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Measurements of RFI from the SOWRBALL Aerostat

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1 Introduction

The US Treasury Department is currently installing a line of aerostats (balloon mounted radars) along the southern border of the US and in the Caribbean to intercept airborne drug traffic. The radars operate just below the 1.35-1.75 GHz receiver band and are potentially a strong source of radio frequency interference (RFI) for several NRAO telescopes. Of particular concern are the Yuma and Fort Huachuca aerostats at VLBA-Kitt Peak, the Deming aerostat at the VLA, the Marfa aerostat at VLBA-Fort Davis and the Puerto Rico aerostat at VLBA-St. Croix. Here we report measurements made on 3/8/89 and 3/9/89 with the VLBA Kitt Peak telescope of the RFI from the Fort Huachuca aerostat. This radar is known as SOWRBALL (Southwest radar balloon). The measurements were made by J.Oty, D.Ross, P.Rhodes and P.Napier. The spectrum analyser and computer system used to make the measurements are described by Oty (1989). Note that throughout the measurements reported here the peak detector in the spectrum analyser was turned on so all power levels reported correspond to peak powers present during the pulse-on part of the radar 2.7 ms pulse repetition period. Measurements of SOWRBALL signals were made only at and above 1310 MHz, the assumption being that the effect of the 1250 MHz signal will be negligible because of its distance from the edge of the VLBA observing band. All measurements were made with a spectrum analyser bandwidth of 3 MHz.

2 System Parameters for SOWRBALL

The main parameters of SOWRBALL necessary for an understanding of its RFI threat to the VLBA are as follows:

Primary radiating frequencies: 1250 and 1310 MHz
Peak power: 34 kw (25 kw = 44.0 dBW during these tests)
Pulse width: 51μsec at 1250 MHz followed by 48μsec at 1310 MHz
Pulse repetition rate: 375 Hz
Antenna gain: 34 dBi
Antenna azimuth beamwidth: 2.15°
Antenna elevation beamwidth: 4.0°
Antenna polarization: vertical
Antenna rotation period: 12 sec
Distance from VLBA Site to balloon: 135 km
Elevation of balloon from VLBA: 0.7°
Azimuth of balloon from VLBA: 112°

3 Field Strength Measurements at 1310 MHz

The field strength at 1.31GHz due to the aerostat was measured with a standard gain horn (gain 13 dBi, -10.8 dBm^2 effective area at 1.31 GHz) at the NRAO 12m telescope site on Kitt Peak. From this location there is a direct, unobstructed line of sight to the balloon. At the time of the measurement the aerostat operator stated that the transmitter was operating at a reduced power level of 25 kw due to transmitter problems. The results are shown in Figure 1 at which time the transmitter was blanked when the main beam of the SOWRBALL antenna was pointed in the direction of Kitt Peak. Figure 1 shows the radiation pattern of SOWRBALL repeating at the rotation period (12 sec) of the radar antenna. The signal falls to zero at the location of the main beam due to the blanking. The large sidelobes at approximately 3 sec (90°) either side of the main beam location are probably due to spillover of power from the SOWRBALL feed past the SOWRBALL reflector. Figure 1 shows that with blanking activated the maximum power out of the standard gain horn is -77 dBW. Using the ratio of main beam power to sidelobe power derived from later measurements in which blanking was turned off (see for example Figure 3) one can predict from Figure 1 that on the main beam of SOWRBALL the power received by the standard gain horn would be -50 dBW. Thus the power flux at the 12m site on the SOWRBALL main beam is -50 dBW - (-10.8 dBm^2) = -39.2 dBWm^{-2}.The power flux expected from SOWRBALL on a line of sight path at a distance of 135 km is 44 dBW + 34 dBi - 113.6 dBm^2 = -35.6 dBWm^{-2}. Thus the measured and predicted values for flux density agree within 3.6 dB which is reasonable considering possible errors in power measurement (±1 dB), standard horn gain (±1 dB) and tolerances on SOWRBALL system parameters.

The field strength from SOWRBALL was next measured at the Kitt Peak VLBA site. Fortunately at this location some local terrain shielding is provided by the ridge line to the east of the antenna which is about 200m away and subtends an horizon angle of +2.5° from ground level and -1.0° from the antenna elevation axis. In addition a large rock outcrop about 7m high and 15m wide sits on top of the ridge within 1° of the azimuth of SOWRBALL. The top of the outcrop subtends an horizon angle of +5.5°, +1.2° and -1.5° respectively from ground level, the elevation axis and the edge of the reflector when pointing at the zenith. From this data it would be expected that about half the aperture is blocked from SOWRBALL signals with the antenna at low elevation angles but this shielding becomes small at the zenith. At the elevation axis of the antenna the peak power flux measured with the standard gain horn with blanking off was -43.2 dBWm^{-2}. This is -4 dB compared to the flux at the 12m site, the reduction presumably being due to blockage and diffraction from the ridge and rock outcrop.

4 Power Levels Received by the VLBA Antenna at 1310 MHz

The power received from SOWRBALL by the VLBA antenna was measured at the output of the cryogenically cooled amplifier at point A in the receiver block diagram shown in Figure 2. The results of the measurement, with the antenna pointed at the zenith and blanking turned off, are shown in Figure 3. From Figure 3 peak received power out of the dewar was -50 dBW. Taking 32 dB as the gain in the dewar gives -82 dBW for power at the feed output and amplifier input. Using the measured SOWRBALL flux of -43.2 dBWm^{-2} the expected power received by an isotropic antenna (effective area -23.8 dBm^2) is -70 dBW, where a -3 dB loss is included because the VLBA feed is circularly polarized and SOWRBALL is linearly polarized. The sidelobe level of the VLBA antenna in the direction of SOWRBALL, with the antenna pointing at the zenith, is therefore inferred to be -82 dBW + 70 dBW = -12 dBi.

(Note that if the higher SOWRBALL flux of -39.2 dBWm^{-2} is used the estimated sidelobe level becomes -16 dBi.) Far-out sidelobe levels of this magnitude are quite plausible for large antennas. To determine the variability of the far-out reception pattern, the VLBA antenna was kept pointing at the zenith and the power received from SOWRBALL was monitored as a function of antenna azimuth. The results of this measurement are shown in Figure 4. As expected the signal fluctuates considerably as azimuth is varied as peaks and nulls of the VLBA far-out sidelobe pattern move across the aerostat. Assuming an incident flux from SOWRBALL of -43.2 dBWm^{-2}, derived in Section 3 above, Figure 4 also shows VLBA sidelobe level in dBi. These sidelobe levels are quite plausible for the far-out sidelobes of a large reflector antenna.

