National Radio Astronomy Observatory

VLA - VLBA INTERFERENCE MEMORANDA No. 2

RFI at Saint Croix due to FAA RADAR at L-Band

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INTRODUCTION

IF signal plots for L-band receiver settings at the IF Distributor front panel monitor in the Saint Croix telescope, made in April 1992 by Jim Oty when the telescope outfitting was completed, are shown in figure 1. Strong radio interference around 1300-1350 MHz was very clearly seen in these plots. Also, I understand that it has been known for some time that there is a strong FAA radar at Pico del este, PR operating at these frequencies. Recently it was decided to find out specifications of a suitable filter which can eliminate this interference.

FILTERING REQUIREMENTS

Block diagram in figure 2 shows the schemetic of the receiver with gain and 1 dB compression levels of the major components. Also 1 dB compression levels of the various components referred to the input of the low noise amplifier (LNA) at the input of the receiver are given in the block diagram.

A quick look at the L-band RFI in the telescope shows that for the antenna in the stow position, output of the frontend is about +12 dBm during the pulses. It means the room temperature amplifiers in the frontend are saturated and their inputs are atleast -6 dBm (and probably more), and the pulses at the inputs of the LNAs are atleast -38 dBm. This suggests that the pulse signal at the input of the low noise amplifiers is atleast near 1 dB compression level, and the LNAs may even be saturating during the radar pulses (of about 6 microseconds followed by no signal for about 6 microseconds and then another pulse of 6 microseconds, every 3 msec roughly).

Plots of variations of the L-band RFI with antenna azimuth and elevation for Sowerball radar at the VLBA-KP, from VLBA Memo. 654 by P. Napier, are shown in figures 3 and 4. Also a theoretical elevation beam cut at L-band is shown in figure 5 (VLBA Memo. 654). From these plots (Figs. 3-5)it is clear that with the Saint Croix antenna pointed in the vicinity of the FAA radar the pulse signal at the inputs of the LNAs is likely to increase by roughly another 30-50 dB (and this general direction is likely to be used quite often at VLBASC). This means we need atleast 40-50 dB of rejection at 1330 and 1350 +/-10 MHz (RADAR frequencies—which I hope will not change) before the input of the LNAs.

Characteristics of the FAA radar at Pico del este, PR, (from Bill Brundage) are given in Table 1. The FAA radar has peak power of 2 MW, frequency 1330 and 1350 MHz, bandwidth 10 MHz, antenna gain 32 dBi (it may be even 37 dBi—see beam size), beam 1.2 deg (horizontal) by 6 deg (vertical), and is located about 140 km away (from VLBASC) on a 1065 m high mountain peak. This means the radar should be almost in our line of sight from VLBASC and it should cause pulses with field strength of about +10 to +15 dBm/sq.m at the site. This will need about 45-50 dB filter rejection before inputs to the LNAs (for input 10 dB below 1 dB compression level) to be able to go to within about 6 deg (and may be even 10 deg— because in this region feed spillover dominates) from the peak of the beam in the direction transmitter radiating towards us (once every 12 sec). In addition atleast another 30 dB of rejection will be required at the inputs of the room temperature amplifiers in the frontend at these frequencies.

This means we need filters with passband atleast from 1400-1700 MHz and a rejection of atleast 45 dB at 1350 MHz at the inputs of the LNAs. Such a filter will probably have atleast 1 dB insertion loss. It is possible to reduce the gain of the LNAs by say about 10 dB, and correspondingly reduce the filter rejection requirement, but this will necessitate changing the room temperature amplifiers. I wonder whether all such approaches are worthwhile, and whether such an approach will do more good or harm to the system performance. (Also a similar problem exists at Los Alamos at probably the same frequencies—details not known).

ALTERNATE APPROACHES AND THEIR LIMITATIONS

One can take a different approach to the problem and ask how does the pulsed rfi effect the data ? Essentially for a large input signal the receiver gain is compressed. What happens during these pulses (for less than 1compressed, and there is no contribution to the measured visibility from either the sky signal or the receiver noise. Essentially it means the effective integration time is reduced by this amount. If the receiver is not fully compressed, it will effect the visibility measurement during this fraction of time. The selfcal should calibrate this error (to a first order).This in itself may not be very serious (assuming that the input pulse power will not damage the LNAs or else we will have to build something to prevent pointing the antenna in that direction, which can only be done manually since software limit is +2 deg elevation —need to varify this), especially for 1 bit quantization. But there are two other considerations, namely intermodulations during the pulses resulting in spurious signals and variations of total power and switched power detector outputs resulting in erroneous system temperature estimates.

To appreciate how data are affected it is instructive to see the signal at various places in the receiver with a spectrum analyser and/or oscilloscope, and monitor the variations in the total power and switched power detector outputs (in the IF distributor and BBCs). The schemetic of the test setup used for the tests is shown in figure 6. Figure 7 shows the spectrum analyser traces for mixer output in the IF Converter module. Figure 8a shows the oscilloscope traces of the signal monitored at the IF Distributor front panel IF monitor, and figure 8b shows the spectrum analyser traces at the BBC front panel video monitor. From these figures it is clear that the most dominant intermodulation components are those due to the pulsed rfi itself, rather than any other signal (including the receiver noise). Tables 2 give total power and switched power detector outputs, monitored at the IF distributor and BBCs, with different input levels and parameters for the pulsed rfi, and some changes in the BBC input circuit (described in the table). From these tests it is clear that the most dominant component effecting the total power and switched power outputs is the inverse pulse duration and its harmonics in the BBC mixers. The error in the system temperature (estimated using BBC TP and SP) due to the pulsed rfi is maximum with narrowest BBC BW, and for BW larger than inverse pulse period falls of with the BW used. It appears that this is caused due to intermodulation components generated in the BBC mixer which has 1 dB compression point of only about 0 dBm. In fact by splitting the 15 dB attenuation at the BBC input (before the amplifier) into 3 dB before the amplifier and 12 dB after it, reduces the increase in TP and SP outputs due to pulsed rfi by a factor of about 3. With the attenuation split (3 dB and 12 dB) the effect on TP due to pulsed rfi is less than 5% (and no effect on the SP) for BBC BW=2 MHz, and nominal output of 16000 counts, and further reduced to about 3% for BBC output of about 28000 counts. If this level of error in the estimating the system temperature is not acceptable, then this approach may have to be abandoned. Also some of the intermodulation components may pass through and may appear in the output. But I do not expect these (intermodulation) components to be correlated from one antenna to another, and therefore should be equivalent to degrading the signal to noise. On the other hand this may limit the use of the antenna (with rfi) for (some) spectral line observations at certain frequencies depending on the frequencies of the rfi, other spurious signals, and their combinations, but they are still incoherent from antenna to antenna. Further the antenna usefulness for narrower BBC BWs becomes very limited. To solve this problem we will have to make the system completely linear (i.e. no compression—how linear the system should be ??).

