ATNF FILE NOTE 39.3/ 053

CSIRO ATNF

SOME COMPARISONS BETWEEN THE DIFFERENT DESIGN CONCEPTS UNDERPINNNG THE WIDEBAND QUAD-RIDGED CIRCULAR-WAVEGUIDE OMTS FOR THE L/S AND THE C/X DUAL-BANDS

Bruce MacA Thomas
16 August 1995

A. BACKGROUND

1. AT developments

During the early stages of OMT development for the AT, two different concepts arose in the profile specification for the four fins:

(1) A design giving minimal change in cut-off frequency, which we call a "constant cut-off" design; the aim is to achieve high return loss across maximum bandwidth. This design was followed through by M W Sinclair for the L/S OMT, and

(2) "Sin-squared" profile design to minimise the OMT length; this concept was followed through by G L James and S Skinner for the C/X OMT.

Return loss measurements showed that the L/S OMT had superior return loss and a (relatively) lower cut-off frequency than the C/X OMT. Ref 1 gives a good description of the two design concepts.

2. JPL developments

As part of the (then) SETI project, a contract was placed on the Division of Radiophysics to supply 2 sets of four wideband OMTs to cover the total frequency range 1 to 10 GHz as follows:

No	Frequency range (GHz)
1	1.0 - 1.63
2	1.61 - 3.02
3	2.86 - 5.35
4	5.34 - 10.0

The basic design adopted was the L/S OMT. However to optimise the return loss performance, R E Shields carried out some detailed refinements to the probes. His notes re OMT probe adjustment are included in Annex 1. The results were compiled in the form of reports: see also Annex 2.

3. Compact array - beam shapes

In May 1995, it was reported that there was considerable antenna radiation pattern asymmetry in S-band (2.376 GHz). This effect was investigated by M J Kesteven who found that, for all antennas:

(a) the pattern in the E-plane was considerably broader (and with negligible first side-lobe level) than in the H-plane, the ratio being about 1.20. (This is opposite to the case for a simple TE_{11} mode in a smooth-walled horn, indicating perhaps significant higher-order mode (TM_{11} ?) excitation.)

(b) similar measurements at the scaled frequency of 8.0 GHz in X-band indicated good radiation pattern symmetry.

4. Purposes of study

Following discussions with G L James, M W Sinclair and M J Kesteven, it was decided to investigate the OMTs and to implement a detailed measurement program on an OMT and horn. It was considered that measurement on a C/X system would be far simpler than on the larger L/S system. However this would require a comparison to be made between the two basic designs and an additional set of fins made to enable comparative measurements to be made with the "sin-squared" and "constant cut-off" profiles. The next section describes the basic differences in design and the proposed measurement program.

This study could also provide useful information for those wishing to scale the designs for use in other frequency bands in the future.

Distribution

M W Sinclair
M J Kesteven
G L James
R E Shields
C Granet
J Whiteoak (Narrabri)
File (2 copies)

B. MacA. Thomas

B MacA Thomas

B. PHYSICAL DIFFERENCES BETWEEN THE L/S AND C/X OMTS

1. Fin-contours

Fig B1 illustrated the two different contours used. Note that the developments to date have been empirical, although the output diameter (smooth circular waveguide) has been determined by the feed-horn design. Note also that the profile for the "sin-squared taper" actually consists of a blending of two tapers, so that half the radial change occurs 60% along the OMT from the input (probe-end).

Referring to Fig B1, it is the current thinking that:

(a) the region close to the input probe defines the return loss; consequently the "constant cut-off" profile which is only slowly changing in the region of the input gives superior return loss characteristics.

(b) for a given length, the "constant cut-off" profile changes rapidly near the output; this is where the TM_{11} mode can be excited at higher frequencies. For the two OMTs, the TM_{11} cut-off frequencies (Fc) in the smooth pipe at the output of the OMT are:

   (a) L/S OMT: OD - 191.0 mm, Fc ^{TM11} = 1.9 GHz

   (b) C/X OMT: OD - 57.18 mm, Fc ^{TM11} = 6.4 GHz

   (The cut-off frequency of the TM_{11} mode in the quad-ridged guide has yet to be determined.)

Consequently, it may be desirable to consider a "compromise" profile which is somewhat along the lines of a sin-to-the-power-4: this is also shown on Fig B1. Where length is not a critical factor, it may also be desirable to increase the OMT length to reduce high-order mode generation.

2. Optimising the parameters of the OMT

To date, it would appear that the major parameters of the OMT that were considered in the earlier studies were:

(a) output diameter: determined by horn design. Note however that the TM_{11} mode can propagate in the upper part of the band if excited. (The radiation pattern of the TM_{11} mode has a null on-axis and in the H-plane, but contributes to the field in the E-plane. When incident on the corrugated surface, considerable off-axis cross-polarised EH mode may be excited.) An alternative configuration would be an OMT using a smaller output diameter, and connected to a horn via a smooth-walled circular waveguide

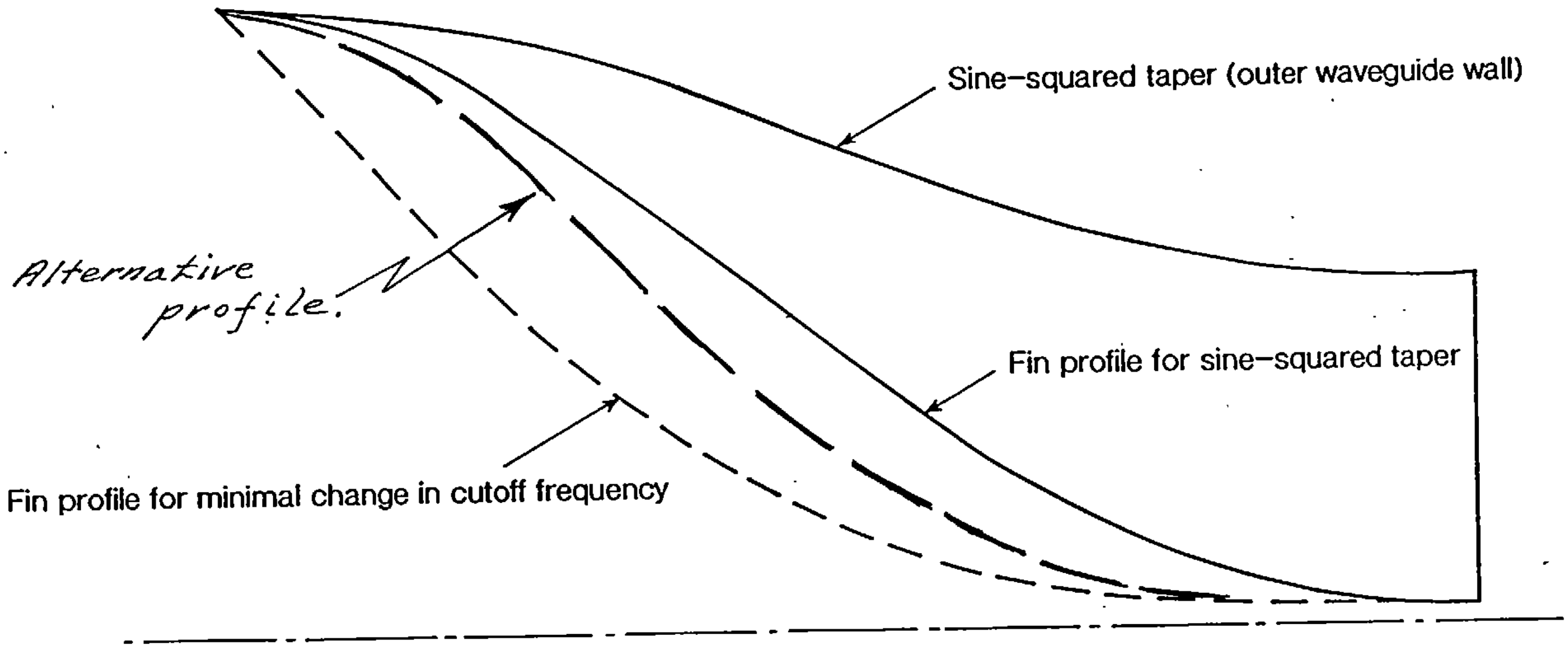

Sine–squared taper (outer waveguide wall)
Alternative profile.
Fin profile for sine–squared taper
Fin profile for minimal change in cutoff frequency

FIG. B1

with a sin-squared taper. However, this may increase the overall length of the feed system.

(b) length: a minimum length is necessary to achieve the required return loss for a given bandwidth. Another important aspect affecting return loss is the coaxial interconnection at the input (see Annex 1).

What is not so clear is the optimum size of the waveguide to be used at the input (probe end): the following shows that quite different values (scaled) have been used for the L/S and C/X OMTs. In fact, the larger diameter of the L/S OMT at the input may be a significant factor in reducing the lower frequency return loss "cut-off" and the improved return loss performance across the band. The other factor (as discussed in Sec B1) is the optimum fin taper to give lowest "cut-off" frequency for return loss, the minimum return loss for a given bandwidth, and the amount of generation of TM_{11} mode in the upper part of the band. And of course for low frequency operation, we usually wish to minimise the overall length!

3. Physical parameters

In the event that further studies are carried out re optimisation in the future, the following gives a summary of the physical parameters used in the L/C and C/X OMTs.

Fig B2 shows sketches of the fins and the major dimensions of the fins and waveguide. One of the first factors in carrying out a comparison is to determine a scaling factor. Ideally this should probably be done using the lower-limit "cut-off" frequency for return loss. As evidenced from the work of R E Shields, this is also dependent on the coaxial probe design, and this expertise only eventuated during the optimisation of the JPL OMTs.