The power received from SOWRBALL was next measured as a function of the elevation angle of the VLBA antenna. The antenna was positioned to the azimuth of the aerostat and then tipped in elevation in 5° steps while monitoring received power at the output of the cryogenic amplifier. The results are shown in Figure 5 where power levels are referred to the receiver input. The measurements were made with SOWRBALL blanking turned off. At the lowest elevation angle, 2.2°, the cryogenic amplifier was severely compressed on the SOWRBALL main beam, as shown in Figure 6 where compression has reduced the apparent main-beam to sidelobe ratio by 15 dB compared to Figure 3. In this case the received power had to be estimated from a measurement on a SOWRBALL sidelobe. Figure 5 also shows the received power expected if SOWRBALL blanking is activated, using the 27 dB difference between blanking on and blanking off determined in section 3 above. Also shown in Figure 5 is an estimate of the envelope of the peak sidelobes as a function of distance from the VLBA main beam. This estimate was made simply by drawing a line by eye through the highest measured points. Figure 7 shows a theoretical prediction of these sidelobes out to 10° including both the effects of main reflector diffraction and feed spillover past the subreflector. There is reasonable agreement between Figures 5 and 7, both indicating about +10 dBi gain at 10° off boresite.

5 The Spectrum of SOWRBALL

The spectrum of SOWRBALL was obtained by measuring the power at the output of the cryogenic amplifier as a function of frequency with SOWRBALL blanking turned off and the antenna tipped towards SOWRBALL at an elevation angle of 10°. This angle was chosen so as to give as much gain as possible in the direction of Swrball without compressing the cooled amplifier with the 1310 MHz signal. The spectrum analyser predetection bandwidth was 3MHz. Measurements at particular frequencies are shown in Figures 8 and 9. Note that at frequencies above 1310 MHz another radar, with an antenna rotation period of 10 sec becomes evident. The SOWRBALL results are summarised in Figure 10 where they are superimposed on a theoretical prediction of the SOWRBALL spectrum provided by the SOWRBALL Project Office. The measurements in Figure 10 were plotted normalised with respect to the 1310 MHz measurement assuming that the gain of the VLBA antenna at 10° below the main beam is constant over the frequency range. This is a reasonable assumption because, as shown in Figure 7, the radiation pattern in this region is dominated by feed spillover. Note that Figure 10 appears to indicate that the SOWRBALL out-of-band transmissions do not decrease as rapidly as expected above 1330 MHz. From these measurements it is not possible to say if this is caused by the SOWRBALL transmitter or by frequency dependent propagation effects resulting from the partial terrain shielding described in section 3.

6 Effect of SOWRBALL on the VLBA

Two aspects of SOWRBALL RFI are of concern. The first is the possibility that the signal at 1310 MHz, which is outside the nominal VLBA receiving band, will be strong enough to compress the receiving electronics. The second is the possibility that signals radiated by SOWRBALL at frequencies above the nominal SOWRBALL transmission band, but within the VLBA receiving band, will degrade the sensitivity of VLBA astronomical observations.

6.1 Possibility of Receiver Compression

Recent tests on HEMT amplifiers show that they can withstand input powers as high as -20 dBW before they burn out. Figure 5 shows that SOWRBALL cannot produce this signal level so receiver burn out is not a concern.

From Figure 2 the 1 dB compression points for the cryogenic amplifier and the last amplifier in the IF chain, expressed as power level at the output of the feed horn, are -66 dBW and -97 dBW respectively. Figure 5 shows that the cryogenic amplifier will never compress if SOWRBALL blanking is active and will only compress when blanking is turned off if the VLBA antenna is pointing within 20° of the aerostat. The normal mode of operation of SOWRBALL is with blanking active. Therefore, it is reasonable to locate a filter to prevent compression of amplifiers further down the receiver chain after the cryogenic amplifier where it will have minimum impact on receiver sensitivity. From Figure 5, with blanking on, the maximum power received from SOWRBALL with the antenna at 2.5° elevation (the eastern horizon) is -75 dBW. Therefore, to prevent compression occuring in the last IF amplifier a high pass filter at the output of the cryogenic amplifier should have an attenuation of at least 75 dBW - 97 dBW = -22 dB at 1310 MHz. Allowing a 10dB margin below the 1 dB compression point requires a filter attenuation of -32dB at 1.31 GHz. This 10dB margin, as well as assuring that non-linearity due to gain compression is negligible, accounts for the fact that during these tests SOWRBALL transmitted power was 1.3 dB below the normal operating level.

On occasions it has been necessary to call the SOWRBALL site manager (Ph 602 3783011) to remind him to activate blanking. Since compression can occur in the cryo-amplifier if blanking is turned off, it is important that NRAO provide sufficient "policing" of the blanking to ensure that it is reliably activated.

6.2 Effect on Sensitivity

From Figure 10 the peak power received from SOWRBALL at 1350 MHz, the bottom of the VLBA observing band, is -76 dB with respect to the signal at 1310 MHz. Therefore, the signal received in 3 MHz bandwidth at 1350 MHz when the antenna is pointing at 2.5° elevation in the direction of SOWRBALL when blanking is on is -75 dBW -76 dB = -151 dBW. This level becomes -149.7 dBW when the SOWRBALL transmitter is producing normal operating power. 3 MHz is a typical baseband bandwidth for redshifted hydrogen observations and the receiver power in this bandwidth (kTB) is -148 dBW. Thus the SOWRBALL signal is 68% of the system temperature, which is well above the goal of keeping RFI less than 1% of the system temperature. However, there are at least 3 factors which significantly reduce the seriousness of this problem. First, the problem only exists over a very small region of the sky. If an area of the sky 5° in radius around SOWRBALL (less than 0.2% of the sky) is excluded then the SOWRBALL signal is never more than 7% of the system temperature. Second, as shown by Figure 1, signals of this magnitude are only present for about 10% of the time as the SOWRBALL radiation pattern rotates around. Third, the

1310 MHz signal is only on for 2% of the pulse repetition period. These considerations lead to the conclusion that the SOWRBALL's signals in the VLBA observing band should not cause significant loss of sensitivity.

