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Investigating the effects of interchanging components used to perform 'ripple' assessments on calibrated vector network analysers

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Abstract

This report presents results obtained from a series of investigations into the effects of changing the components used to perform a 'ripple' assessment of the residual error terms in a calibrated vector network analyser. The three principle components — a load, short-circuit and reference air line — are interchanged with nominally similar, but physically different, artefacts to illustrate the effect such changes have on the performance of the ripple technique.

1 Introduction

The 'ripple' technique [1] is now well established as a method for evaluating the size of some of the residual error terms in a calibrated vector network analyser (VNA). The technique uses a precision reference air line terminated with a low reflecting load and, in turn, a precision short-circuit. The air line/load combination is used to determine the effective directivity error term, D, for the system, and the air line/short-circuit combination determines the effective test port match error term, M. These error terms are used subsequently to determine the uncertainty of measurement for the calibrated VNA. An accurate determination of these residual error terms is therefore essential in order to provide an estimate of the uncertainty of the calibrated VNA.

Reference [1] gives guidance on the nominal choice of artefacts to be used to perform the ripple assessment. However, there is little documented evidence to show how the technique is affected by varying the choice of artefact. Such a situation may occur when implementing the technique in a laboratory where a selection of suitable components may be available.

This report presents results obtained from a series of experiments employing a range of different components used whilst performing ripple assessments on a calibrated VNA. The same calibration was used throughout the investigations, thus enabling comparisons to be made between the various component configurations, independent of the VNA calibration scheme. For the purposes of this investigation, the maximum likely values for the residual error terms are computed based on the maximum adjacent peak-to-peak ripple seen in each plot. Thus, D is evaluated from the air line/load combination as follows:

$$D = \frac{Maximum\ \ Ripple\ \ Amplitude}{2}$$

and M is evaluated from the air line/short-circuit combination using:

$$M = \frac{Maximum\ \ Ripple\ \ Amplitude}{2}$$

2 Experimental

An HP8510C VNA was set up to measure GPC-7 items from 1 GHz to 18 GHz in 0.1 GHz steps. A short-open-load technique (using a fixed broadband load) was used to calibrate port one of the VNA. This port was used exclusively throughout the investigations.

2.1 Interchanging loads

The first series of experiments used an unsupported air line of nominal length 100 mm (taken from an HP verification kit) terminated in turn with the following loads:

1) HP 85050-60006 broadband load (also used to calibrate the VNA);

2) HP 85050-60006 broadband load (*not* used to calibrate the VNA);

3) HP 85050-60001 low band load;

4) (An alternative) HP 85050-60001 low band load;

5) 1.1 VSWR mismatch load (i.e. nominal VRC of 0.05);

6) 1.3 VSWR mismatch load (i.e. nominal VRC of 0.13).

The mismatch loads were included in the investigation since in [1], it states that: “a load with Voltage Reflection Coefficient (VRC) in the range 0.1 to 0.2 is most suitable”.

The resulting ripple plots, produced using the air line in conjunction with the above six loads, are shown in Figures 1 to 6, respectively. These results have also been presented elsewhere [2]. The dashed trace in each figure shows the response of the load connected directly to the VNA test port[1]. Table 1 gives the maximum values for *D* derived from these plots.

Figure No	Load type	Maximum directivity error, *D* (linear units)
1	Broadband load (used during calibration)	0.009
2	Broadband load (not used during calibration)	0.008
3	First low band load	0.011
4	Second low band load	0.011
5	1.1 VSWR mismatch load	0.014
6	1.3 VSWR mismatch load	0.013

Table 1: Values for the maximum directivity error term evaluated using the different loads

[1] The dashed trace in Figure 1 is superimposed along the frequency axis and is therefore not visible. This is to be expected since this load (i.e. the calibration load) is assumed to have zero reflection during a short-open-load calibration employing a fixed broadband load.

2.2 Interchanging short-circuits

The second series of experiments used the same unsupported air line, as in section 2.1 above, terminated in turn with four colleted short-circuits. The resulting ripple plots produced using the air line/short-circuit combinations are shown in Figures 7 to 10. Table 2 gives the maximum values for *M* derived from these plots.

Figure No	Short-circuit No	Maximum test port match error, *M* (linear units)
7	1	0.020
8	2	0.020
9	3	0.020
10	4	0.020

Table 2: Values for the maximum test port match error term evaluated using the different short-circuits

2.3 Interchanging reference air lines

The third series of experiments used a load and a short-circuit in conjunction with the following air lines:

1) 300 mm line manufactured by Maury Microwave Corporation;

2) (An alternative) 300 mm line manufactured by Maury Microwave Corporation;

3) 100 mm line from an HP verification kit[2];

4) (An alternative) 100 mm line from an HP verification kit[2];

5) 150 mm line manufactured by Rosenberger Microwave Corporation;

6) 50 mm line manufactured by Rosenberger Microwave Corporation.

2.3.1 Using the lines terminated with a load

The above lines were terminated with one of the loads used previously in section 2.1. This load was chosen arbitrarily and, in this case, was the broadband load not used in calibration. The resulting ripple plots produced using the different air lines terminated with this load are shown in Figures 11 to 16. Table 3 gives the maximum values for *D* derived from these plots.

[2] These lines are of the same type as the line used in sections 2.1 and 2.2, above.

Figure No	Line type	Maximum directivity error, *D* (linear units)
11	First 300 mm Maury line	0.007
12	Second 300 mm Maury line	0.006
13	First 100 mm HP line	0.007
14	Second 100 mm HP line	0.007
15	150 mm Rosenberger line	0.009
16	50 mm Rosenberger line	0.008

Table 3: Values for the maximum directivity error term evaluated using the different air lines

(A similar degree of variation in the determinations of *D* was found when a different load was used in conjunction with these air lines.)