For the sake of comparison, let us take the output waveguide inside diameter as being the relevant parameter to define a scaling factor between the two OMTs:

$$\text{Scaling Factor} = \frac{191.0}{57.18} = 3.34$$

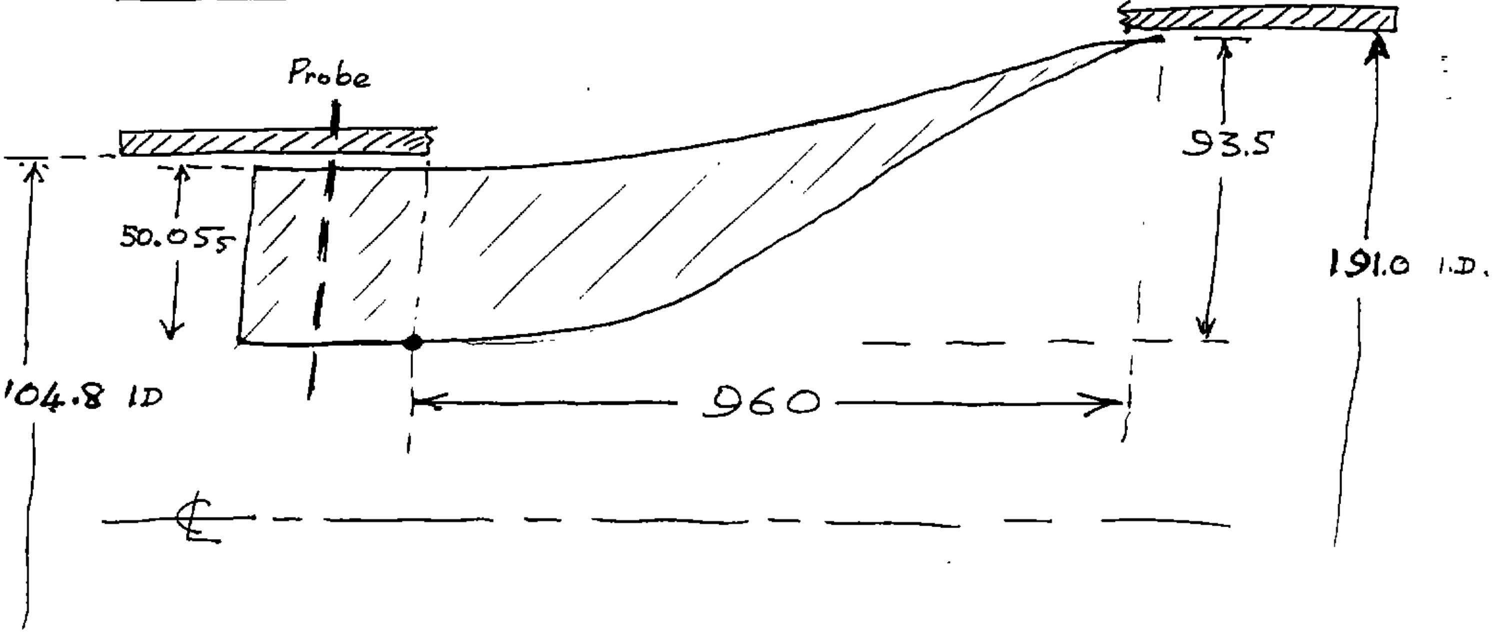
Using the L/S OMT as reference, we get, when scaled to C/X, the following:

(a)	length of taper:	287 mm (cf. 270 mm)	✓
(b)	inside diameter at input:	33.4 mm (cf. 26.24 mm)	!
(c)	max change in fin (radial):	28.0 mm (cf. 28.1 m)	✓
(d)	depth of fin at input:	15.0 mm (cf. 12.5 mm)	!

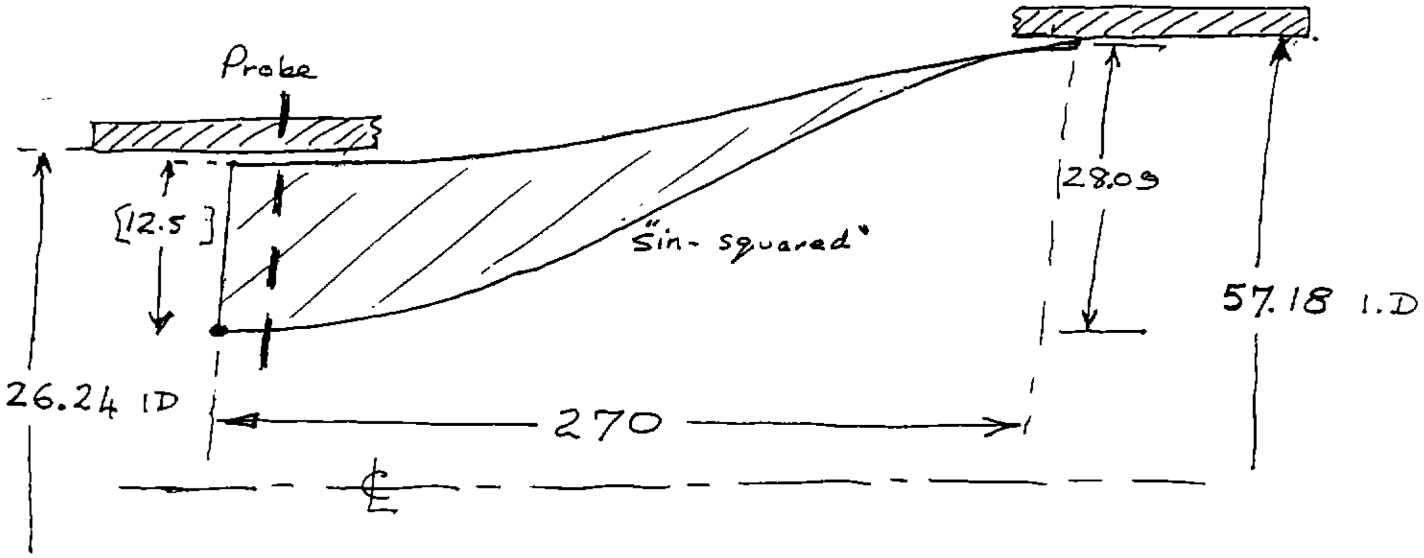
Note the greatest difference between the above sizes is that the inside diameter of the L/S OMT at the input is greater than that used on the C/X - OMT (hence the radial thickness of the fin is also larger at that point.)

COMPARISON OF FIN PROFILES AND WAVEGUIDE DIAMETERS FOR THE L/S AND C/X DUAL-BAND OMT'S

NOT TO SCALE!



(a) L/S OMT



(b) C/X OMT

FIG. B2.

Finally, is it interesting to compare the nominal frequency ranges:

(a)	L/S Feed:	1.25 - 1.75 ;	2.2 - 2.5 GHz
	Scaled by 3.34:	4.17 - 5.85;	7.35 - 8.35 GHz
(b)	C/X Feed:	4.40 - 6.10;	8.0 - 9.2 GHz

Because there are considerable differences between the OMT designs for L/S and C/X, it has been decided to carry out pattern measurements on the L/S OMT and AT horn using the two different fin types ("constant cut-off" and "sin-squared").

C. SUMMARY OF MEASUREMENTS

1. Return loss

1.1 AT designs

(a) L/S OMT

Fig B3(a), (b) and (c) show the measured return loss, including the effects of the gradual improvements made to the measurement technique, coaxial feeding, and back-short design. Fig B3(a) was an early measurement: the lower frequency "cut-off" (1.22 GHz) was due to the load design, a taper having been used to match the smaller diameter load. The design, however, met the specifications for the AT (1.25 GHz). Fig B3 (b) shows the result with an optimum load; a "cut-off" frequency of 960 MHz was achieved. Fig B3(c) shows the performance using improved coaxial feeding and optimised back short.

(b) C/X OMT

Fig B4 shows the return loss for one of the C/X OMTs. Note that the low-frequency "cut-off" is 4.5 GHz, which is above the specification of 4.4GHz. The return loss in the centre of the overall band is also relatively low.

1.2 JPL Designs

The return loss results for these OMTs are included in Annex 2. Note that the on-axis isolation is typically greater than 40 dB in all cases.

2. Radiation Patterns

To detect the effect of TM_{11}-mode generation, we need to measure E, H and ±45° radiation patterns on a complete feed system consisting of a horn and OMT. In particular, we are looking for E- and H-plane asymmetry and hence high cross-polarisation generation.

Measurements were carried out on the SETI prime-focus horn No 2 (1.6 - 3.0 GHz) using the L/S OMT with a down-taper* (191 to 146 mm)

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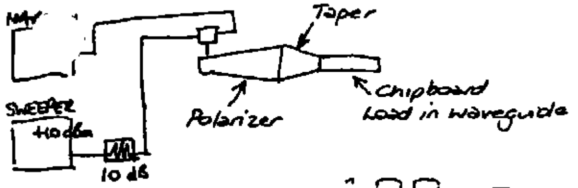
* Note that the down-taper will prevent propagation of the TM_{11} mode below 2.5 GHz.

L-S POLARIZER #2 - 13/11 9
RETURN LOSS MEASUREMENT : SHORTING PLUG WITH CONE RECESSED 5mm.
CHIPBOARD LOAD - [redacted] WILTRON BRIDGE (MODEL 60N50 *)

PROBE NOT BEING MEASURED IS TERMINATED IN 50Ω.



* ALTHOUGH NOT SPECIFIED PAST 2GHz TESTING SHOWED IT IS USABLE PAST 3GHz.