7 Conclusions

The conclusion to be drawn from these tests is that RFI from SOWRBALL should not significantly effect VLBA observations down to frequencies as low as 1350 MHz provided that:

1. The SOWRBALL signal is blanked whenever the SOWRBALL antenna gain in the direction of Kitt Peak is greater than -27 dB of the peak main beam gain (ie. above +7dBi). This was the blanking in effect during these tests.
2. A high pass filter is installed at the VLBA L band dewar output with an attenuation at 1310 MHz of at least -32 dB. The filter should have less than 1 dB of loss at 1350 MHz.

8 References

Oty,J., 1989, An Overview of the RFI Monitoring System, VLBA Memo 643.

Figure 1

Power received by standard gain horn. f = 1.31 GHz, Δf = 3Mhz, 12 m site.

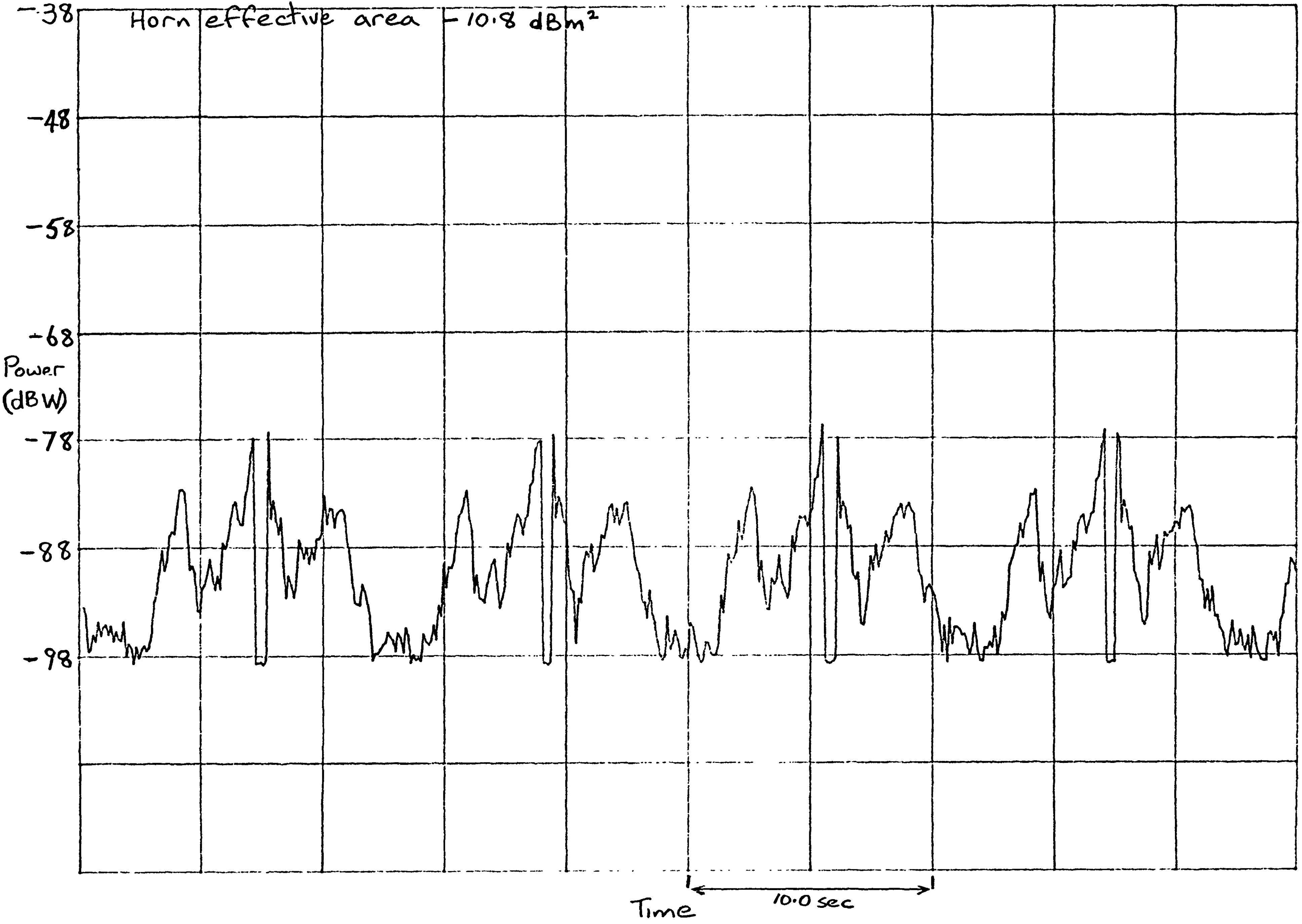
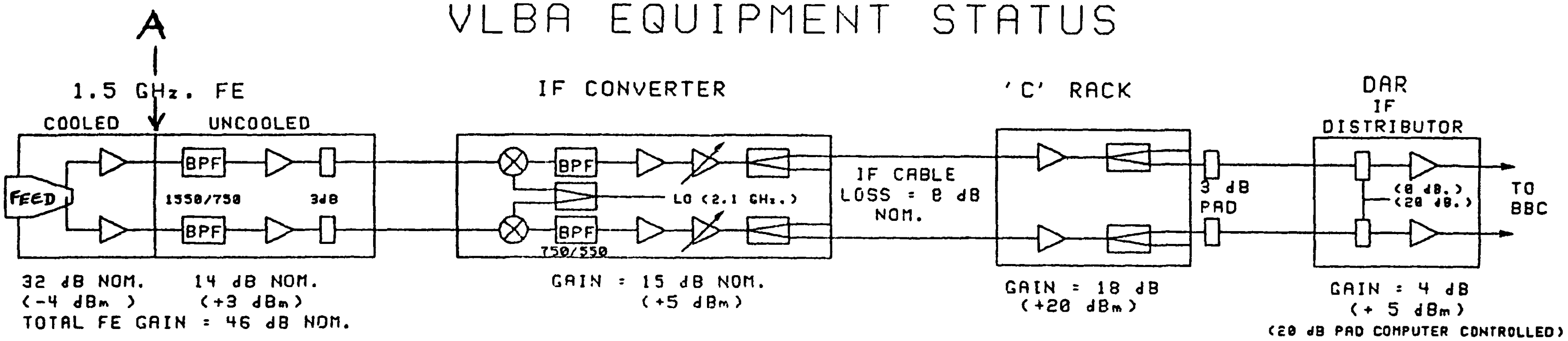


Figure 2

SOWRBALL TESTS
VLBA EQUIPMENT STATUS



NOTE: NUMBER IN PARENTHESIS IS 1 dB COMPRESSION POINT AT AMPLIFIER OUTPUT.