2.3.2 Using the lines terminated with a short-circuit

The air lines were then terminated with a short-circuit (chosen arbitrarily, as No 2). The resulting ripple plots produced using the different air lines terminated with the short-circuit are shown in Figures 17 to 22. Table 4 gives the maximum values for *M* derived from these plots.

Figure No	Line type	Maximum test port match error, *M* (linear units)
17	First 300 mm Maury line	0.019
18	Second 300 mm Maury line	0.019
19	First 100 mm HP line	0.020
20	Second 100 mm HP line	0.020
21	150 mm Rosenberger line	0.022
22	50 mm Rosenberger line	0.015

Table 4: Values for the maximum test port match error term evaluated using the different air lines

3 Observations

All values of *D* and *M* achieved during these investigations show good agreement with typical values published elsewhere [3]. However, of principle concern here is the degree of variation found in the evaluated error terms due to varying the components used for the ripple assessment.

3.1 Variation due to interchanging loads

There is significant variation in the values of *D* established using different loads (as shown in Table 1). It is interesting to note that the ripple plots for similar types of load show a similar behaviour. For example, there are similarities between the plots obtained using the broadband loads (Figures 1 and 2), the low band loads (Figures 3 and 4) and the mismatched loads (Figure 5 and 6). The resulting values of *D*, derived from these plots, also show this correspondence.

It is clear from examining the traces produced by the loads connected directly to the VNA test port (the dashed traces in Figures 1 to 6) that the low band loads and the mismatched loads exhibit considerable variation in VRC with frequency. It is therefore likely that the values of D obtained from these plots are affected by this underlying frequency response. However, it must be remembered that this perceived variation is *with respect to the broadband load used during calibration*, which is assumed to have zero reflection (!) for the calibration scheme used here.

3.2 Variation due to interchanging short-circuits

There is very little variation in the values of M established using the different short-circuits (as shown in Table 2). Indeed, the ripple plots for these air line/short-circuit combinations are almost identical. This is very encouraging, since one would expect that zero offset precision short-circuits will have very similar reflection characteristics, i.e. a VRC close to (-1, 0) in the complex plane. This indicates that the evaluation of M is essentially independent of the choice of short-circuit used to terminate the air line.

3.3 Variation due to interchanging reference air lines

Each of the air lines used in these investigations will have slightly different mechanical dimensions. Of particular importance here are the cross-sectional diameters of the inner and outer conductors, since these dimensions define the characteristic impedance of each air line. The line’s characteristic impedance forms the reference impedance for the ripple assessment, and should ideally be 50 Ω exactly.

To verify the suitability of these lines as reference impedances, the diameters of the inner and outer conductors of each line were measured using an air-gauging system [4]. These diameter measurements are subsequently converted to an equivalent characteristic impedance value for each line. These values, and their associated uncertainties, are given in Table 5. It can be seen that the range of characteristic impedance values (allowing for the uncertainty of measurement) for all lines, except the 50 mm Rosenberger line, includes the 50 Ω reference value. An allowance can be made for the departure from the nominal value of 50 Ω for each line [1], although this is not considered here.

Line type	Characteristic impedance (Ω)
First 300 mm Maury line	49.994 ± 0.135
Second 300 mm Maury line	49.982 ± 0.088
First 100 mm HP line	49.999 ± 0.093
Second 100 mm HP line	50.014 ± 0.038
150 mm Rosenberger line	49.937 ± 0.092
50 mm Rosenberger line	49.871 ± 0.082

Table 5: Air-gauge determinations of the air lines’ characteristic impedance values

3.3.1 Using the lines terminated with a load

The ripple plots obtained using the different air lines terminated with the load (Figures 11 to 16) show a similar overall shape, although the rate of ripple varies considerably with the air line length (as discussed in [1]). In principle, the longer the length of line, the more ripples will be produced for a given frequency range. This implies that a more detailed account of the residual error as a function of frequency will be discernible. However, due to the physical limitations of air line lengths (for example, due to the potential sagging of the inner conductor of long lines), it is generally considered that lines longer than 300 mm should be avoided when performing standard ripple assessments on VNAs. Similarly, lines much shorter than 100 mm are likely to miss some of the detailed structure exhibited by the frequency dependent residual error terms, and should therefore also be avoided for this frequency range.

There is very little variation in the values of D obtained for the range of lines considered in this investigation. Generally, a value of $D \approx 0.007$ was obtained, although 0.009 was obtained using the Rosenberger 150 mm line.

3.3.2 Using the lines terminated with a short-circuit

The ripple plots obtained using the different air lines terminated with the short-circuit (Figures 17 to 22) again show similar overall trends, with maximum ripples occurring at a similar frequency region (at approximately 15 GHz). The values of M obtained from these plots are also very similar, being typically 0.020, although a value of 0.015 was obtained from the plot produced using the Rosenberger 50 mm line. This lower value of M may be due to the length of this line being inadequate to fully display the extent of the error term's frequency characteristics, as discussed previously. This results in a value for the error term which is lower than the notional 'true' value.

4 Conclusions

This investigation has examined the effects of interchanging the components used when performing a ripple assessment on a calibrated VNA. From this investigation the following conclusions can be made:

1) The choice of load used to terminate the air line when evaluating the residual directivity error, D, can have a significant effect on the value obtained. More work needs to be done in order to establish the most suitable type of termination for evaluating this residual error term;

2) The choice of short-circuit used to terminate the air line when evaluating the residual test port match error, M, has very little effect on the value obtained for the residual error. This implies that any precision short-circuit, in good working order, can be used to perform this assessment;

3) The choice of air line used with either the load or the short-circuit when evaluating the residual error terms D and M, respectively, has very little effect on the value obtained for the residual error terms. However, in practice, it is anticipated that lines

either longer than 300 mm or shorter than 100 mm should be avoided for ripple assessments[3].

5 Acknowledgements

The work presented in this report was funded by the National Measurement System Policy Unit of the Department of Trade and Industry.