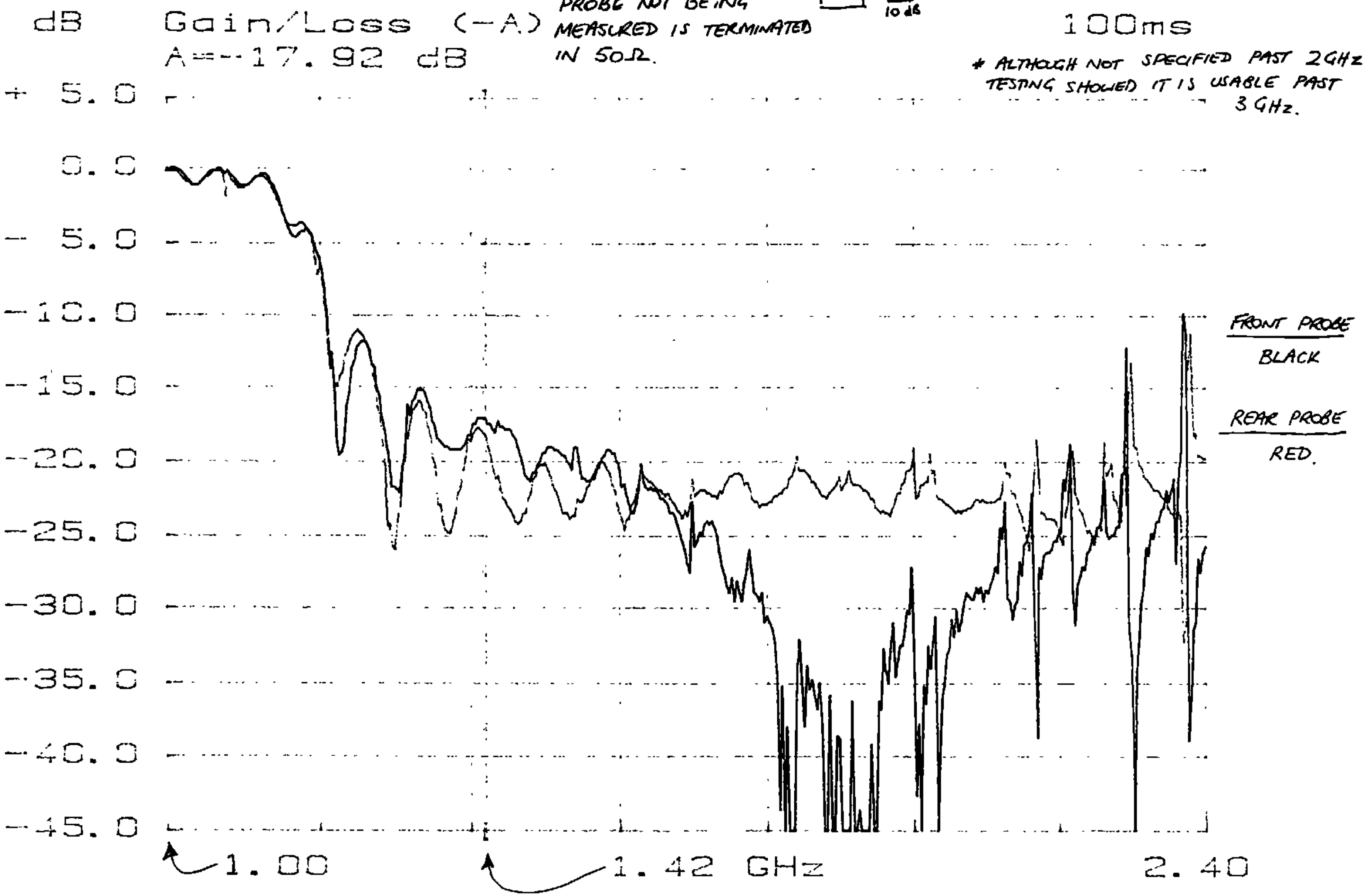
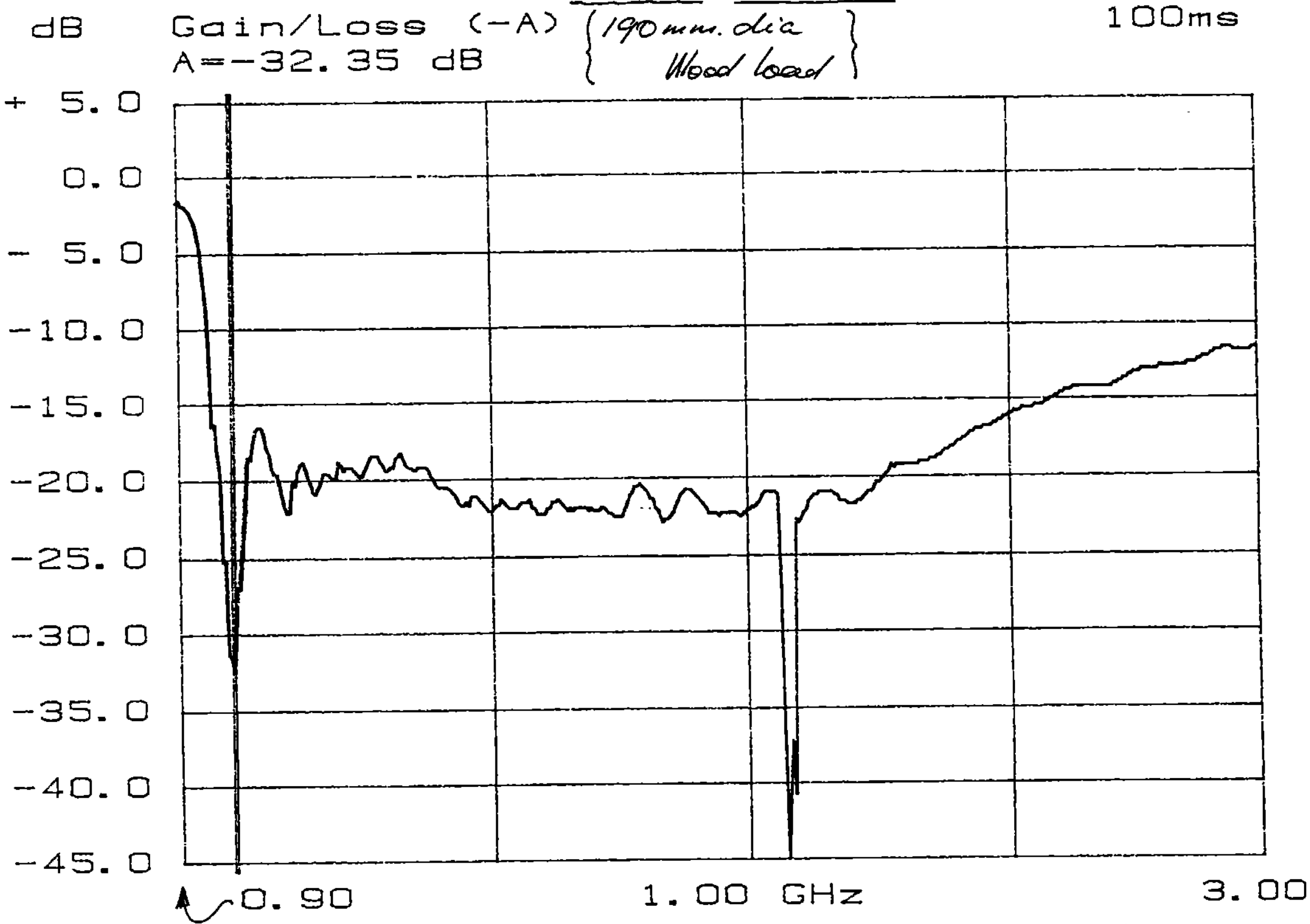


FIG.B3(a)

ATNF- L-S Band OMT. - Return Loss.

12 Mar. 1993



Waveguide Termination
{190mm. dia
Wood load}

FIG. B3(b)

Seti OMT Double hollow backshort — optimised
12/10/94

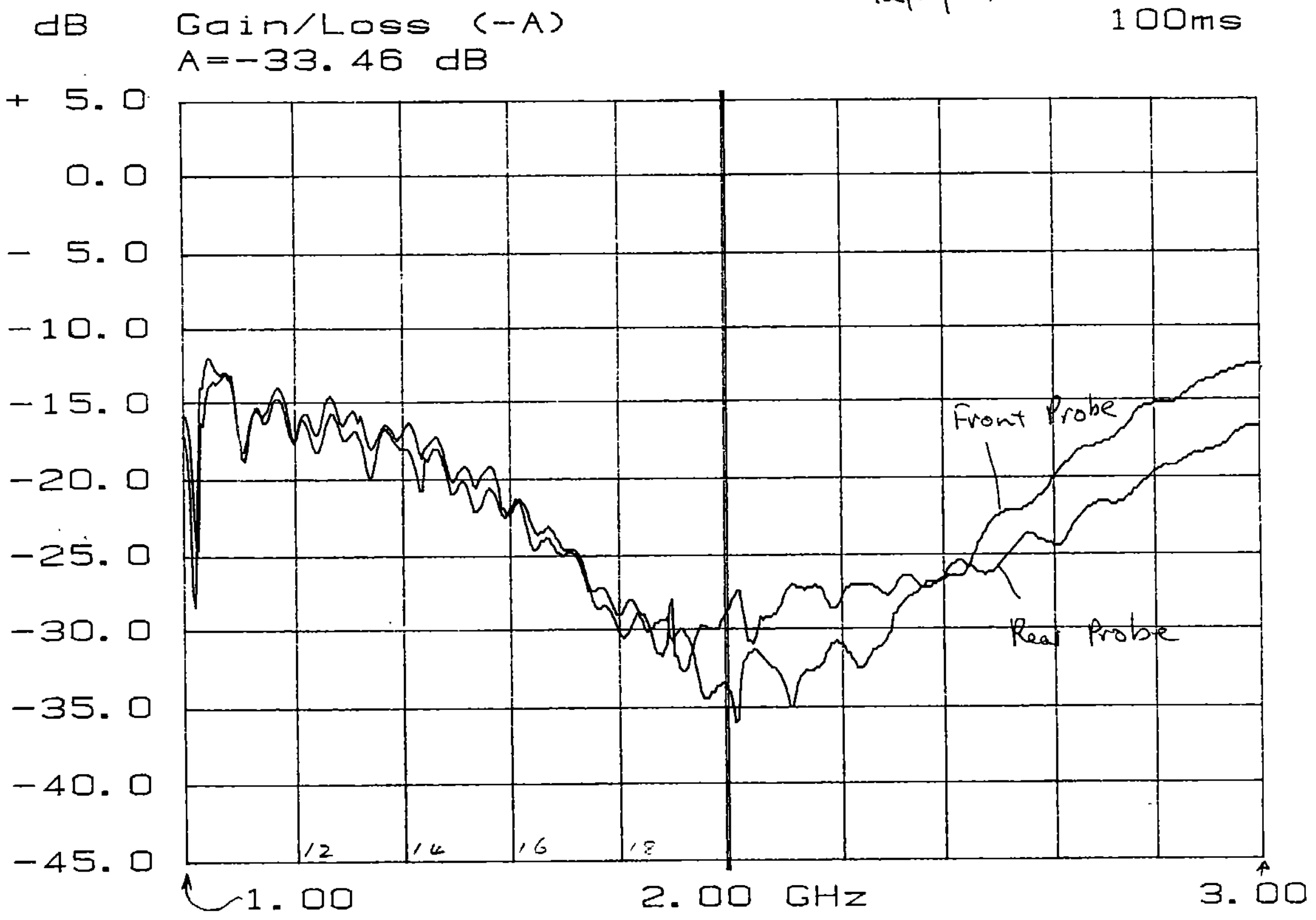


FIG. B3(c)

POLARIZER C/X #3

RETUR LOSS MEASUREMENT 27.6.89.
WITH CONVENTIONAL SHORTING PLUG AND
3mm RING INSTALLED.