A way out may be to gate out the RFI pulses (either replace by zero signal or random noise). This can be achieved at either the correlator or the antenna (for example, this can be done at the inputs of the IF Distributors). Ofcourse we will have to build additional hardware to do so. This may not be a simple change and below we briefly examine its implications for our system. It seems gating out rfi in the correlator is not easy due to a variety of reasons (pulsar gate may not work if pulsed rfi in more than one antenna), and we should consider gating at the antenna. There are two types of questions, namely technical (level of sophestication and design), and budgetary (including manpower etc.). Do we need gating at IF Distributors or BBCs or both, and as these modules are full, where to add the hardware ? It may be possible to add gating in the Formatter, but that is adding more complication to already comlicated hardware. Do we need to measure the (fraction of) time lost due to the rfi pulses ? How much gate leakage is tolerable, etc. ? Further one may ask whether we modify only affected antennas or do we impliment changes in every antenna to keep all antennas similar. Many of these questions require discussions (and probably some compromises).

BACK TO FILTERING

Considering above aspects I wonder whether we should go back to the filtering solution of some sort. With practical considerations (modify as few things as possible) in mind one appoach will be to not worry about the loss of data during the pulsed rfi but limit its effect on the total power and switched power measurements only by simple means. It may be possible to achieve this by adding filtering after the room temperature amplifier in the frontend and/or at IF in the IF Converter to provide adequate rejection at the rfi frequency so that the BBC mixer is not hit with large pulses which otherwise result in intermodulation products at baseband (due to pulsed rfi). It means we will have to ensure that peak pulse rfi at the BBC mixer input is less than -5 dBm (a few dB below 1 dB compression point of the mixers), i.e. about 45 dB rejection at 1350 and 1330 MHz in the B-rack after the IF converter. According to a Mini-circuit LMX-113 double balanced mixer intermod data I expect 2 times rf input frequency components to be $\leq$ -70 dBm when rfi pulses are present, which should contribute less than a few percent to the total power in the video signal for narrowest bandwidths. A 13 section cavity filter with 700-1000 MHz passband or equivalent filter (located in B-rack at the outputs of IF Converter) should do the job.

There is only about 50 dB switch isolation between different IFs in the 4-way switches at the inputs of BBCs. Therefore we suggest that to avoid coupling of unintended spurious signals, like these rfi pulses, set unused IFs to a safe frequency setting or terminate unused IF cables in the vertex room (using switches S1-S4).

CONCLUSIONS

It seems that filter solution as well as alternate approaches have limitations, and are going to effect the system performance. It is hard to get any filter having 45-50 dB rejection only 40 MHz away from 1400 MHz (passband 1400-1700 MHz) without introducing considerable attenuation (atleast 1 dB, and probably more) before LNAs. Gating out the radar pulses seems best, but will need additional hardware, which needs to be thought out carefully. DO NOTHING (peak detectors seem still desirable) seems to be workable in the continuum but it is not clear whether it will work in the case of spectral line observations. It will effect spectral line observations/calibrations, especially those requiring narrow BBC bandwidths. Post LNA filtering, though not a clean approach, is a practical solution, and should allow both continuum and spectral line observations without introducing too serious calibration problems (though there is going to be loss of coherence during pulsed rfi— less than 1at Los Alamos for some time (interference level is not known). Do we know its effects on the data or have any other information about it?