1dB compression levels referred to cooled amplifier input:

Cooled amp	-66 dBW
Uncooled amp	-73 dBW
IF Converter	-86 dBW
C Rack	-81 dBW
IF Distr.	-97 dBW

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Figure 3

Power out of cryo-amp. f = 1.31 GHz, Δf = 3 MHz. Antenna pointing at zenith.

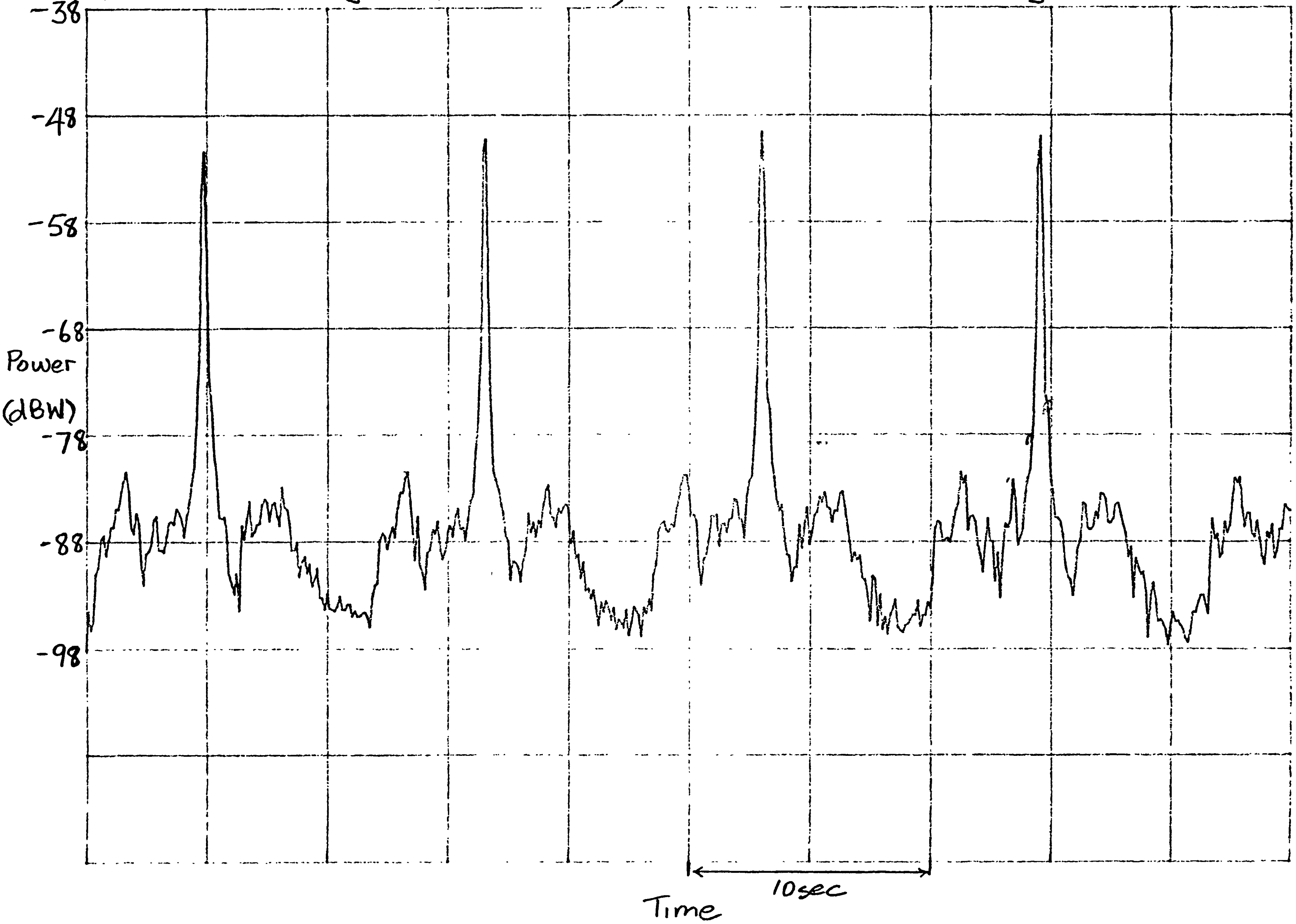
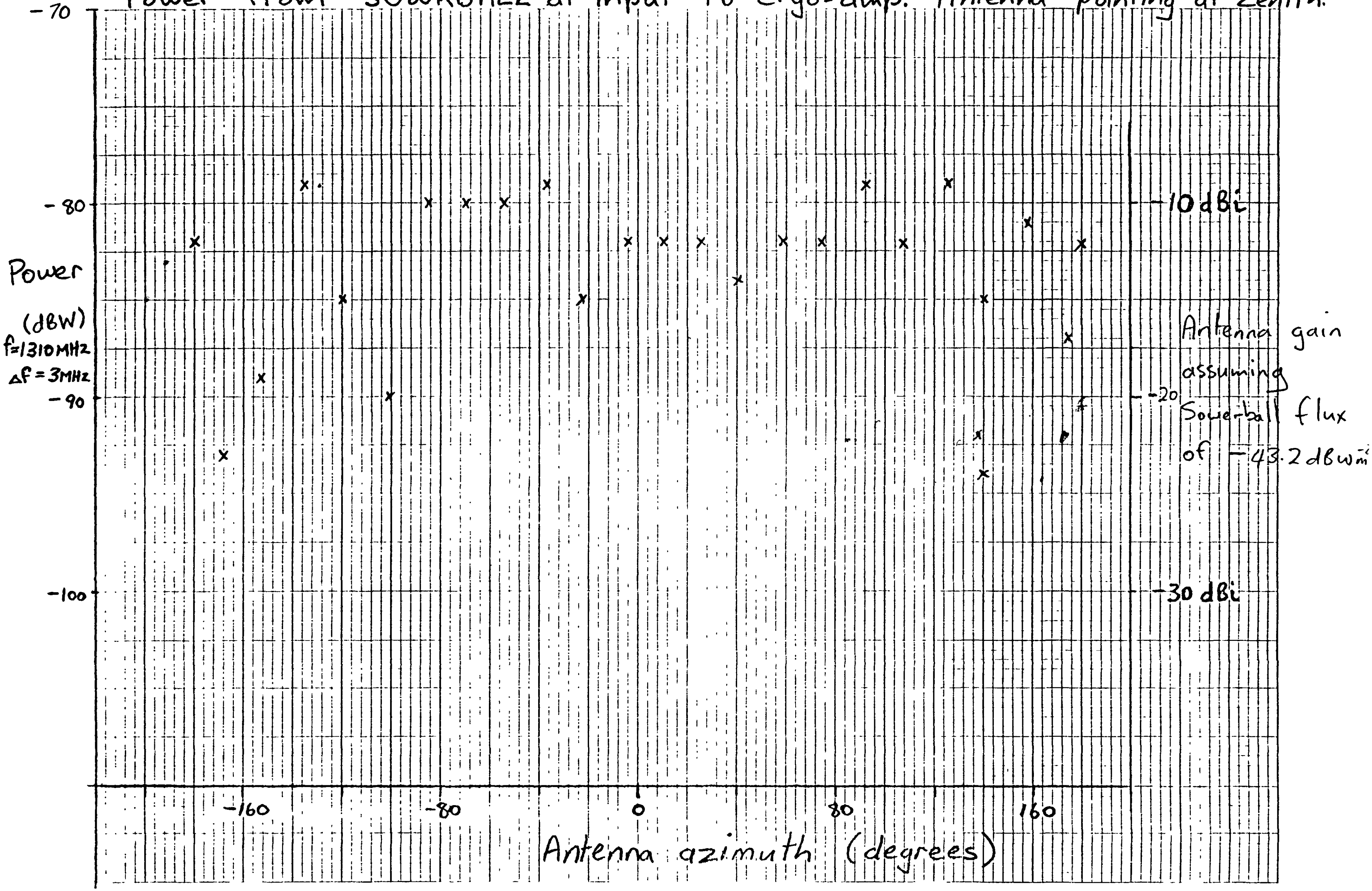