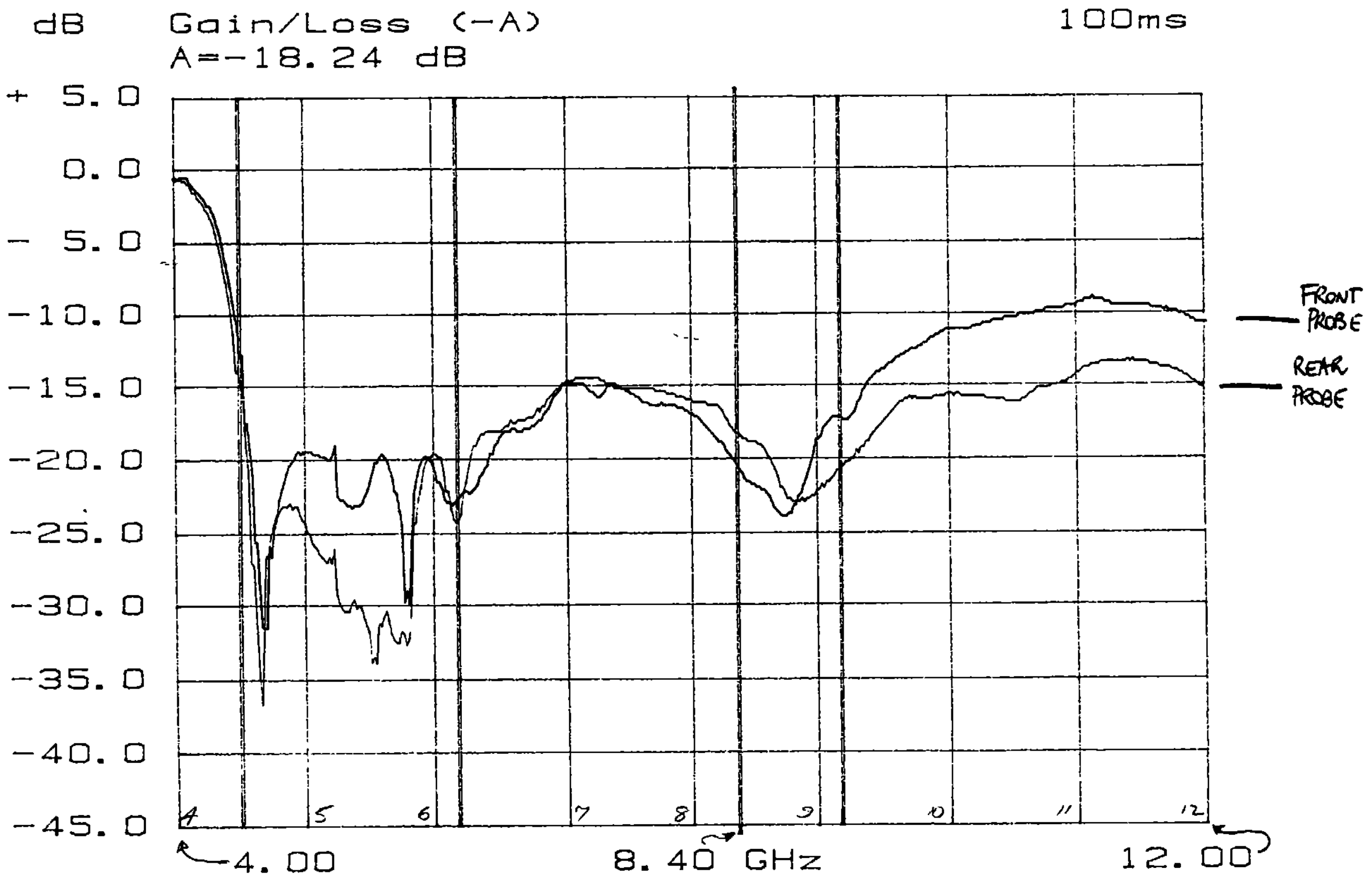


FIG. B.4

connecting the two components. The radiation pattern measurements were only carried out at 1.6, 2.2 and 3.0 GHz (without the teflon plug). The main deviant pattern characteristics were:

(a) significant levels of cross-polarisation in the E-plane at 2.3 and 3.0 GHz

(b) extreme pattern asymmetry between the E- and H-planes at 3.0 GHz

(c) significant levels of cross-polarisation at 2.2 and 2.6 GHz in the -45° plane.

Unfortunately, the pattern measurements are somewhat sparse, and more information is needed before drawing any definite conclusions.

D. CONCLUSIONS

The "cut-off" frequency for return loss appears to be considerably superior for the L/S OMT design, but the apparent high level of TM_{11} mode generation in the upper band is of concern, and is currently being investigated.

It would appear that further optimisation of the wideband OMTs is warranted, given the need to consider:

(a) return loss, including low-frequency "cut-off",

(b) higher-order mode generation in the upper part of the band,

(c) length (particularly for the lower frequency applications).

It is recommended that, following the measurements on the L/S OMT and AT horn, more detailed measurements should be carried out on a L/S system, where fins using the "alternative profile" (Fig B1) should be manufactured and tested.

E. REFERENCES

[1] G L James, "The feed system", Special Issue on the Australia Telescope, JEEE, 12, No 2, June 1992, pp 137 - 145

F. DRAWINGS (CSIRO)

A.	L/S - "Polariser"*:	F01/ 015/01 to 04
B.	C/X - "Polariser"*:	F02/ 013/01 and 02

C. OMTs for JPL†:

No		**Assembly Drawing No**	**Output I.D. (mm)**
1	–	41371	234.0
2	–	41393	146.0
3	–	41402	82.0
4	–	?	44.0

* "Polariser" should read "OMT". Note also that some errors appear on these drawings.

† These drawings were updated by R E Shields and J J Oprzedek following adjustment.

ANNEX 1

OPTIMISING THE PROBE MATCH AT THE INPUT TO THE OMTS

By R E Shields

The Optimisation of Probe Match for the JPL SETI OMTs went through several stages of development which finally resulted in a true wideband system of matching with a procedure which could be easily implemented.

Adjustment of the backshort also played a large part in the final adjustment.

1. No 1 OMT λ/4 Matching Section

As the distance between the input connector is slightly greater than λ/4, it was possible to transform the impedance in this section to provide a good match to the radiating part of the probe. This was done experimentally by tapering the diameter of the probe before it entered the fin gap. The dielectric in this case was air although other dielectrics were considered in the development stages.

Matching using a λ/4 section provided a good match across the desired band but with large variations which were due to the tuned nature of this approach.

2. Varying the air gap between fins

With OMT No 1 the air gap was varied from the nominal value as set by G L James and S Skinner. These variations did improve the match slightly but this is clearly a second-order effect.

3. Wideband matching

With OMTs Nos 2, 3 and 4 it was decided to improve the matching for the following reasons:

(a) λ/4 matching sections are not wideband

(b) due to the smaller size of the OMT it would be difficult to incorporate a λ/4 matching section. The matching procedure used the following steps:

- the coaxial section from the connector through to the fin was designed to be 50 ohms
- using a vector network analyser and a special shorting piece a reference plane was established at the point where the X probe leaves the fin and enters the air gap. This gives a reference plane to calibrate so that the impedance into the waveguide may be accurately measured.

When the impedance into the guide is known it is only matter of calculating the percentage change in probe diameter required to match into 50 ohms.

When designing the 50 ohm coaxial section, it is important to select a dielectric which allows a large centre conductor which can be machined down to the correct diameter.

Using this technique gives a smooth wideband return loss curve which changes only gradually at the band edges.

4. The Backshort

The backshort used in all OMTs was of the same design as used by G L James and S Skinner. The position of the short is a compromise due to the different axial position of each probe relative to the short.

On OMT No 4 a polarised backshort was tried and this enabled the position to be optimised for both probes. The polarised backshort was not used in the production OMTs.

ANNEX 2

JPL OMTS - RETURN LOSS

for

BATCH NO 1 AND BATCH NO 2

OMT Parameters

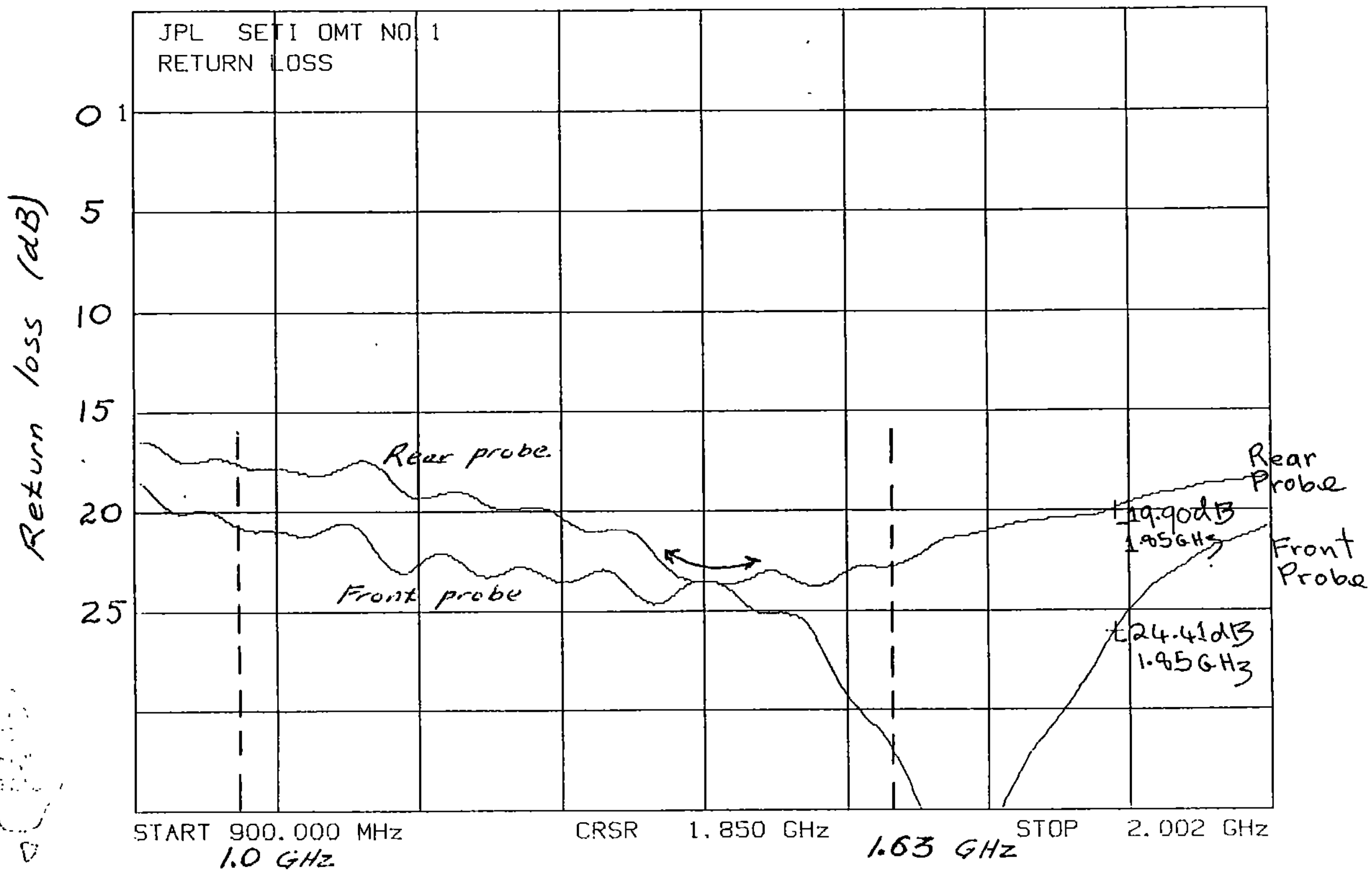
No	Frequency range (GHz)	Output dia (mm)	TM11 cut-off freq (GHz)*
1	1.0 - 1.63	234.0	1.56
2	1.61 - 3.02	146.0	2.50
3	2.86 - 5.35	82.0	4.5
4	5.34 - 10.0	44.0	8.3

* Reference to output waveguide

WAVETEK Precision Scalar Analyzer Model 8003 June 26, 92 14:32:58
CH1: SW A -PC CRSR -19.90 dB
5.0 dB/ S REF 0.00 dB

R Shields 30-6-92.