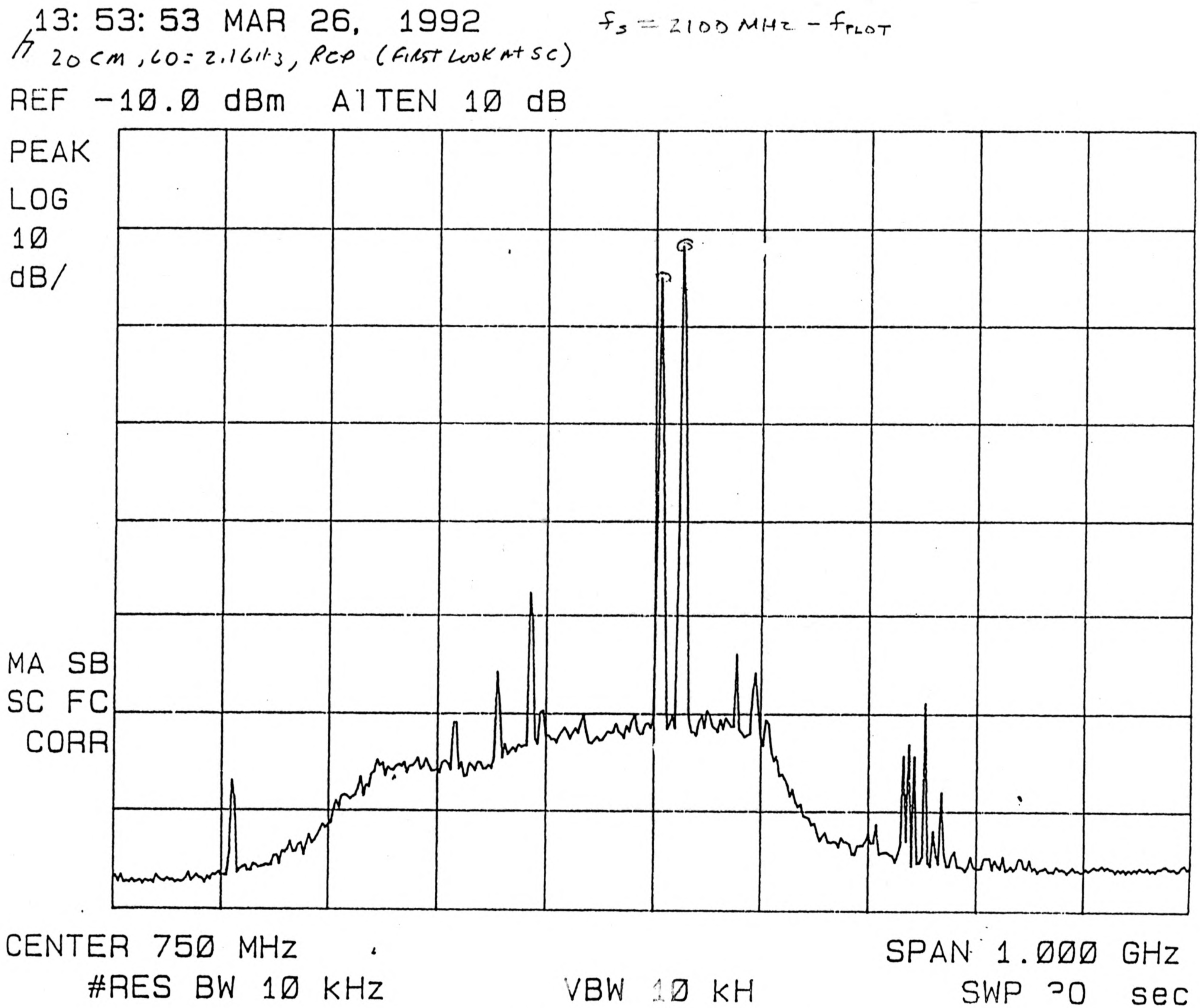
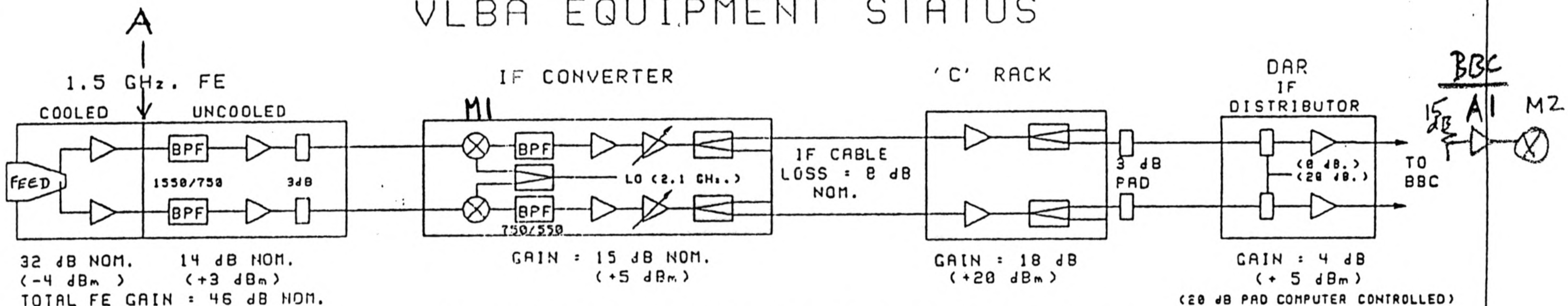


FIGURE 1 – FAA RADAR RFI AT St. Croix

Figu

SOWRBALL TESTS
VLBA EQUIPMENT STATUS



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

1 dB Compression

M1	+22 dBm
A1	+ 7 dBm
M2	+1 dBm

1 dB 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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FIG. 2 — VLBA SIGNAL PATH AND COMPRESSION LEVELS FOR VARIOUS COMPONENTS