Figure 4

Power from SOWRBALL at input to cryo-amp. Antenna pointing at zenith.



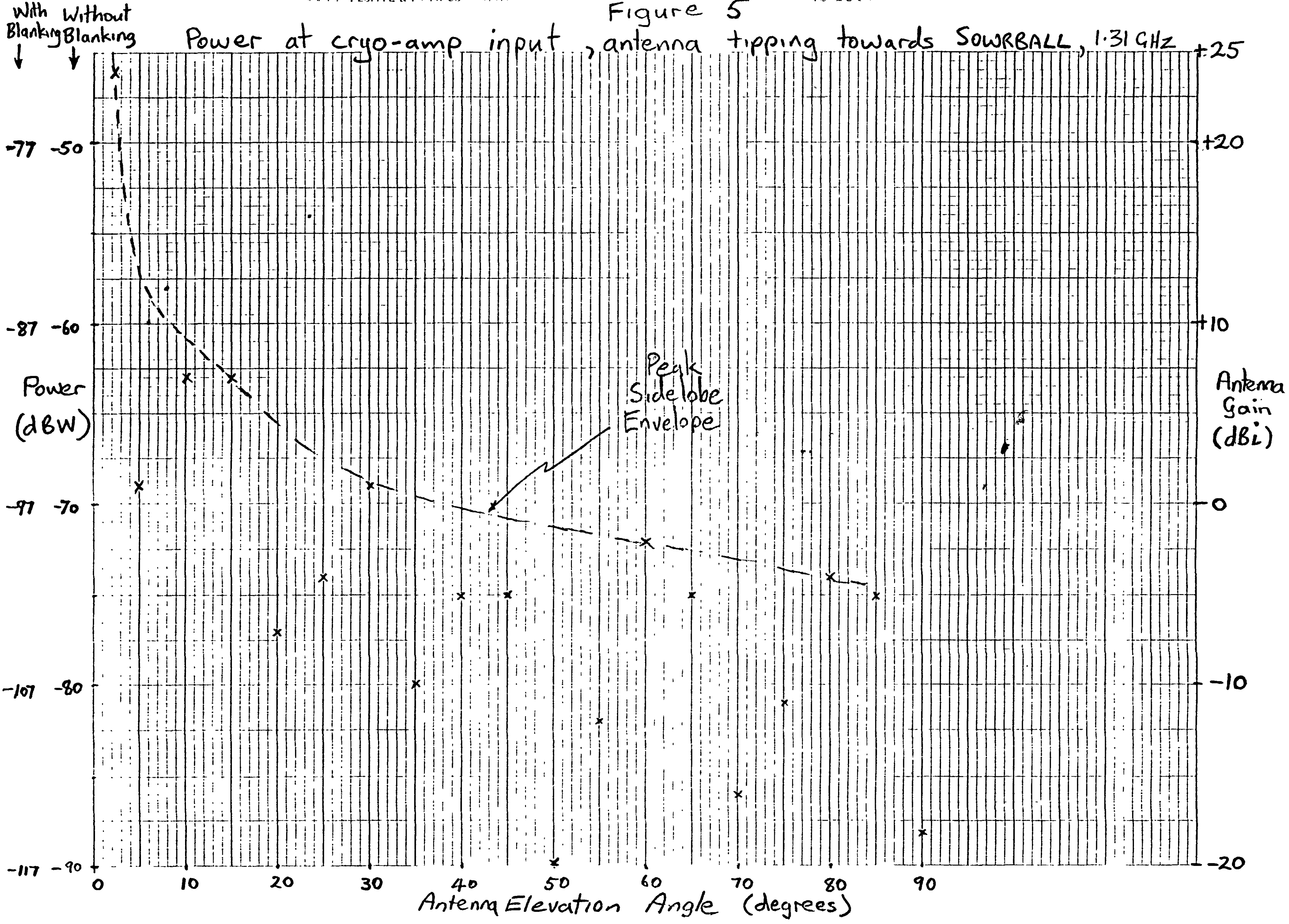


Figure 5

Power at cryo-amp input, antenna tipping towards SOWRBALL, 1.31 GHz

Figure 6

Power at cryo-amp output. Antenna pointing towards SOWRBALL at 2.2° Elevation angle.