1.7.92



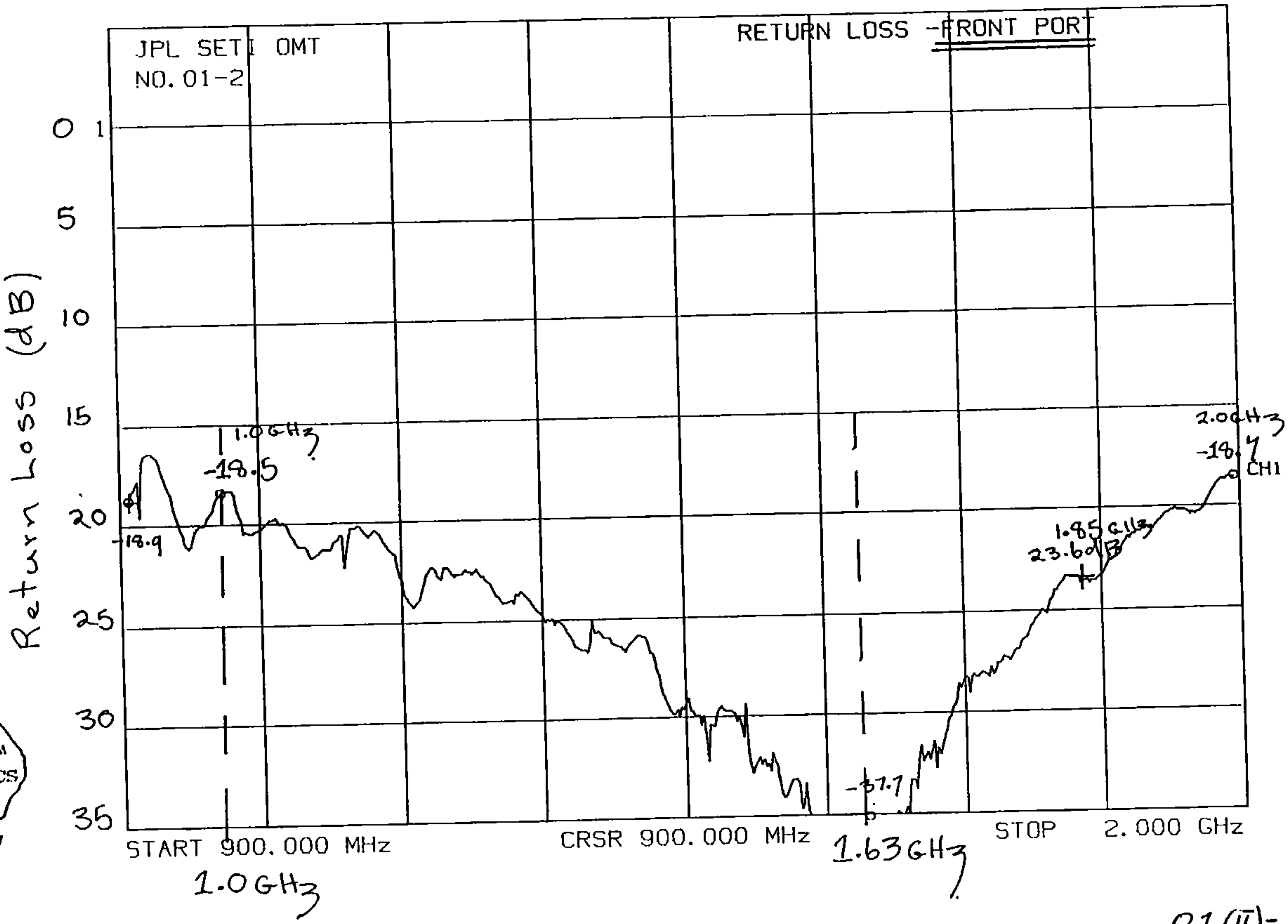
WAVETEK Precision Scalar Analyzer Model 8003 June 04, 93 11:42:

CH1: SW A -PC CRSR -18.88 dB

5.0 dB/ H REF 0.00 dB

R Shields 4-6-93

B. [illegible], 8.6.93



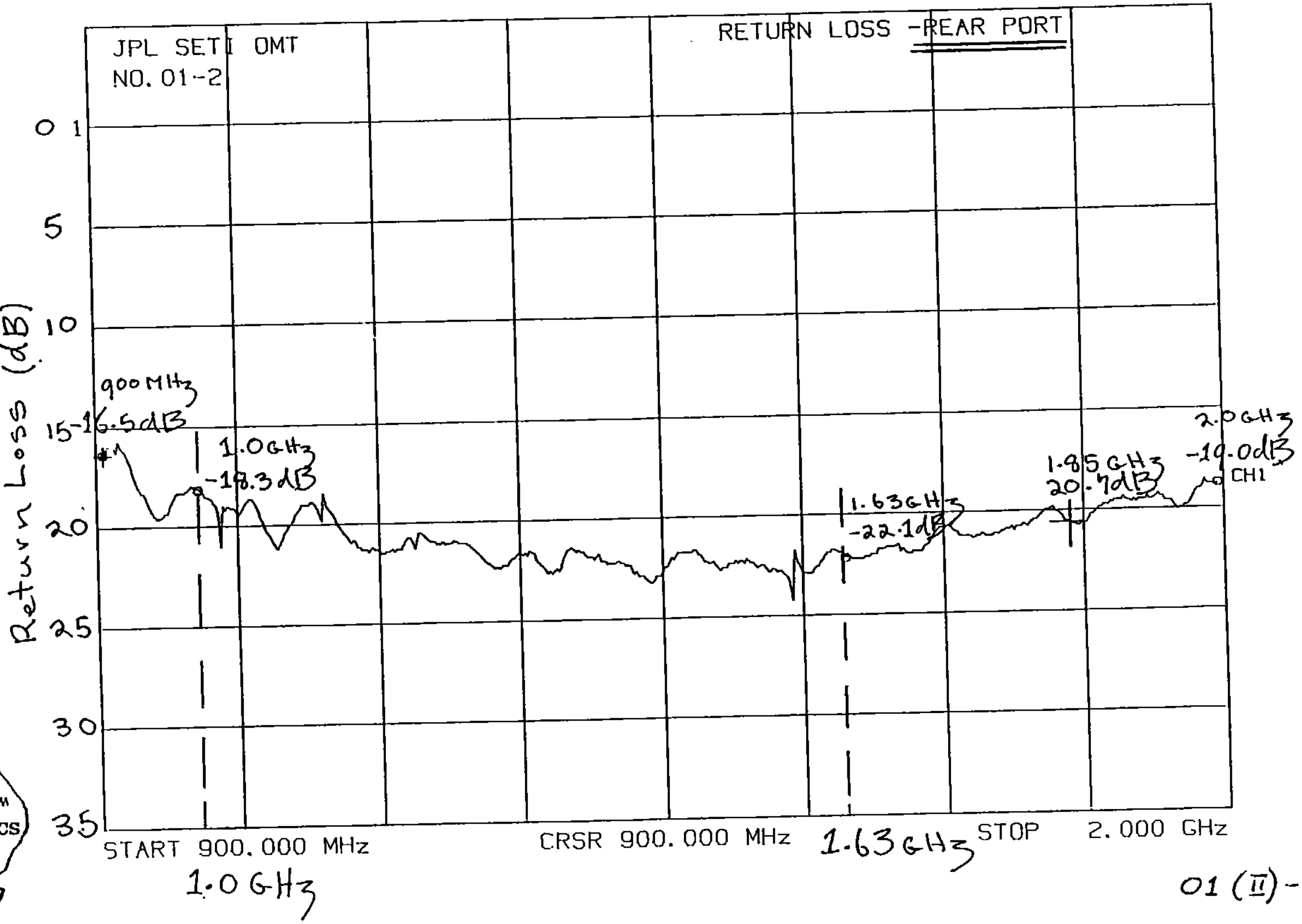
D

01 (II) - 1A

WAVETEK Precision Scalar Analyzer Model 8003 June 04, 93 09: 59: 37
CH1: SW A -PC CRSR 16. 51 dB
5. 0 dB/ H REF 0. 00 dB