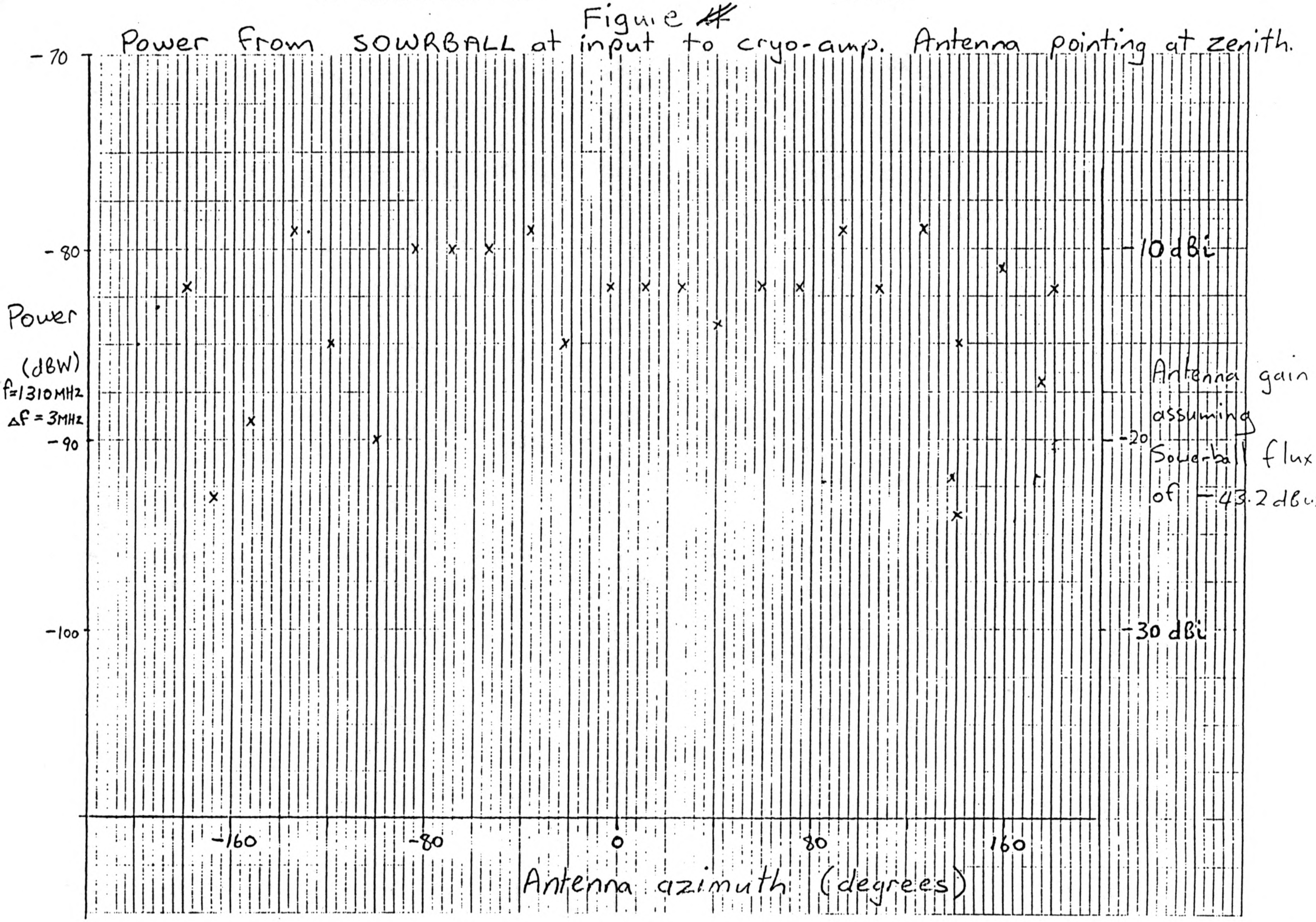
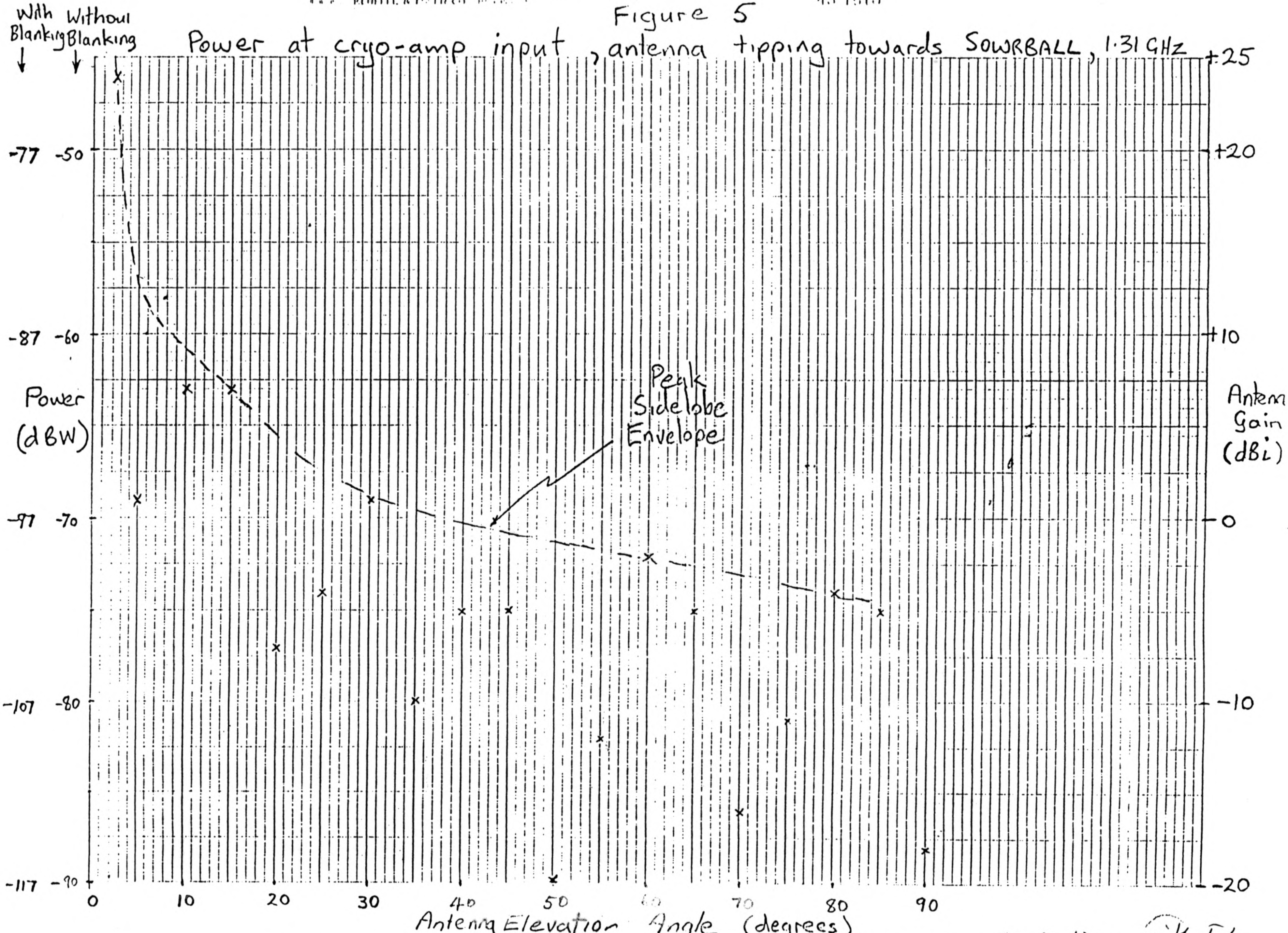


FIG. 3 — RFI MEASUREMENTS DUE TO SOWRBALL AT VLBA-KP — variation with the antenna azimuth

Figure 5

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



RFI MEASUREMENTS DUE TO SOWRBALL AT VLBAKP – Variation with EL.

Figure 5

VLBA 1.31 GHz predicted radiation pattern – elevation cut.