6 References

[1] "EA Guidelines on the Evaluation of Vector Network Analysers (VNA)", *European co-operation for Accreditation*, Publication reference EA-10/12, May 2000. (Available from the EA web-site at: `www.european-accreditation.org`).

[2] A G Morgan and N M Ridler, "Load effects on ripple plots", *ANAMET News*, Issue 14, pp 2-3, Spring 2000.

[3] N M Ridler and C Graham, "Some typical values for the residual error terms of a calibrated vector automatic network analyser (ANA)", *BEMC'99 Conference Digest*, pp 45/1-45/4, November 1999.

[4] J P Ide, "Traceability for radio frequency coaxial line standards", *NPL Report DES 114*, July 1992.

[3] Lines shorter than 100 mm may be suitable as ripple assessment lines when the frequency range of the measurements is sufficiently large. For example, for broadband measurements in the smaller coaxial line sizes.

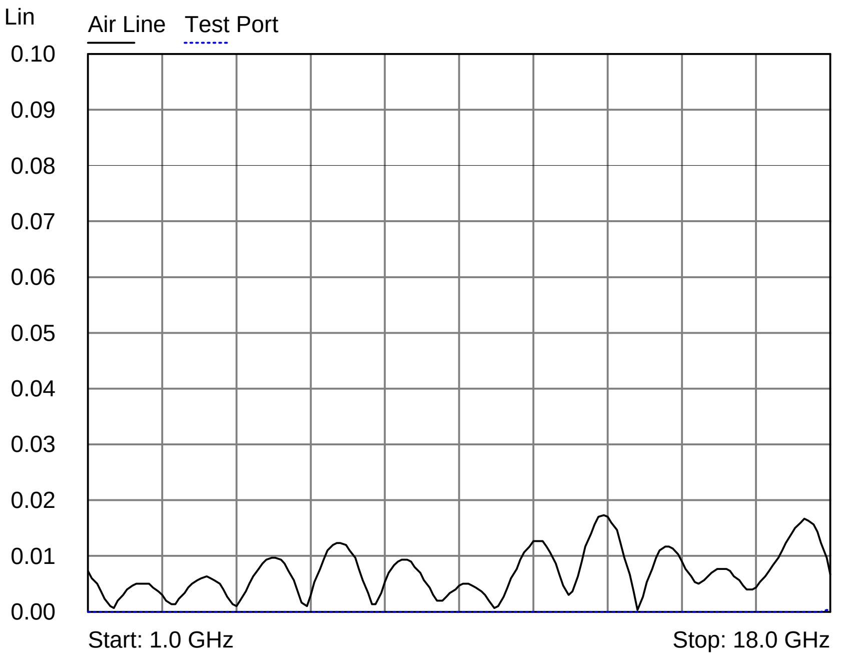

Fig 1. Broadband load (used during calibration) connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

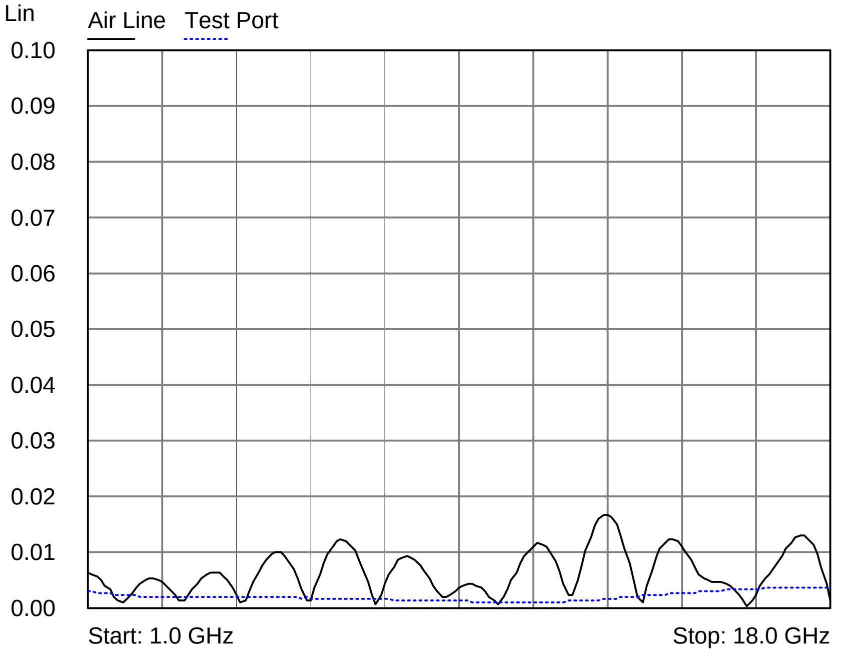

Fig 2. Broadband load (not used during calibration) connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

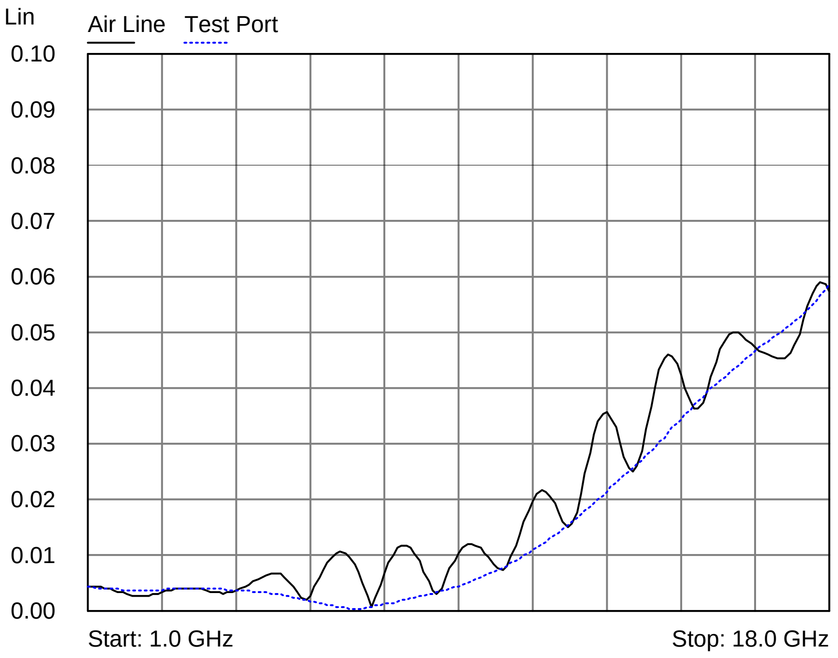

Fig 3. First low band load connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

