescope is extremely high compared to that of a communication receiver, by more than 50 dB. A radio astronomer measures the difference between the received noise power for the cases when the antenna is pointed towards a celestial source and when it is pointed away from the source. Therefore, the sensitivity of a radio telescope is dependent upon the root mean square (rms) fluctuations of the receiver noise. The rms value, ΔP_{rms}, of the receiver noise power is given by

$$= kTs\ \Delta f / \Delta t . \Delta f)^{1/2} \qquad (1)$$

where T_s is the system temperature, Δt is the integration time and Δf is the bandwidth of the receiver.

As per ITU RA-769.1, the harmful level, $\Delta P'H$, is taken as 10% of the receiver rms fluctuations. Hence,

$$\Delta p'_H = 0.1\ \Delta p_{rms} \text{ Watts} \qquad (2)$$

The relation between the receiver noise power, Δp_H, and the Power flux density (p.f.d.) of the harmful radiation, ΔS_H at the input of a radio telescope.

$$\Delta p'_H = (\Delta p'_H / A) \quad W.m^{-2}$$
$$= (4\pi/\lambda^2 G)\ \Delta p'_H \qquad (3)$$

Where A is the collecting area of the antenna, G is its gain and λ is the mean wavelength of the receiver passband.

Hence, from (2) to (3), we get

$$\Delta p_H = \frac{0.4\pi}{\lambda^2 G} \cdot \frac{kTs\ \Delta f}{(\Delta t\ \Delta f)^{1/2}} \quad W.m^{-2} \qquad (4)$$

OR

$$\Delta p_H = \frac{0.4\,\pi f^2}{c^2 G} \; \frac{kTs\ \Delta f}{(\Delta t\ \Delta f)^{1/2}} \quad W.m^{-2}\,Hz^{-1} \qquad (5)$$

The spectral power flux density is given by ($\Delta p_H/\Delta f$).

Where f is the mean frequency of the receiver passband, c is the velocity of light.

For calculating the RFI levels, ITU-R RA769.1 recommends that the gain G of the antenna may be taken as unity, corresponding to expected level of the distant sidelobes of a parabolic dish, Δf = allocated bandwidth and Δt = 2000 seconds (although radio astronomers integrate upto tens of hours).

Values of Δp_H, ΔS_H and ΔS_H are given in Tables 1 and 2 of RA 769.1 for continuum and spectral line radio astronomical observations. These Tables also give applicable values of receiver temperature and bandwidth for continuum and spectral observations at various frequencies.

At microwave frequencies, the gain of distant sidelobes of a large parabolic dish antenna may be much lower than 1. However, one should take the gain of side lobes 10 or 15 Deg, away from the main lobe because the antenna is often pointed close to the horizon, whence the gain of the sidelobe level will correspond to that only 15° away from the main lobe and will be higher than unity. Therefore G=1 seems to be a good compromise for calculating the harmful level.

For GMRT, gain of sidelobes may be higher than 1, particularly at 21 cm, since the 45-m dishes are made of about 900 plane facets and also rms errors of the wire mesh surface exceeds 1 cm. This aspect may be kept in mind in frequency coordination for GMRT.

For the GMRT interferometer system, the harmful level is about 10 to 20 dB lower than given in Tables 1 and 2 of ITU-R RA 769.1 because the response of the interferometeric array gets averaged, for a RFI source, whilst the fringes are stopped for the celestial sources being tracked. If there are n fringes, the effect of RFI gets decreased approximately as $n^{1/2}$ where n is the no of observed fringes for a given baseline in the integration time Δt (Thompson Moran and Swenson, 1994). At longer wavelengths, such as the 150 MHz and for the central array, the effects of RFI will get decreased by only about 7 or 8 dB. Similar is the case for satellites as has been estimated by ______

However, GMRT is also to be used quite frequently as phased array of N antennas. In this case, the harmful level will be about $(N)^{1/2}$ higher than that, if observations are made only for a single dish of GMRT, because the output of the phased array for the celestial radio source will be N times higher but phased array output for the RFI signal will increase by only $N^{1/2}$ on an average because RFI signal will have different phases for different antennas. Thus, the phased array will be less sensitive to RFI than the single dish. Same will hold for interferometric observations.

As can be seen from Table-1 of ITU RA 769.1, the harmful level of radiation from continuum observations is about -190 dBW/m^2 at 150, 325 and 610 MHz. The receiver noise power ($kT\Delta f$) of a radio communication receiver at 150 MHz lies in the range 10^{-14} to 10^{-15} W depending upon its noise temperature T and bandwidth Δf. Hence, it becomes desirable that the p.f.d. of the received communication signal is more than 10^{-13} W/m^2 for a satisfactory operation of the radio service. Thus, it is seen that the sensitivity of a radio telescope is about 60 dB higher than that of a radio communication service. It is therefore important that no transmitters are located in the R.A. band at distances exceeding 400 to 600 km depending upon the transmitter power of the communication service.