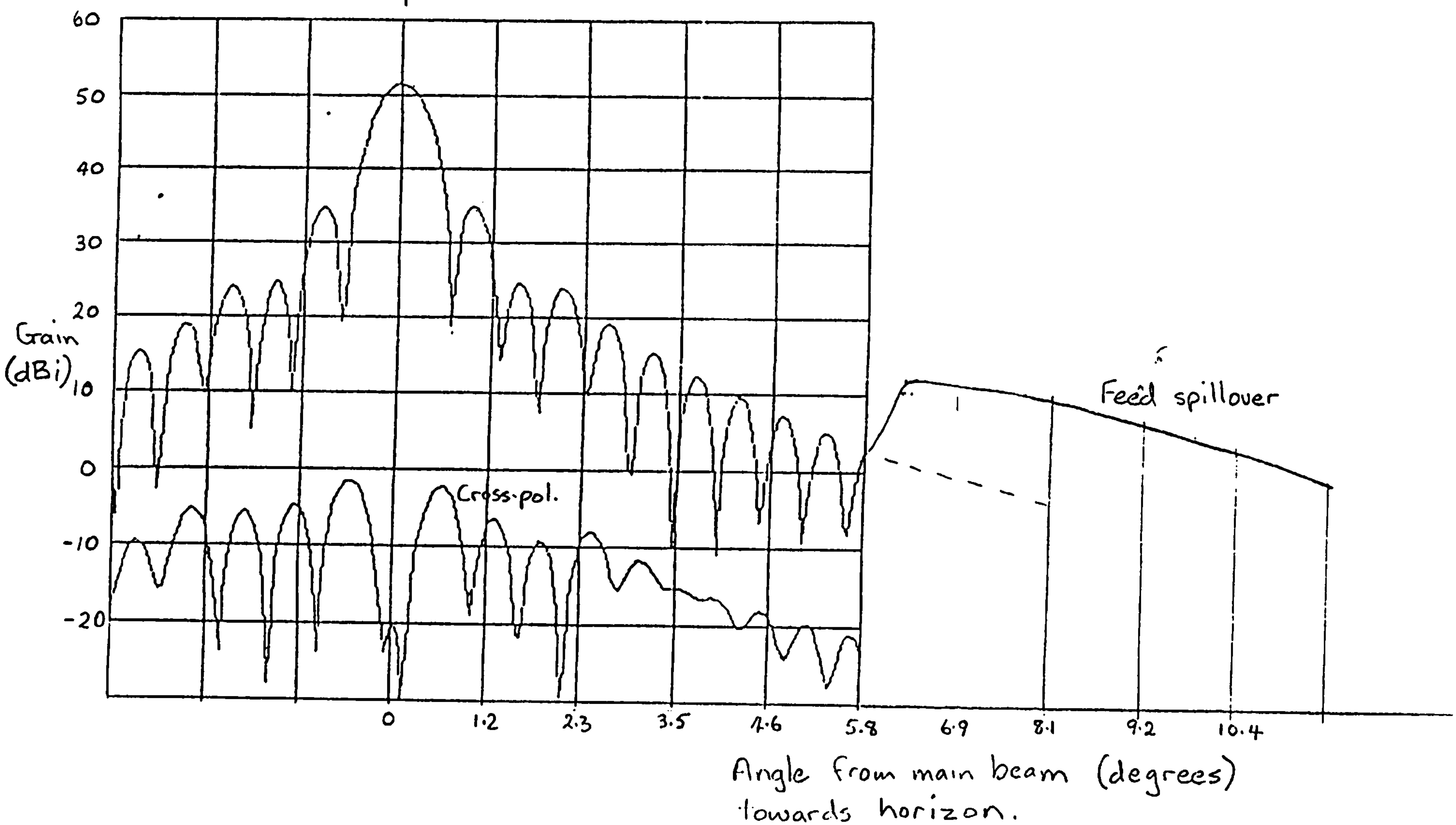


FIG. 5

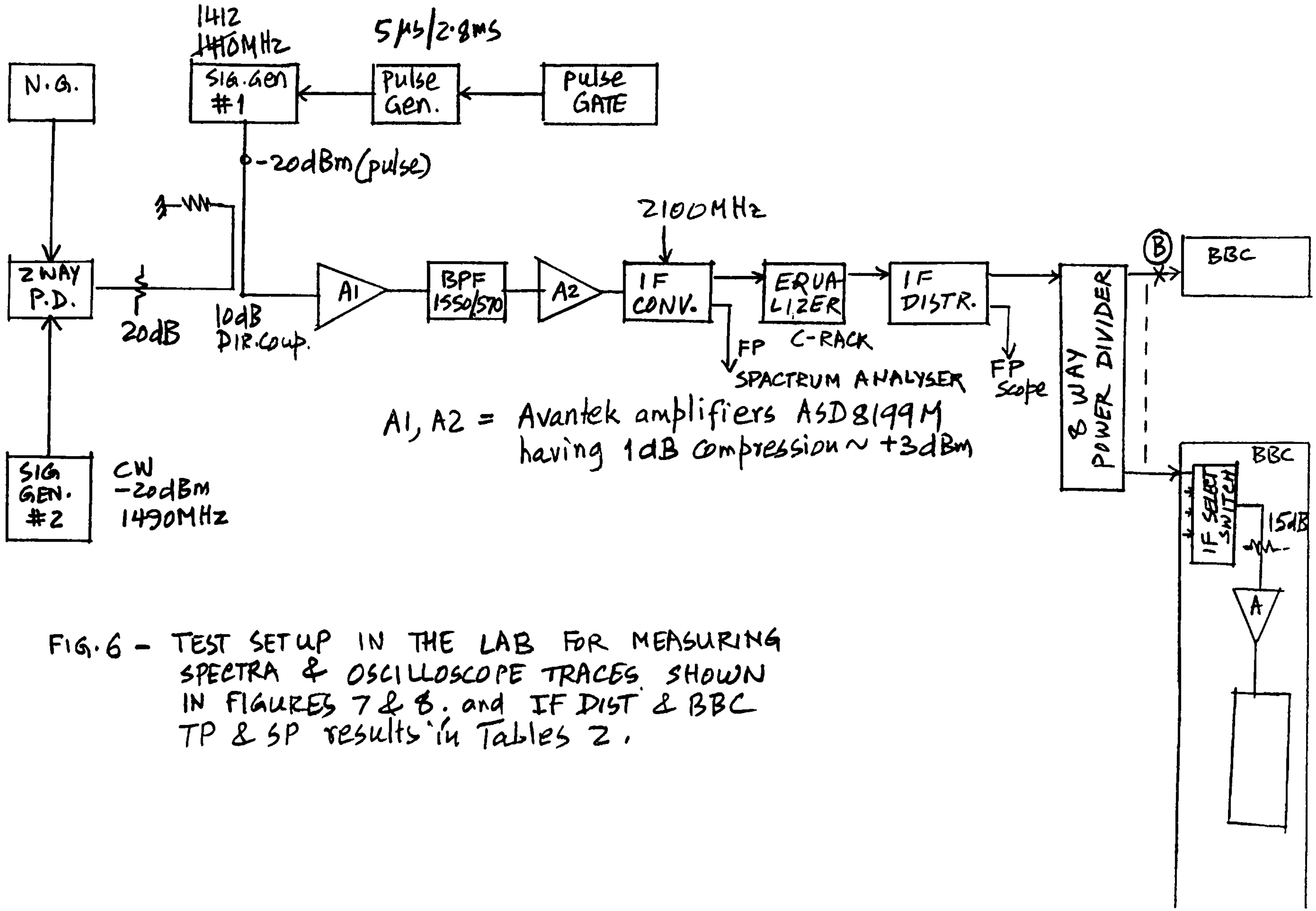
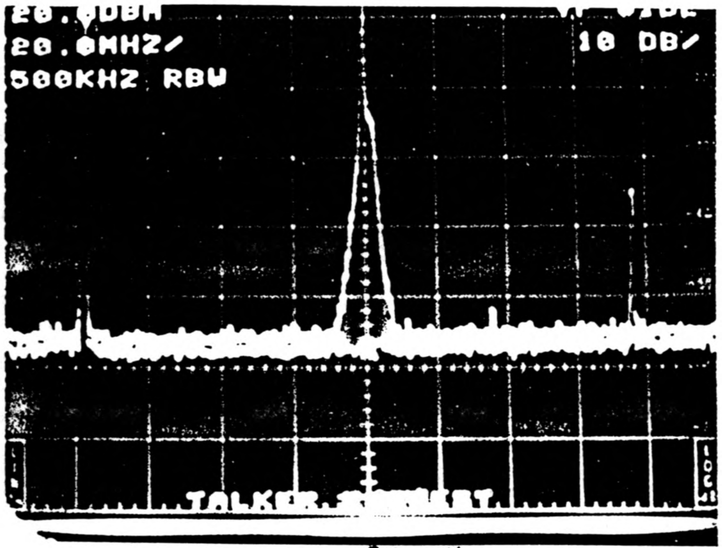
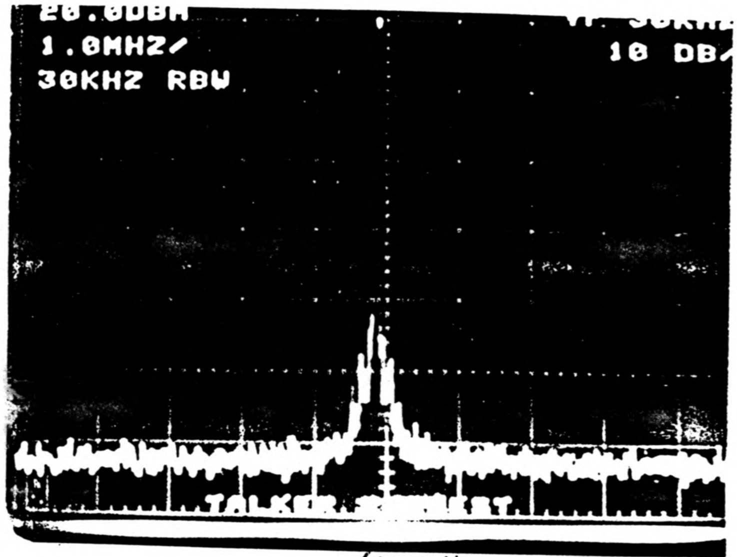