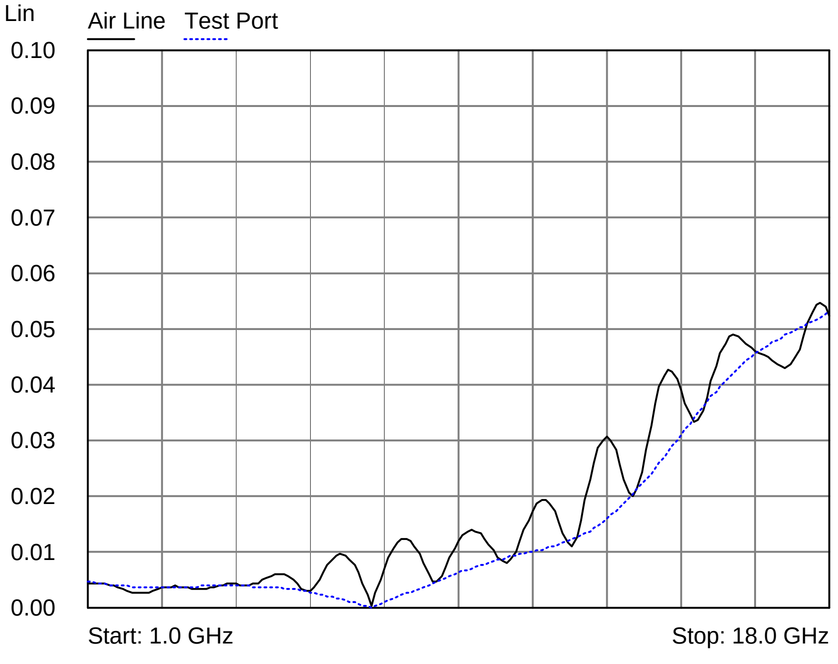

Fig 4. Second low band load connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

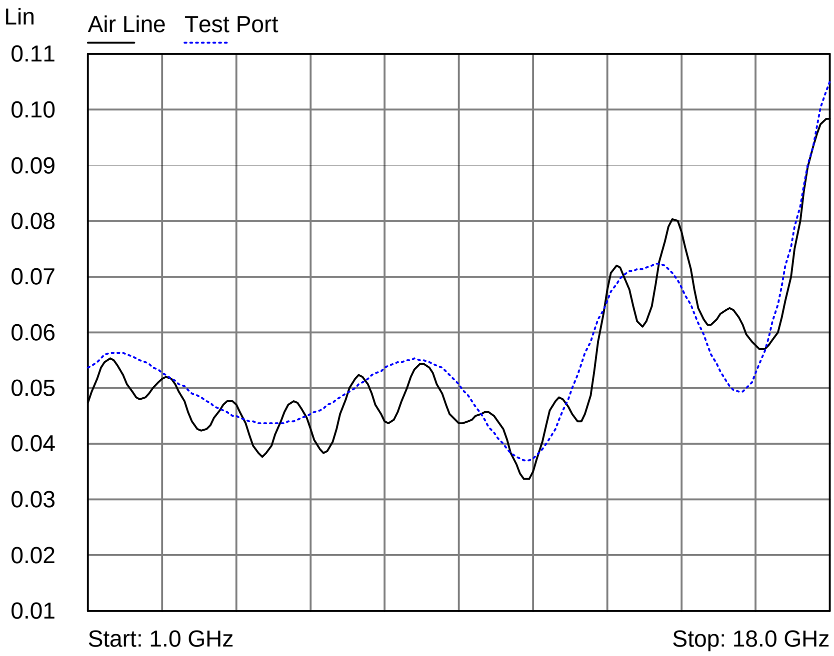

Fig 5. 1.1 VSWR mismatch connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

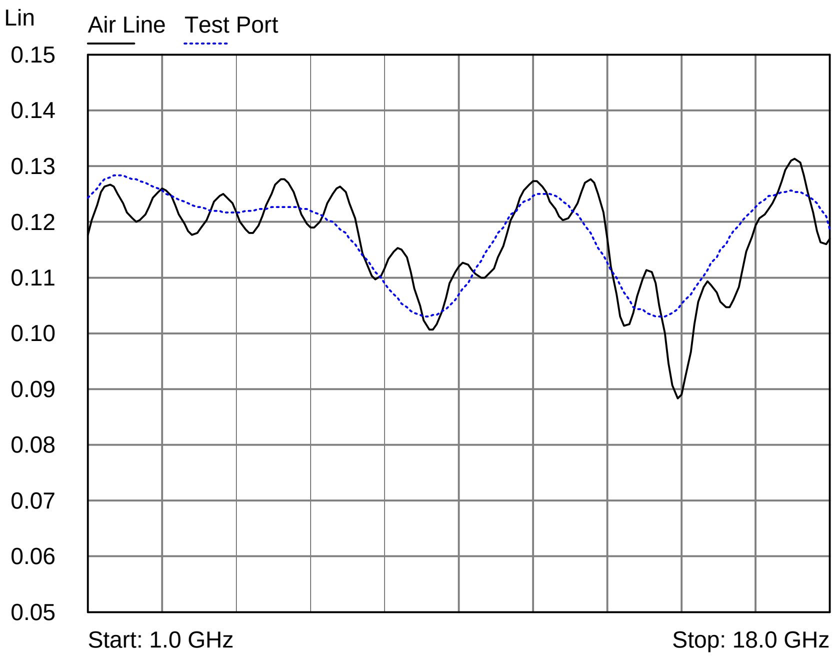

Fig 6. 1.3 VSWR mismatch connected in turn to the 100 mm air line (solid trace) and directly to the VNA test port (dashed trace)