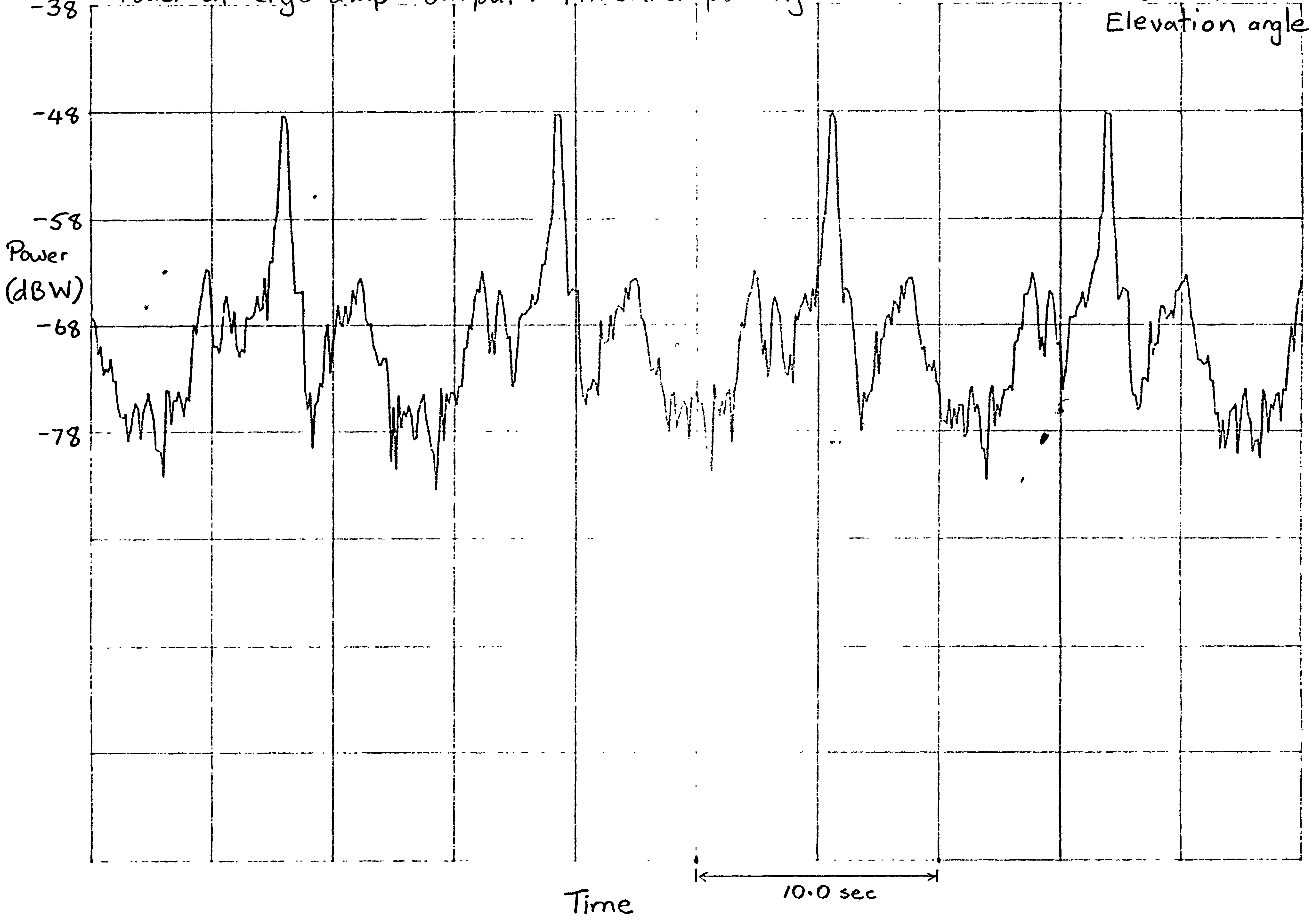
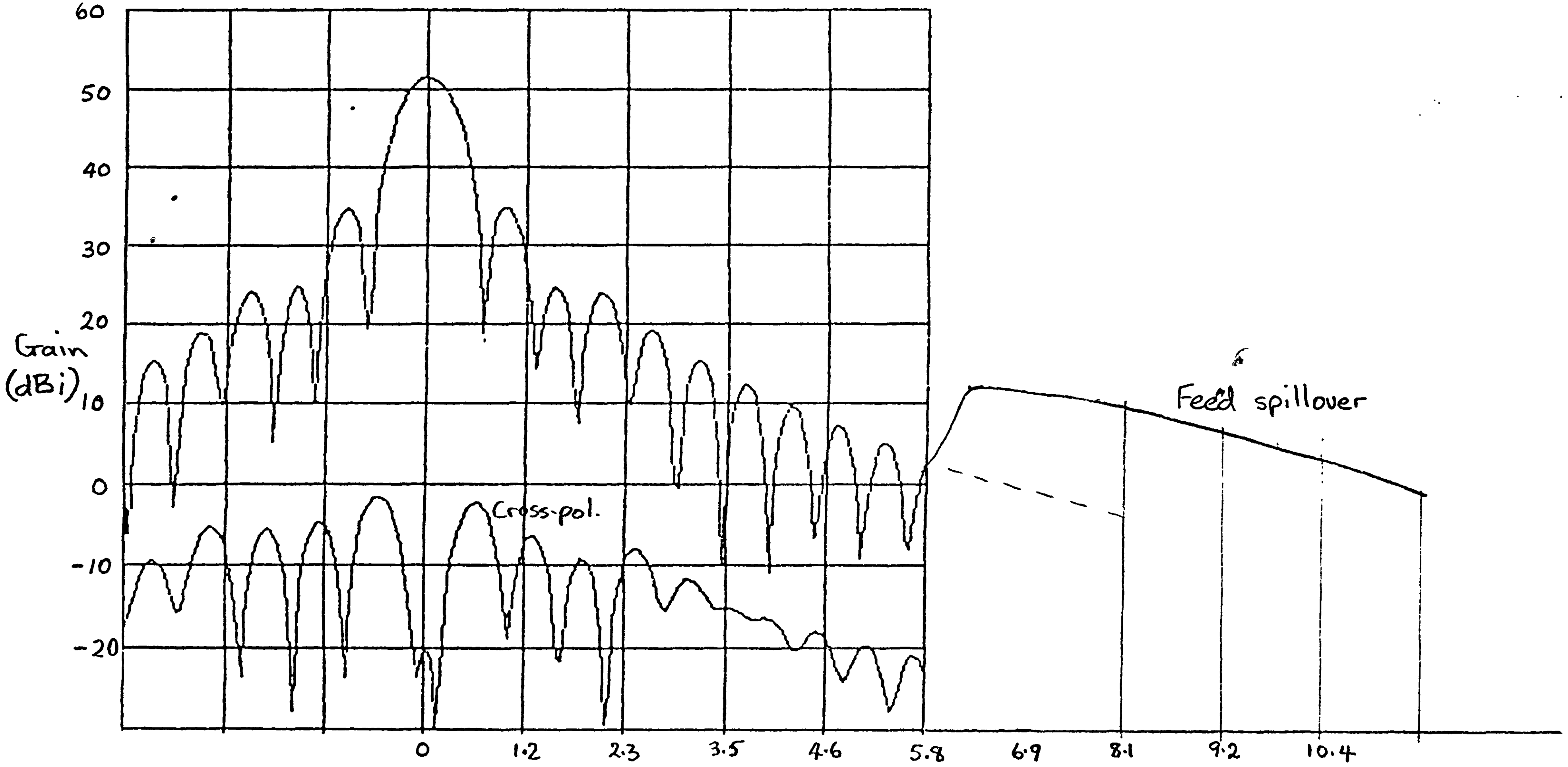


Figure 7

VLBA 1.31 GHz predicted radiation pattern – elevation cut.