FIG. 6 – TEST SETUP IN THE LAB FOR MEASURING SPECTRA & OSCILLOSCOPE TRACES SHOWN IN FIGURES 7 & 8. and IF DIST & BBC TP & SP results in Tables 2.

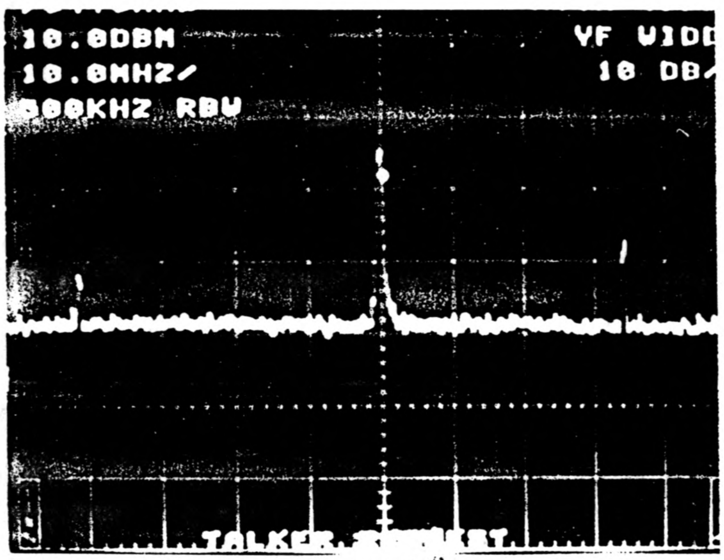
pulsed CW -30 dBm (Sig. gen. 1), Sig. gen 2 = -20 dBm