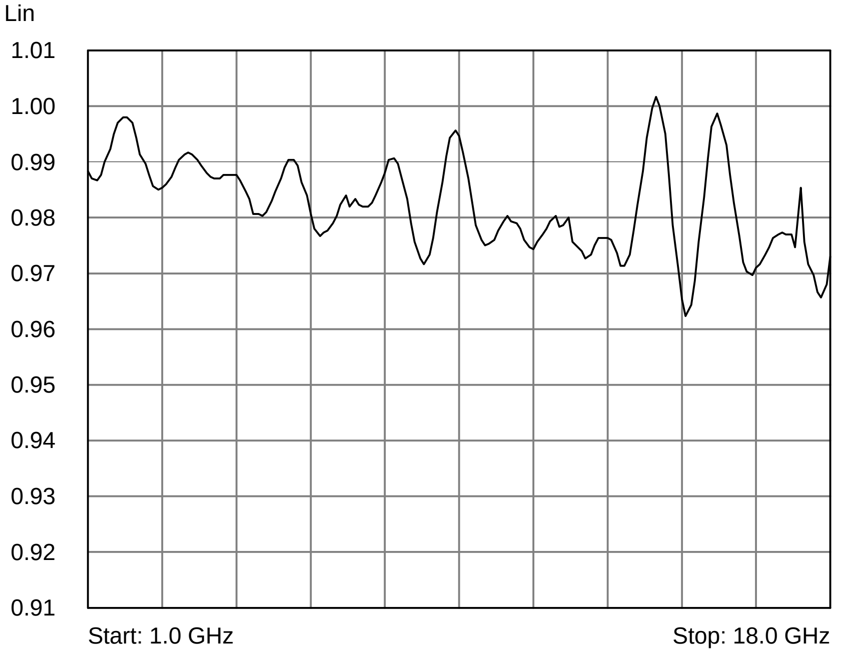

Fig 7. Short-circuit No 1 connected to the 100 mm air line

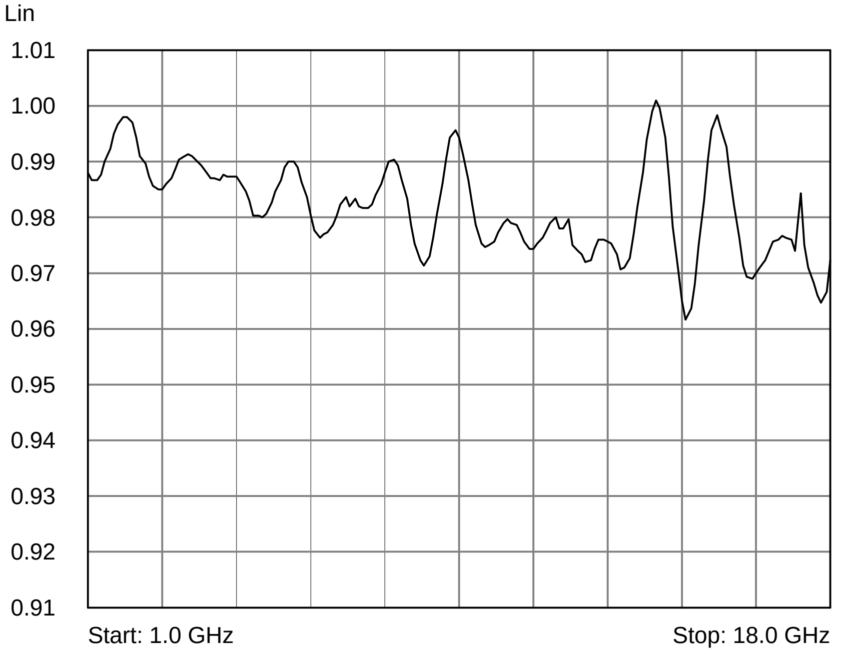

Fig 8. Short-circuit No 2 connected to the 100 mm air line

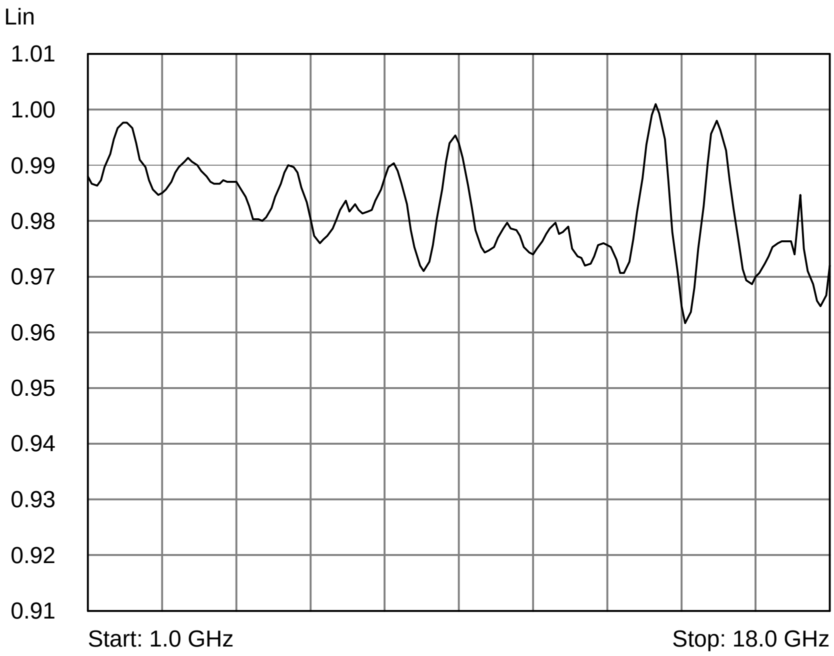

Fig 9. Short-circuit No 3 connected to the 100 mm air line