R Shields 4-6-93

B. Mock. Thom 8. 6. 93



CSIRO
RADIOPHYSICS

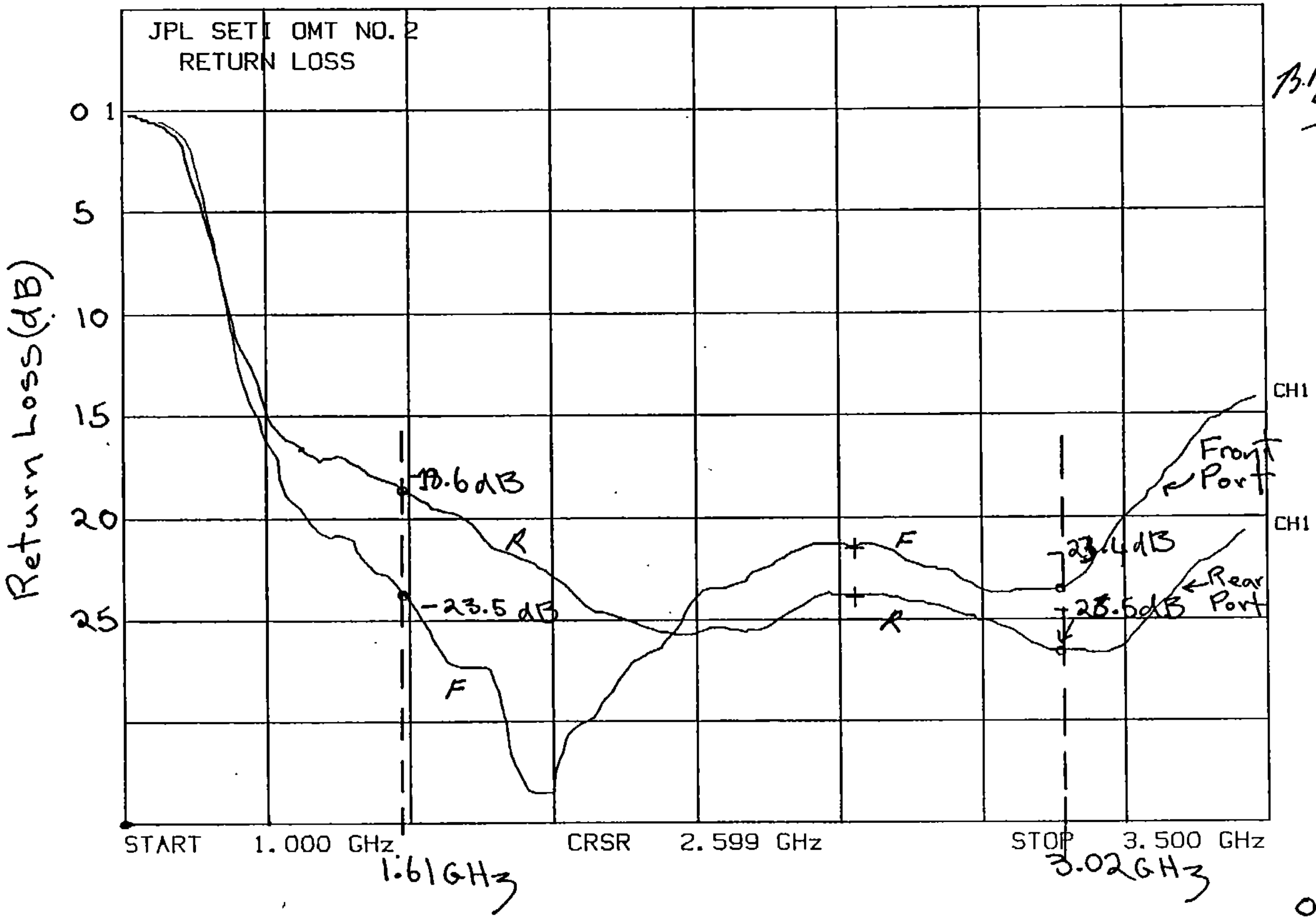
D

01 (II) - 1B.

WAVETEK Precision Scalar Analyzer Model 8003 Sept 09, 92 14:49:22
CH1: SW A -PC CRSR -21.35 dB
5.0 dB/ S REF 0.00 dB

R Shields 9-9-92.

9.9.92



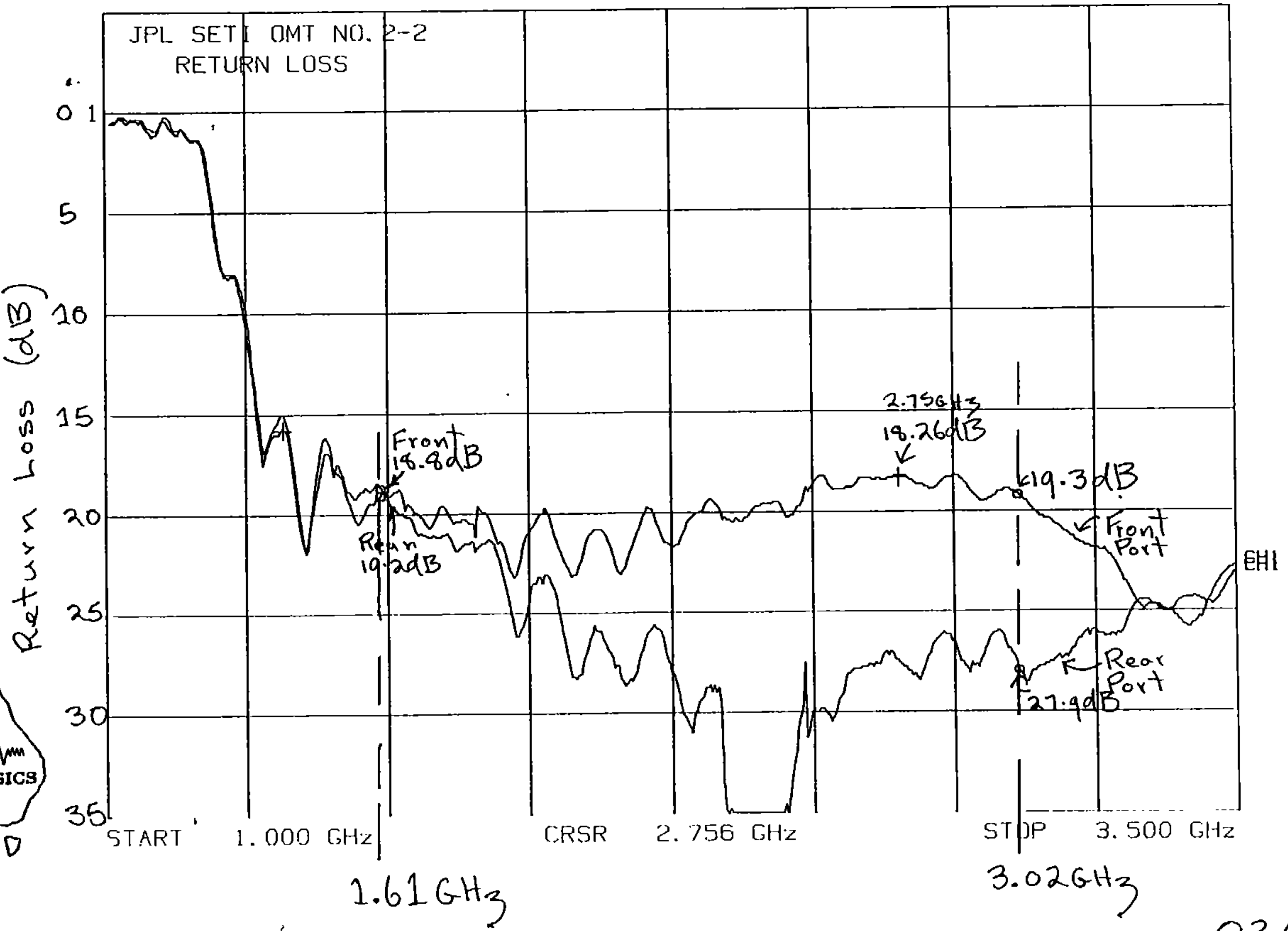
02-1

CH1: SW A -PC CRSR -18.26 dB
5.0 dB/ REF 0.00 dB

Oct 08, 93 09: 28: 19

R Shields 9-10-93

11.10.93



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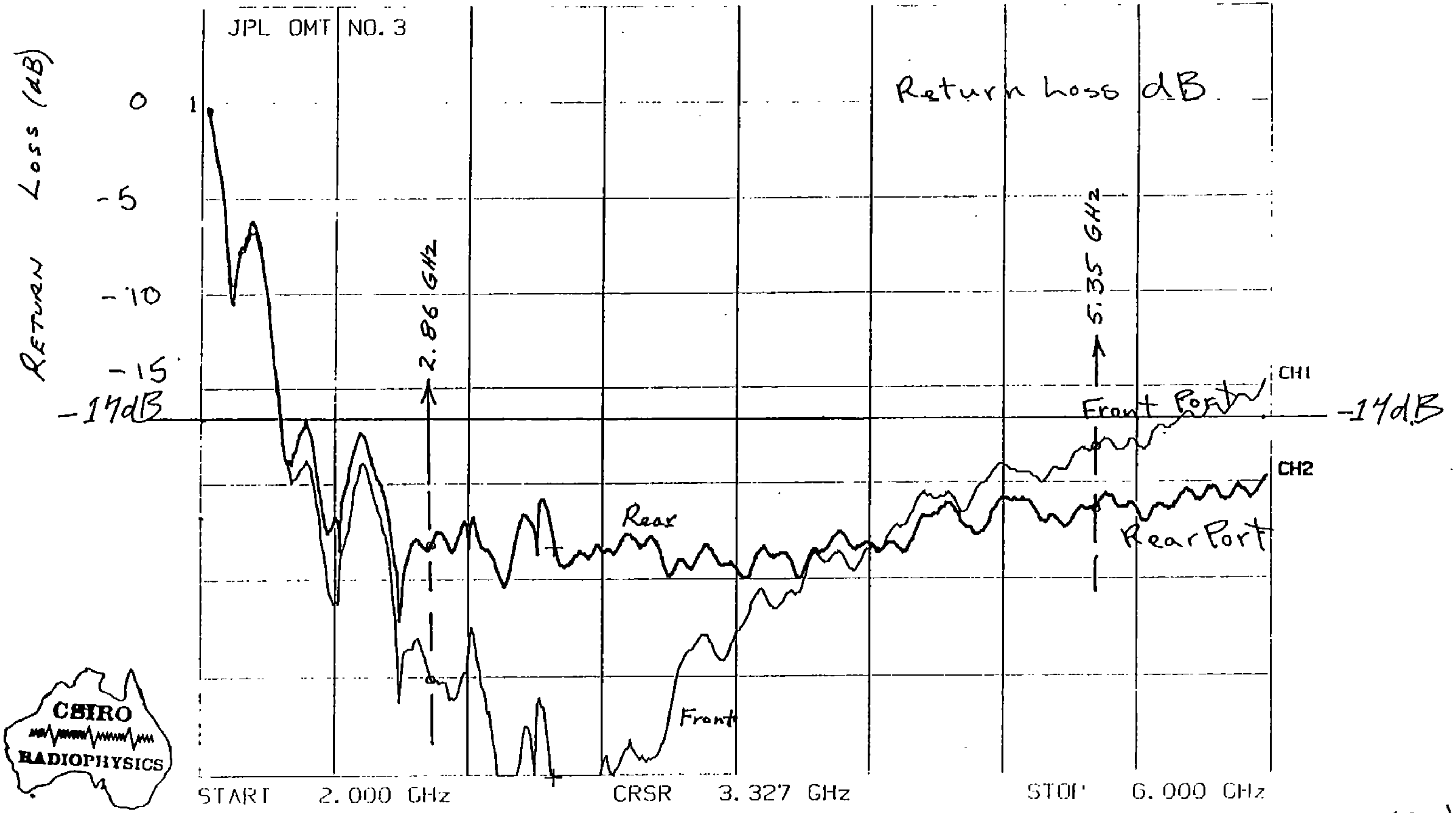
RADIOPHYSICS

02 (II)-1

WAVETEK Precision Scalar Analyzer Model 8003 Dec 21, 92 11:05:34
CH1: SW A -PC CRSR -38.17 dB
5.0 dB/ H REF 0.00 dB

R Shields 21-12-92.