690 MHz



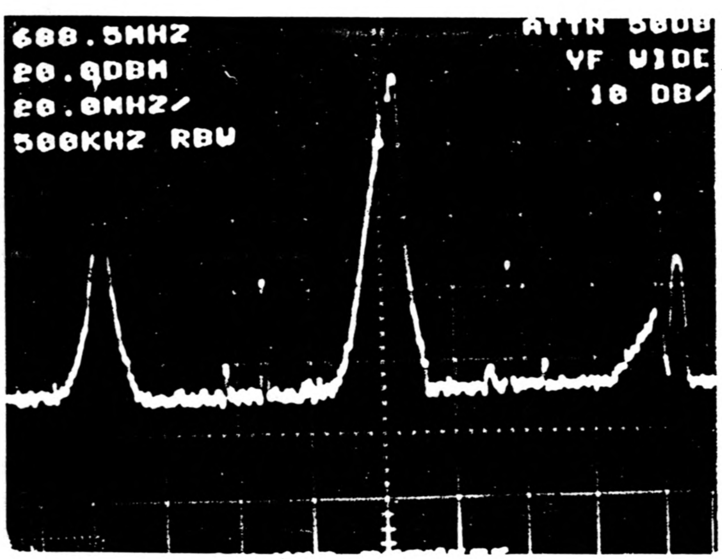
610 MHz



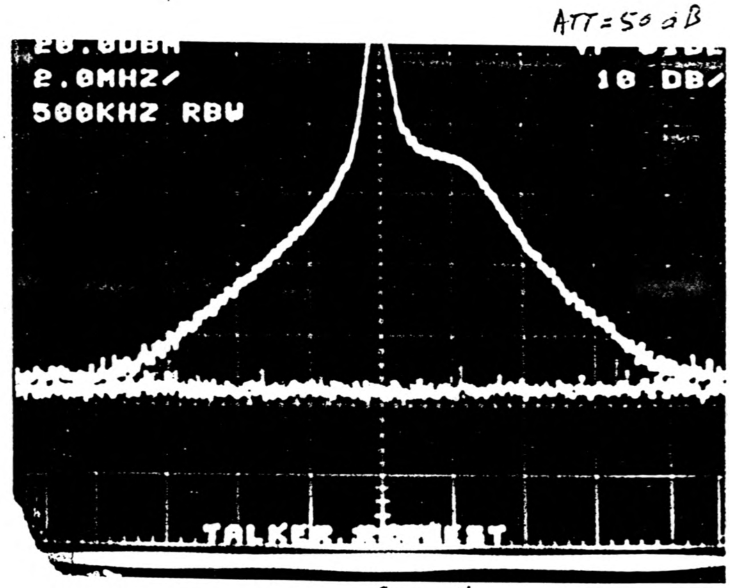
768 MHz

Fig. 7 – Spectra taken at IF CONVERTER FP BNC (IF MONITOR). See figure 6 for the test setu

↓Pulsed CW -20 dBm (Sig. gen #1) Sig. gen #2 = -20 dBm



ATT = 50 dB



688 MHz

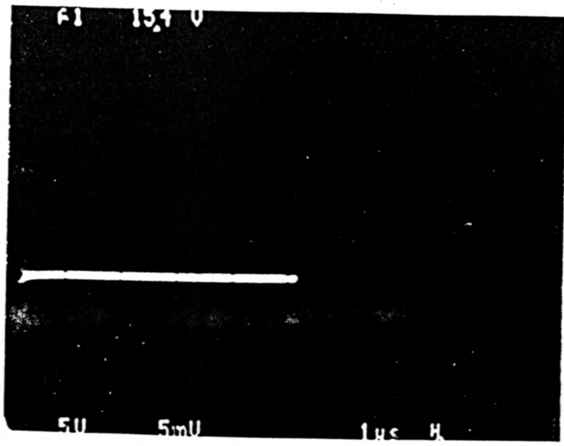
(... #2 OFF)

① Oscilloscope Trace at IF DIST FP for signal −65 dBm pulse width 5 µs/2.8 ms

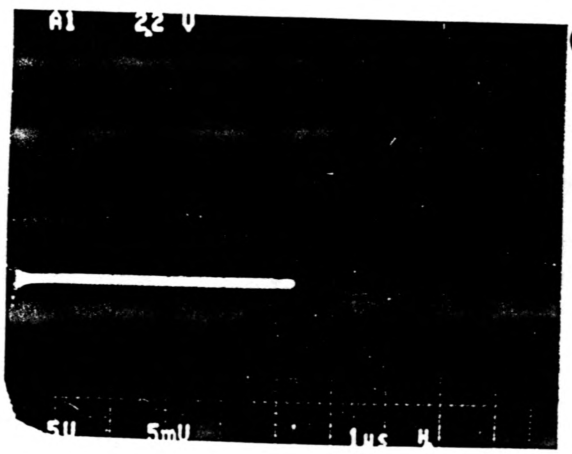
② Oscilloscope Trace for signal −55 dBm pulse 5 µs/2.8 ms

③ BBC OUTPUT spectrum @ FP (BNC) BW = 2 MHz

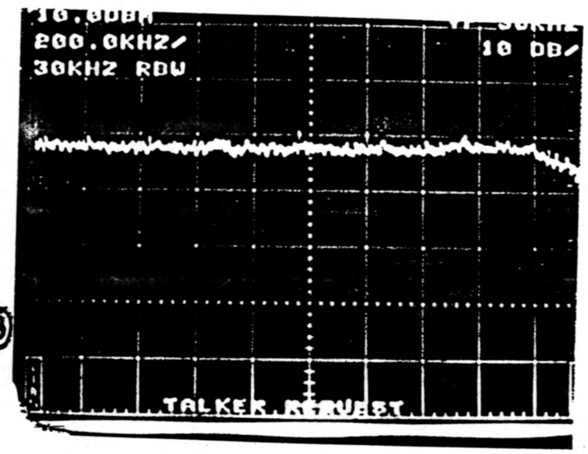
①



②



③

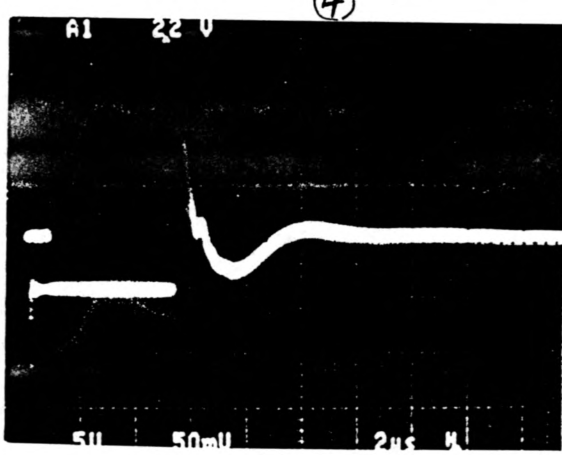


④ Oscilloscope Trace at IF DIST FP For signal input −35 dBm pulse 5 µs/2.8 ms

⑤ BBC OUTPUT spectrum for −35 dBm as in ④

⑥ BBC OUTPUT spectrum for −35 dBm pulse 22 µs/2.8 ms

④



⑤

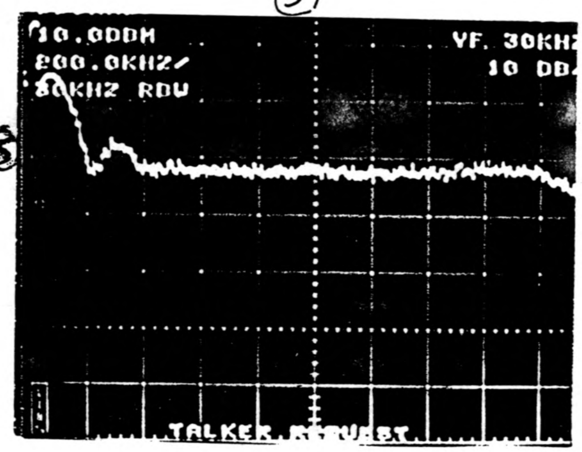


Fig. 8 (For test set up see Fig. 6)

⑥

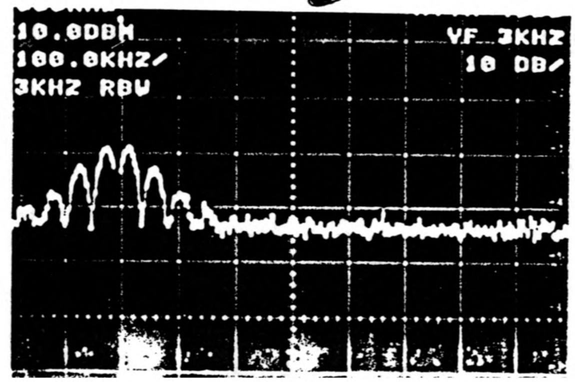


Table 1. Characteristics of FAA RADAR at Pico Del Este (from Bill Brundage).