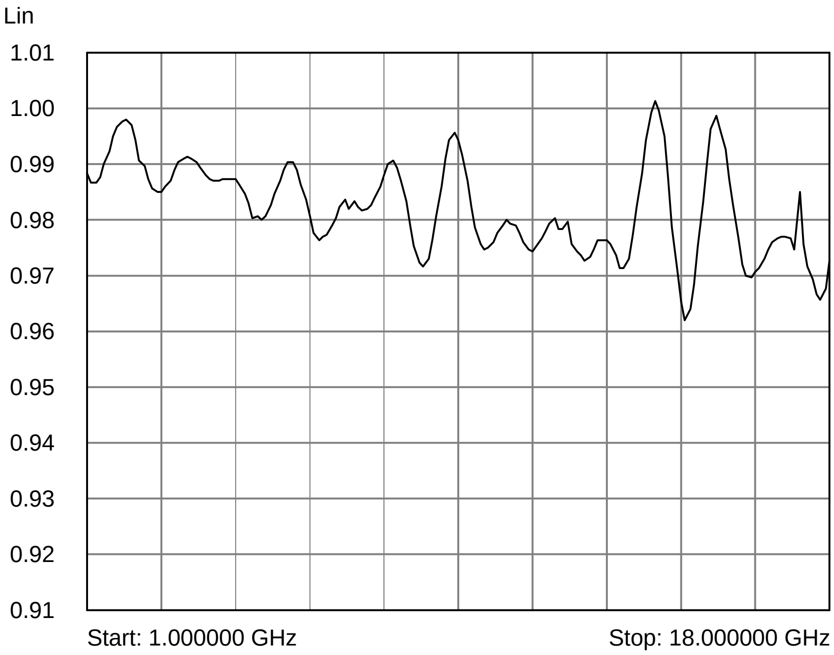

Fig 10. Short-circuit No 4 connected to the 100 mm air line

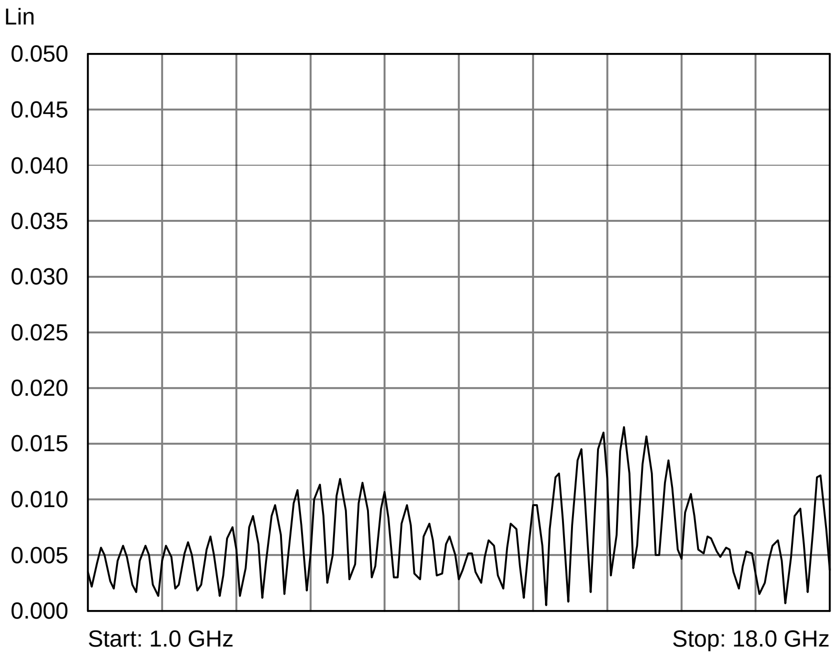

Fig 11. Broadband load connected to the first 300 mm air line

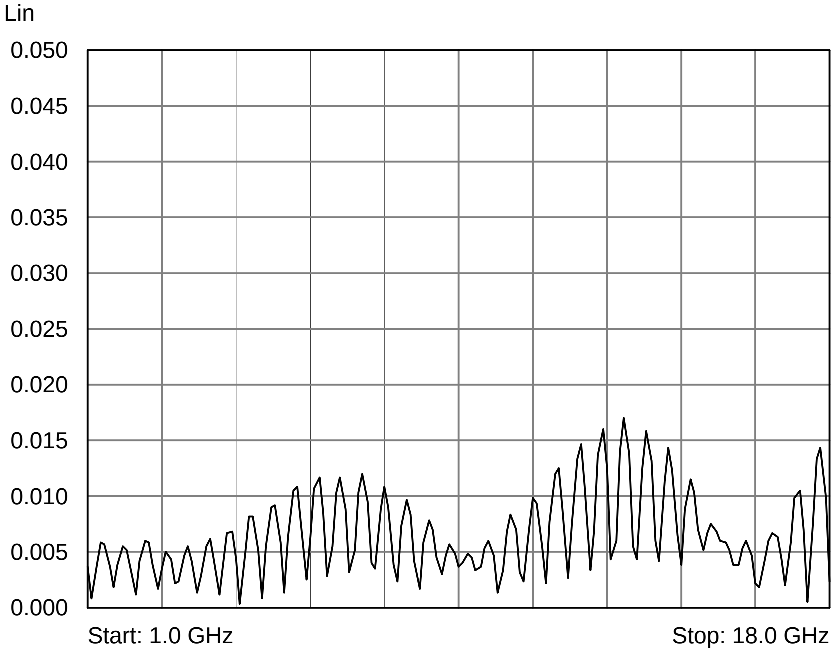

Fig 12. Broadband load connected to the second 300 mm air line