B. MacA. Thomas 6.1.93

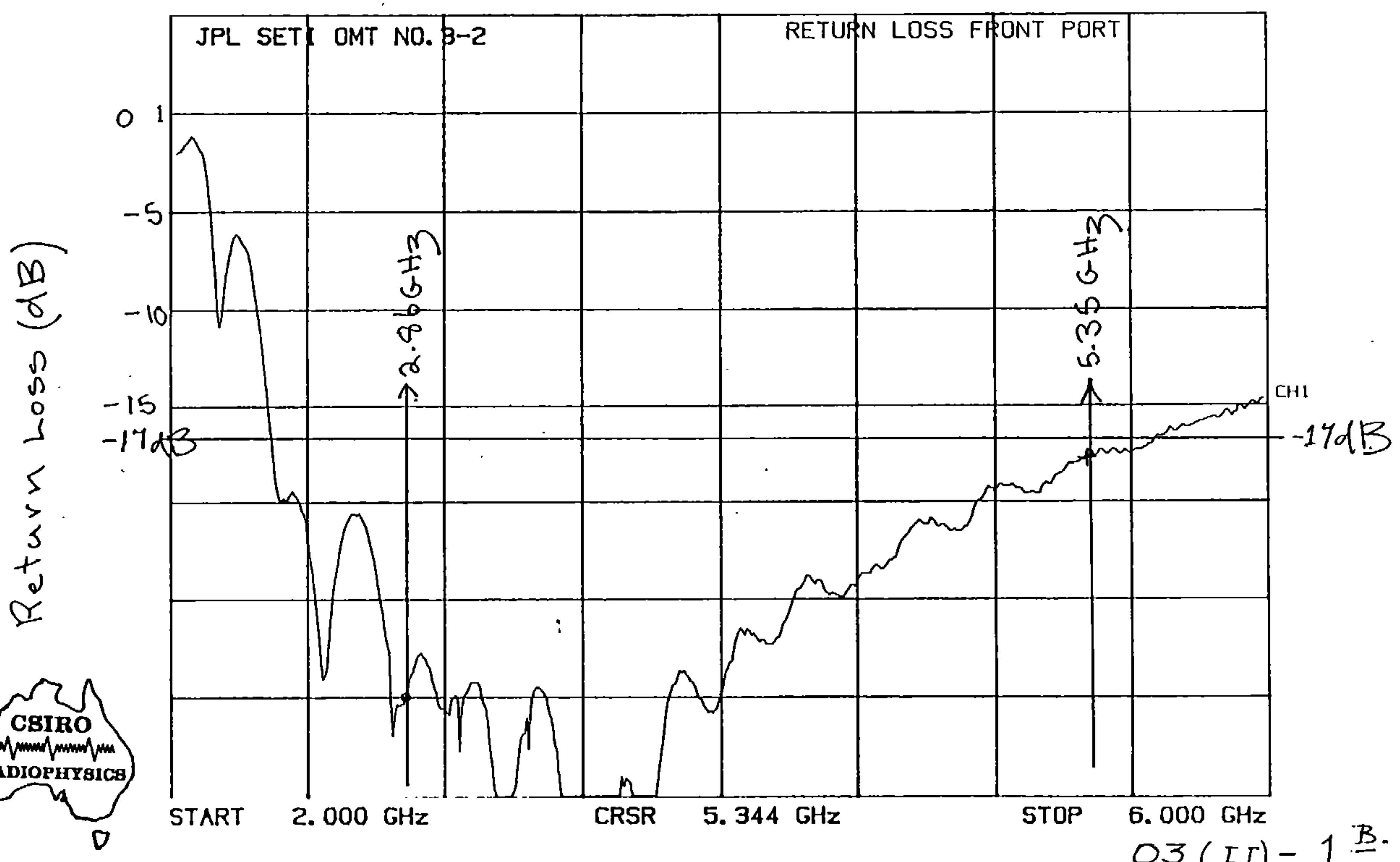


03-1 (Rev).

R Shields 10-12-93.

10 12-93

CH1: SW A -PC CRSR -17.73 dB
5.0 dB/ REF 0.00 dB



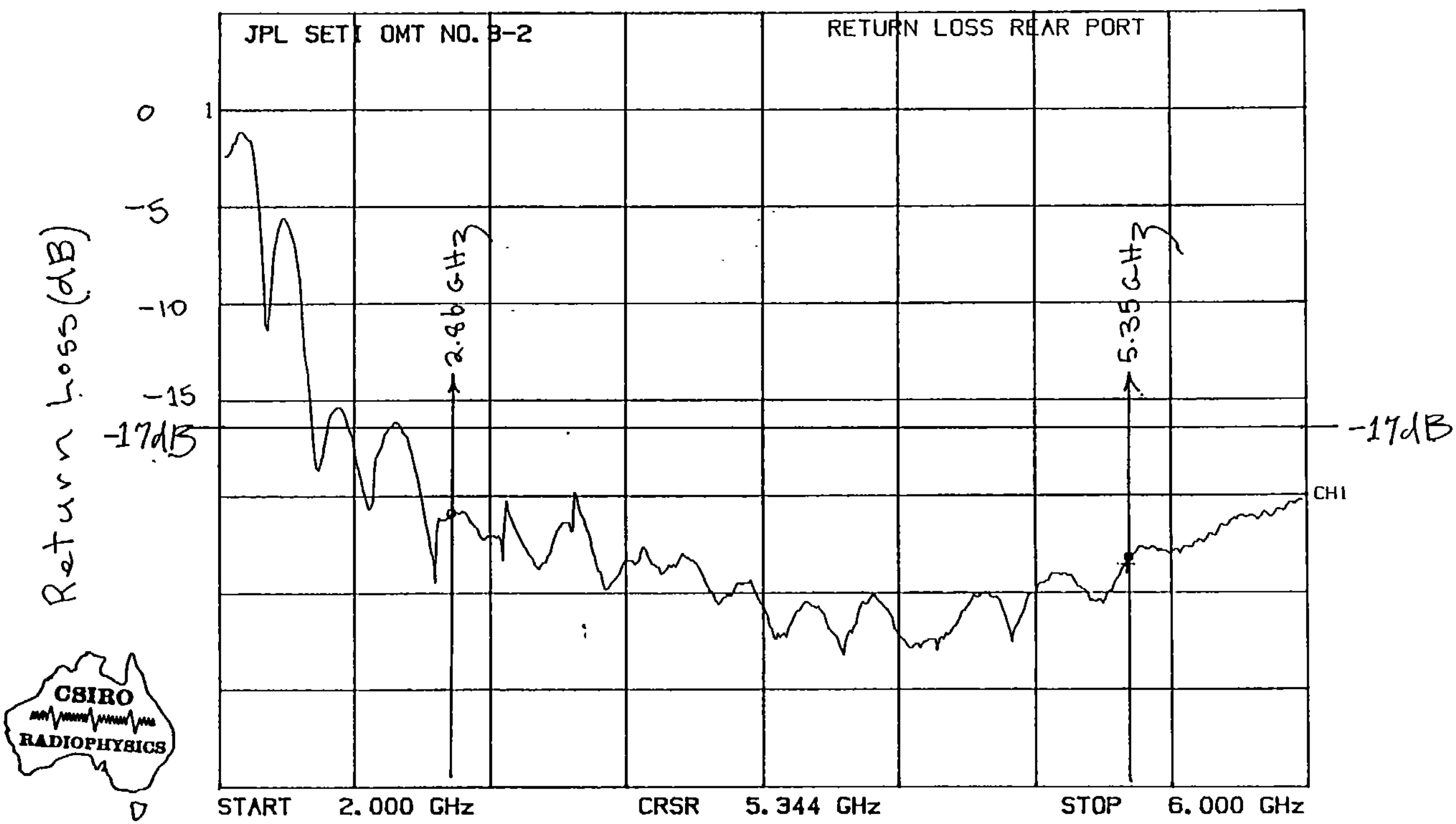
CSIRO RADIOPHYSICS

03 (II) - 1 B.