FAA RADAR, Pico Del Este

Frequencies 1330 and 1350 MHz on alternate pulses
Bandwidth 10 MHz
Loaction 18d 16m 15s N latitude, 65d 45m 33s W longitude
Elevation 3280 ft AMSL
Antenna radiation center 50 ft AGL
Polarization H or V
Antenna azimuth sweep rate ?
Beam vertical 6 deg FWHP, horizontal 1.2 deg FWHP
Antenna beam gain 32 dBi
Pulse tx modulation, wpulse width 6 microsec.
transmit pulse rep rate 355/sec
antenna peak/ave power ratio 27 dB
Peak EIRP ant beam 97 dBWi
Peak EIRP antenna beam 5.0* 10E9 watt
distance from VLBASC 136.5 km

TABLES 2. VARIATIONS OF TOTAL POWER AND SWITCHED POWER LEVELS WITH PULSED RFI INPUT LEVEL IN IF DISTRIBUTOR AND BBCs.
BBC 2 has a 10 dB pad between input amplifier and sideband separating mixer in all following tests. T = 2 sec

(a) Effect of a 4 section BPF (600/50 MHz) at the input of BBC 3. Pulsed rfi frequency at IF = 2100 − 1412 = 688 MHz

INPUT Pulsed RFI dBm	IF DIST TP	IF DIST SP	BBC # 3 TP	BBC # 3 SP	BBC # 2 TP	BBC # 2 SP
	Pulse 5 μs/2.8 ms; BBC BW = 2 MHz					
−120	14283	377	15952	432	8703	219
−80	14254	376	15925	430	8684	224
−70	14647	376	15855	415	8654	215
−60	15093	377	15816	427	8639	218
−50	17849	361	15799	413	8660	211
−40	18373	367	15733	428	9278	215
−30	18465	349	15680	425	9397	217
0	18560	356	15634	432	9466	225

(b) Effect of changing pulse width (BBC BW = 2 MHz)

INPUT	IF DIST TP	IF DIST SP	BBC # 3 TP	BBC # 3 SP	BBC # 2 TP	BBC # 2 SP	IF TP	IF SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP
	Pulse 5 μs/2.8 ms						pulse 10 μs/2.8 ms					
−120	14278	380	20807	564	8684	218	13833	367	20127	551	8415	213
−80	14263	378	20744	545	8663	210	13845	367	20096	527	8401	203
−60	15320	379	20629	542	8620	216	16328	374	20080	540	8392	209
−50	18164	378	21100	544	8670	214	18632	353	20680	526	8412	214
−40	18447	380	23157	525	9314	211	18700	327	23831	526	9872	199
−30	18458	347	23278	551	9392	219	18731	348	23912	544	10051	204
0	18552	358	23239	532	9416	210	18825	344	23914	515	10106	212
	Pulse 20 μs/2.8 ms											
−120	13712	363	19935	542	8344	215						
−80	13761	359	19929	523	8344	205						
−40	19395	337	24965	544	11327	200						
−30	19500	311	25055	523	11486	203						
0	19631	320	25046	514	11589	195						

(c) Effect of changing pulse repitition rate (BBC BW = 2 MHz)

INPUT	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP
	Pulse 5 μs/2.8 ms						Pulse 5 μs/1 ms					
−120	14278	380	20807	564	8684	218	13559	352	19728	532	8258	202
−80	14263	378	20744	545	8663	210	13611	357	19717	526	8258	205
−40	18447	380	23157	525	9314	211	25601	359	26949	510	10270	207
−30	18458	347	23278	551	9392	219	25878	276	27507	490	10571	204
0	18552	358	23239	532	9416	210	26293	314	27718	502	10764	206

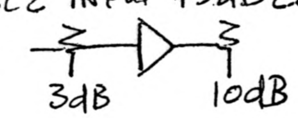
(d) Effect of BBC bandwidth changes — (pulse 5μs/2·8ms)

INPUT	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP
	BBC BW = 125 kHz						BBC BW = 250 kHz					
−120	13405	349	5202	134	5863	130	13405	349	14998	333	6704	147
−30	17755	324	10490	135	8787	114	17755	324	17777	392	8894	163
	BBC BW = 2 MHz						BBC BW = 16 MHz					
−120	14278	380	20807	564	8684	218	13418	350	22917	757	9980	308
−30	18458	347	23278	551	9392	219	17760	312	23902	763	10180	307

(e) Effect of BBC Sideband spliting mixer input pulse level limiting by splitting input, 15 dB at the amplifier input to 3 dB at the amplifier input & 10 dB the amplifier & mixers in BBC 2 — VARIATION WITH BAND WIDTH (pulse 5μs/2·8ms)

INPUT	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP
	BBC BW = 250 KHz						BBC BW = 2 MHz					
−120	14894	399	12712	356	11913	320	14812	396	15898	434	15298	425
−30	18993	370	16541	329	14444	272	18933	376	18196	415	16020	396
	BBC BW = 16 MHz											
−120	14503	386	18382	622	18075	605						
−30	18675	363	19134	617	18174	597						

BBC2 INPUT 15dB changed a.



(f) Effect of BBC OUTPUT Level changes with attenuator modified in BBC2 as described in (e) above — pulse width 5μs/2·8ms, BBC BW = 2MHz

	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP	IF DIST TP	IF DIST SP	BBC 3 TP	BBC 3 SP	BBC 2 TP	BBC 2 SP
−120	14690	416	9577	253	8997	235	14812	396	15898	434	15298	425
−30	19526	1378?	11431	257	9620	235	18933	376	18196	415	16020	396
−120	14950	390	30397	825	27773	741						
−30	19708	416	32992	819	28785	752						