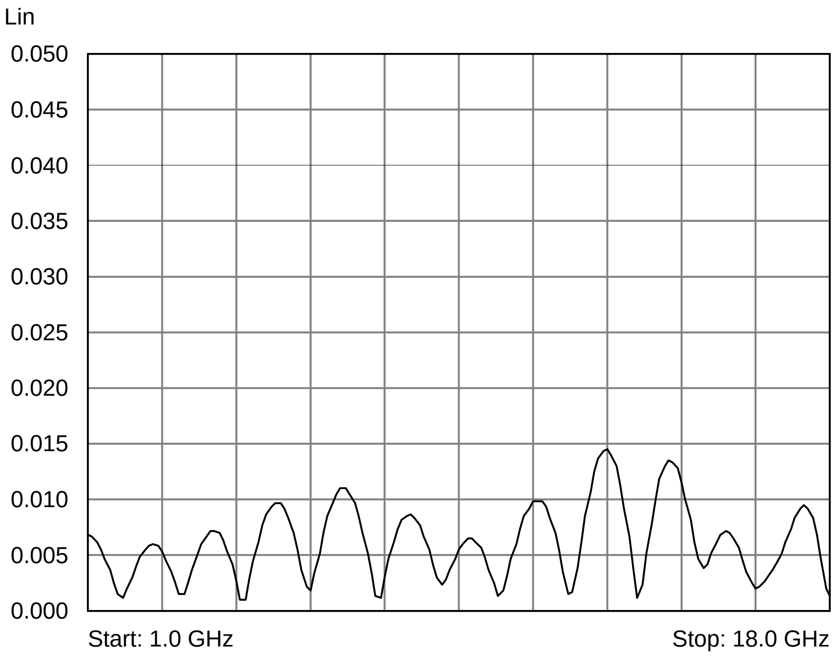

Fig 13. Broadband load connected to the first 100 mm air line

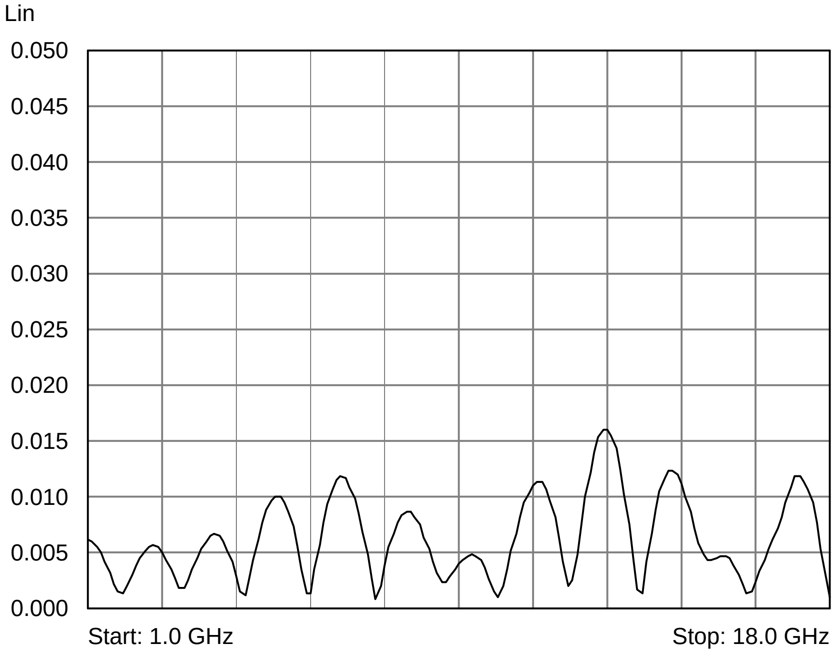

Fig 14. Broadband load connected to the second 100 mm air line

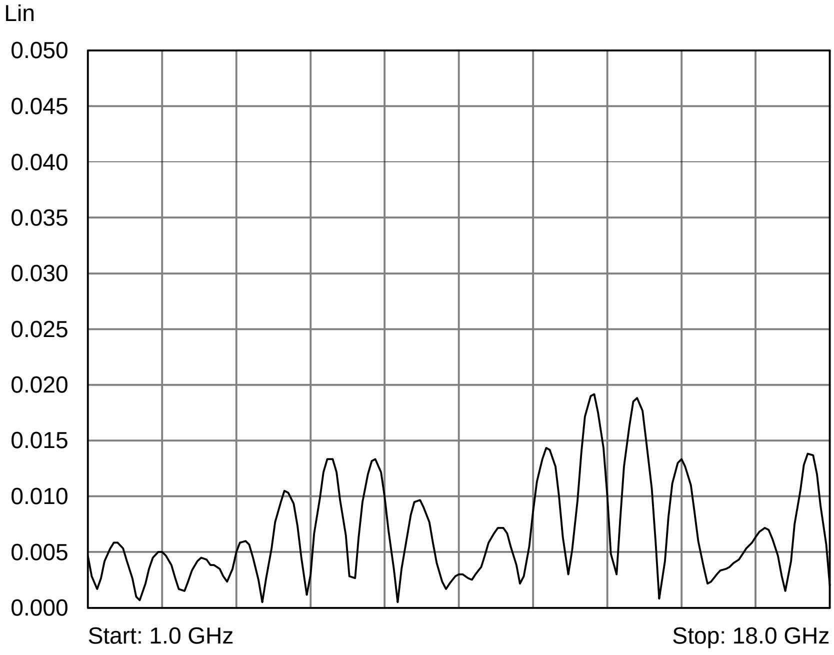

Fig 15. Broadband load connected to the 150 mm Rosenberger air line