R Shields 10-12-93

10.12.93

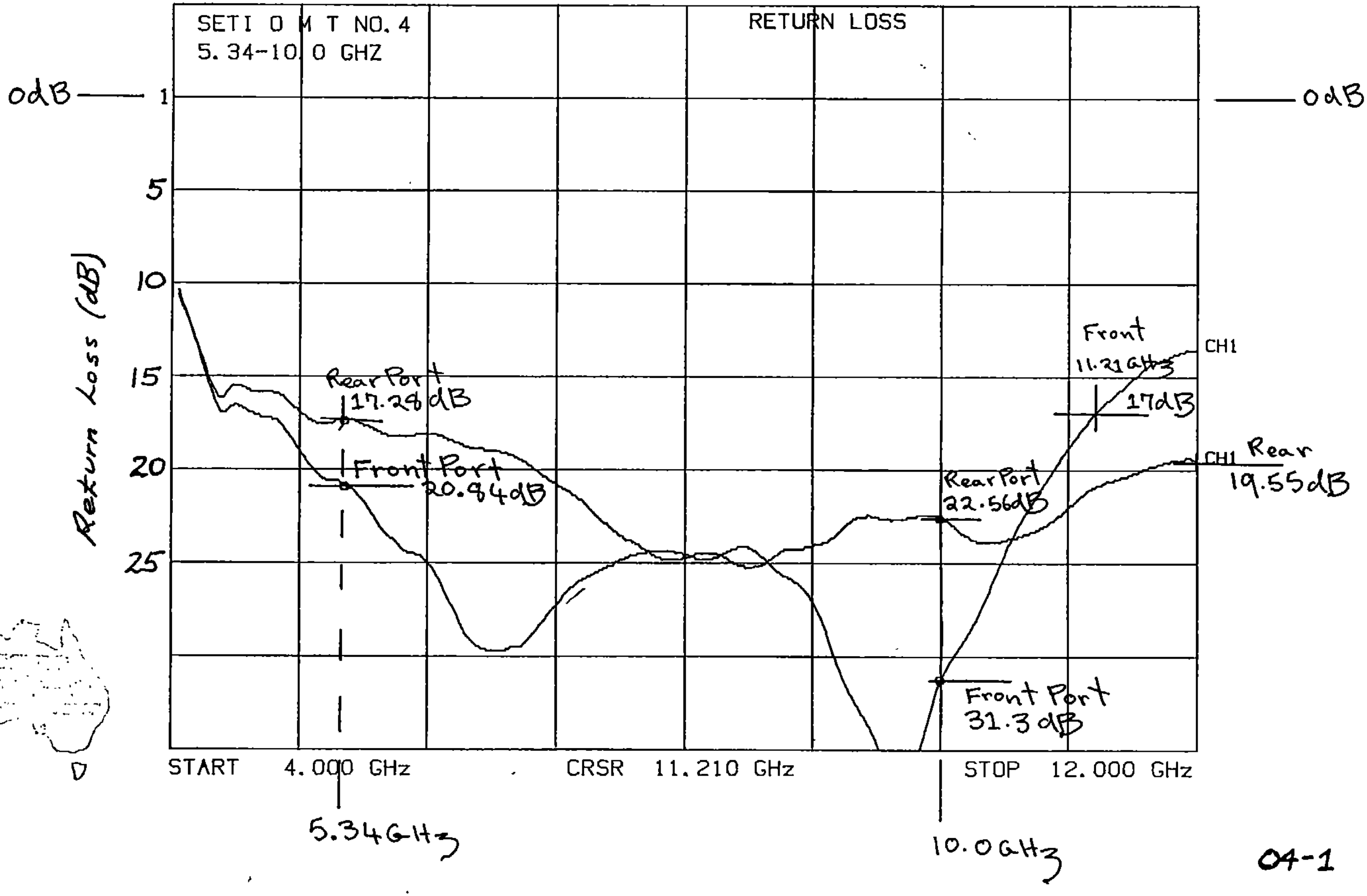
CH1: SW A -PC CRSR -23.50 dB
5.0 dB/ REF 0.00 dB



O3(II)-1A

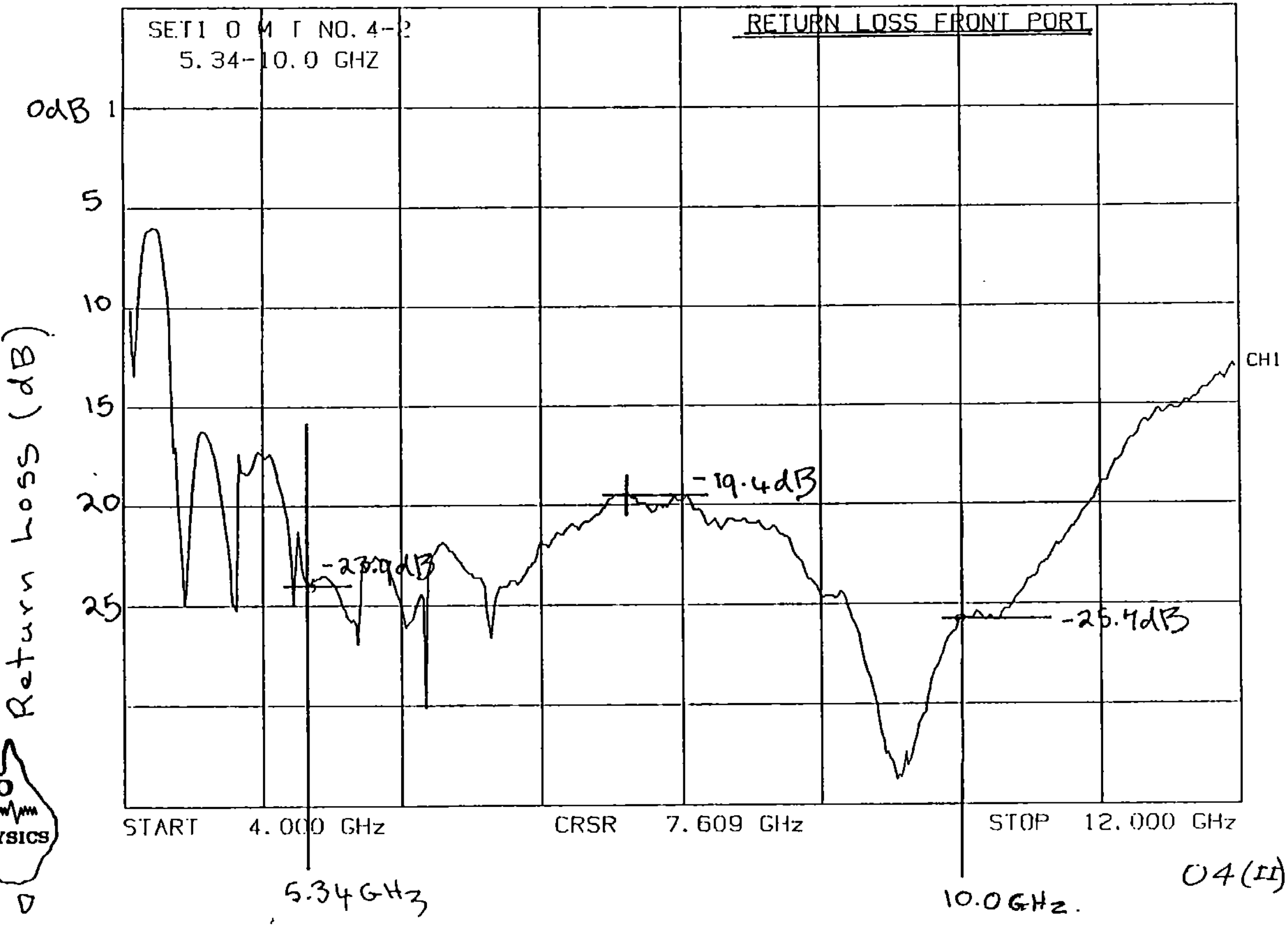
WAVETEK Precisi Scalar Analyzer Model 80 Aug 07, 92 09: 54: 06
CH1: SW A -PC CRSR -17. 02 dB
5. 0 dB/ S REF 0. 00 dB

R Shields 7/8/92
B. Mod. Vers. 7. 8.



CH1: SW A -PC CRSR -19.43 dB
5.0 dB/ REF 0.00 dB

July 29, 93 09: 19: 03
29/7/93
29.7.93

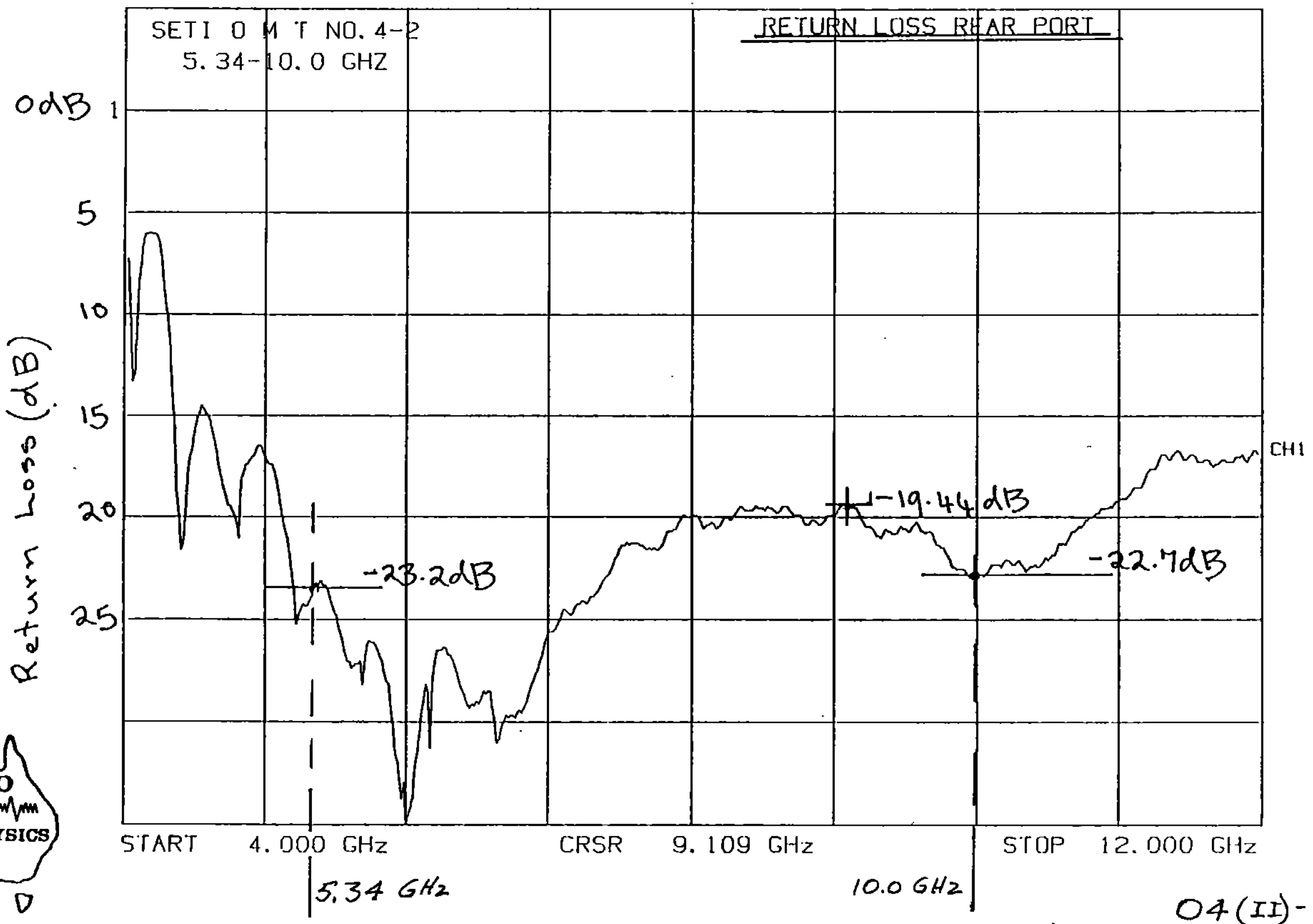


04(II)-1Δ

H

CH1: SW A   -PC CRSR -19.44 dB
5.0 dB/   REF   0.00 dB

July 29, 93   09:24:13
R Shields 29/7/93
B. Mad. Thomas 29.7.93



CSIRO RADIOPHYSICS

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04(II)-1B