Angle from main beam (degrees) towards horizon.

Figure 8

Power at cryo-amp output. Antenna 10° from SOWRBALL (a) 1.31 GHz, (b) 1.32 GHz

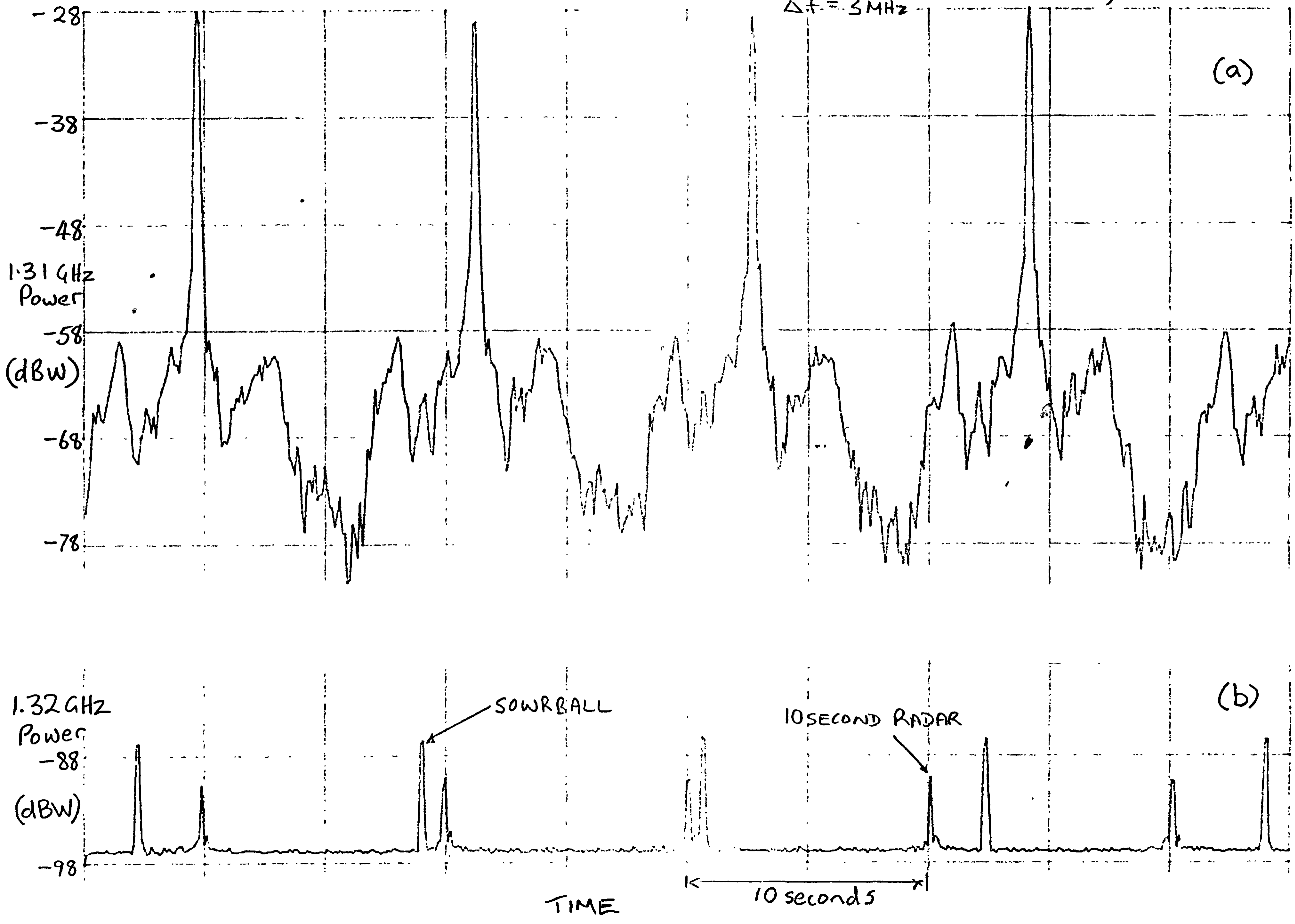


Figure 9

Power at cryo-amp output. Antenna 10° from SOWRBALL (a) 1.35 GHz, (b) 1.40 GHz

$\Delta f = 3$ MHz

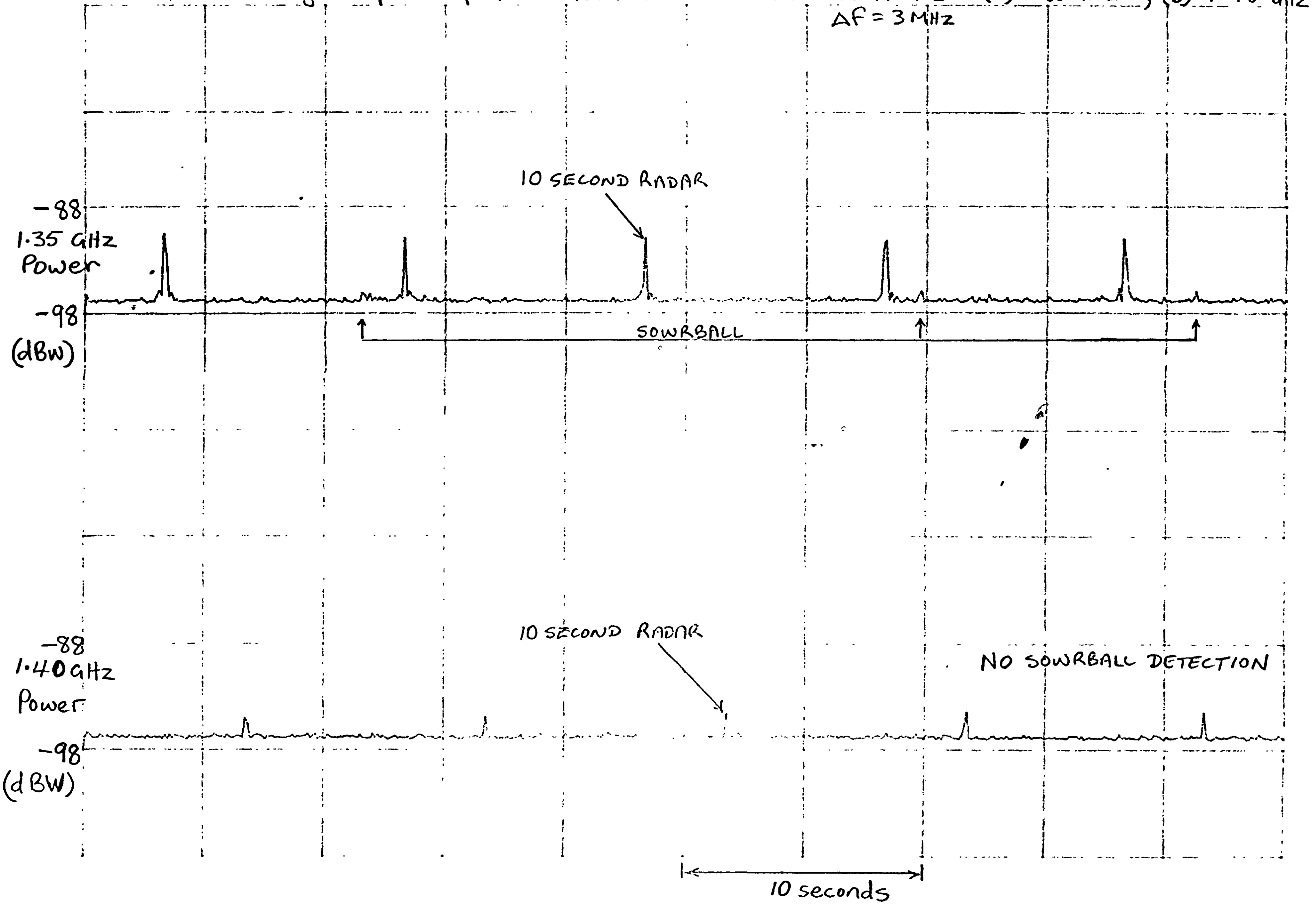
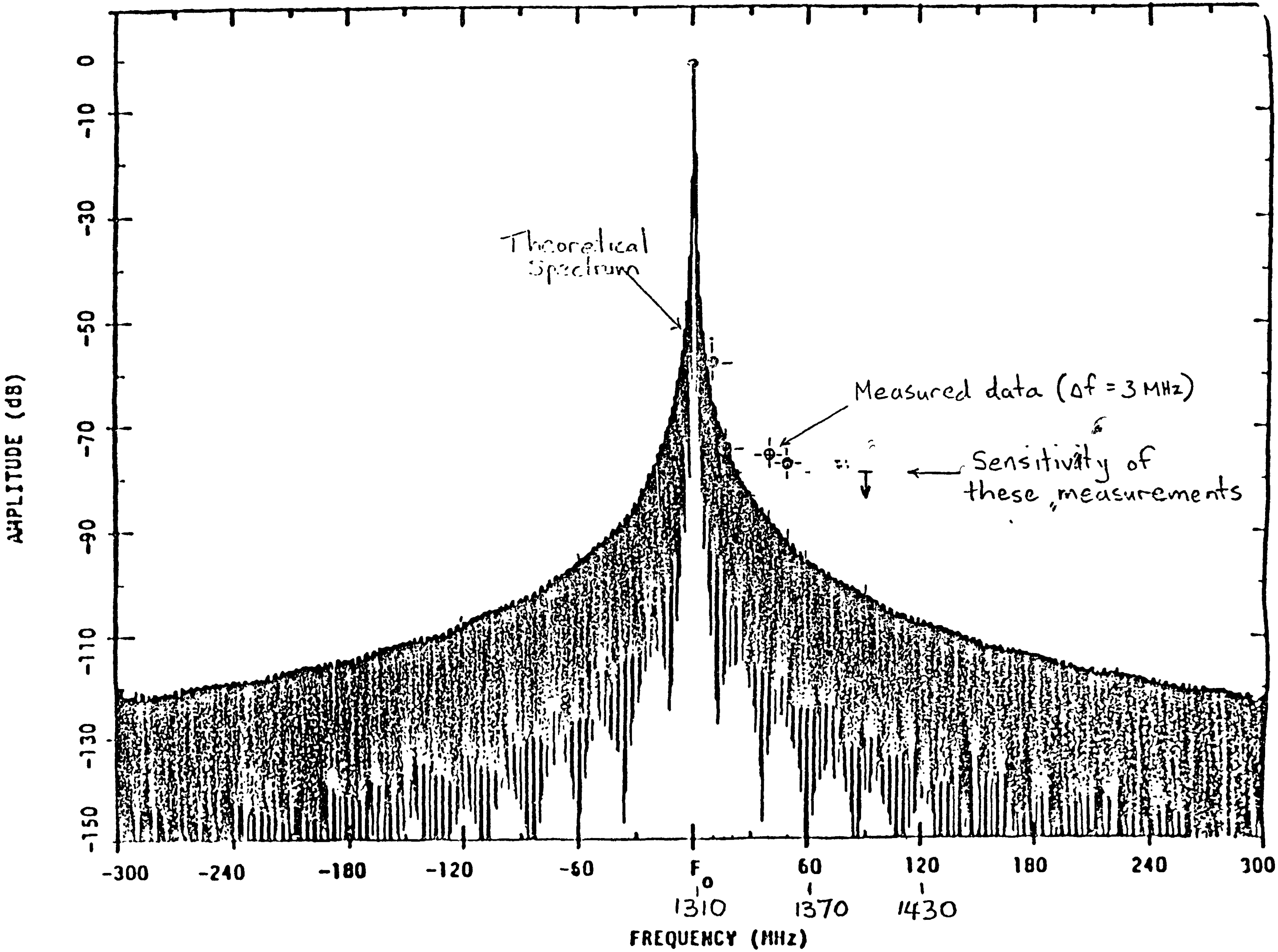


Figure 10 **PULSE SPECTRUM**



Frequency Spectrum of the SOWERBALL Pulse (± 300 MHz)