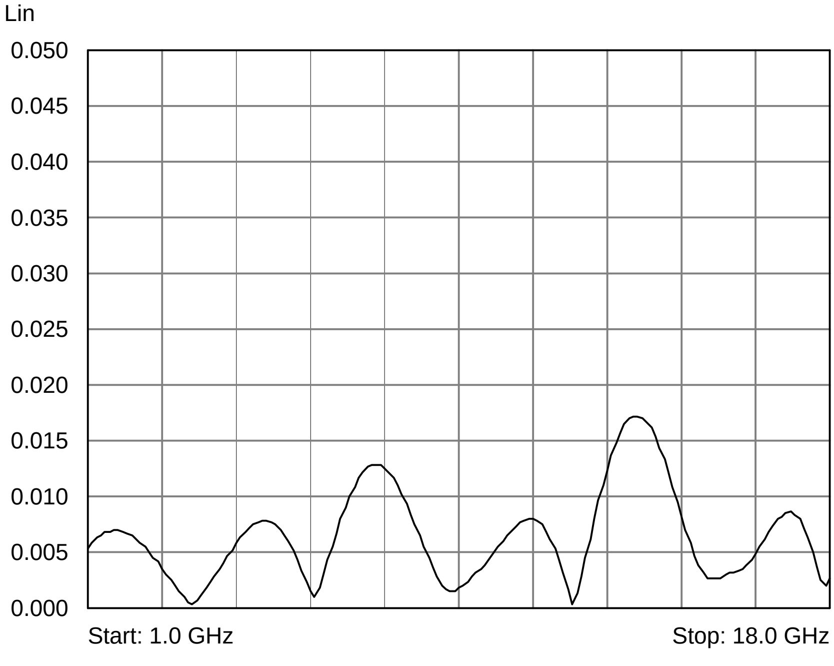

Fig 16. Broadband load connected to the 50 mm Rosenberger air line.

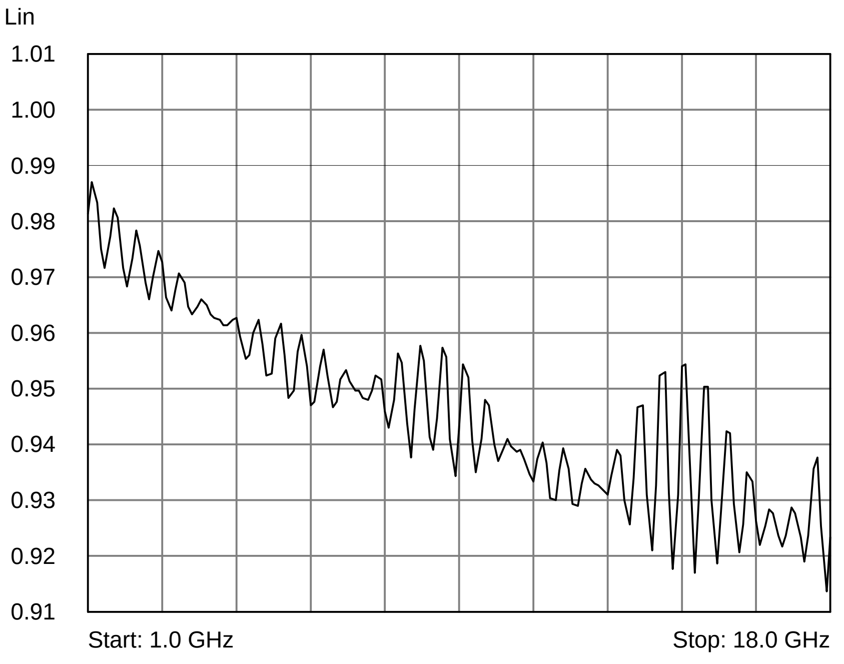

Fig 17. Short-circuit No 2 connected to the first 300 mm air line

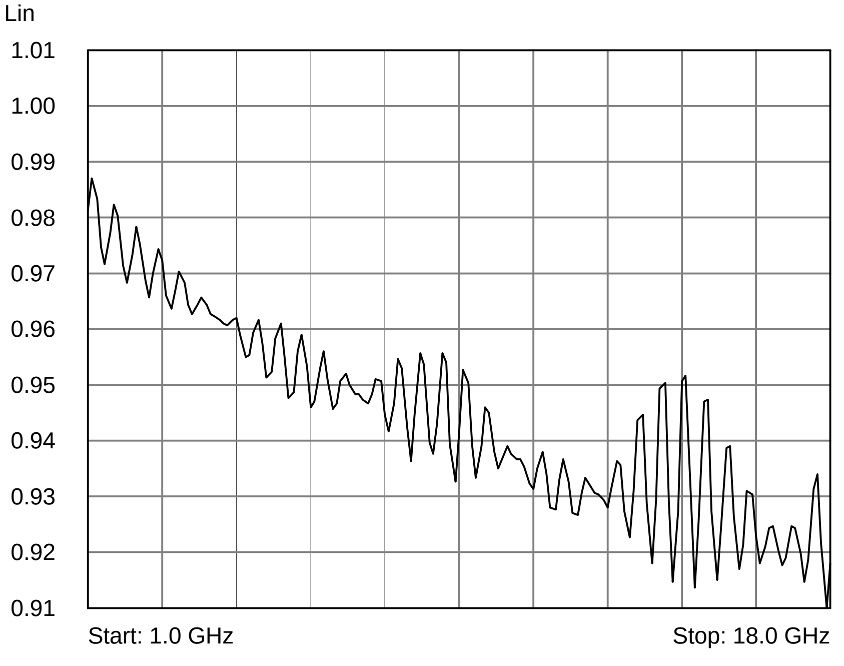

Fig 18. Short-circuit No 2 connected to the second 300 mm air line

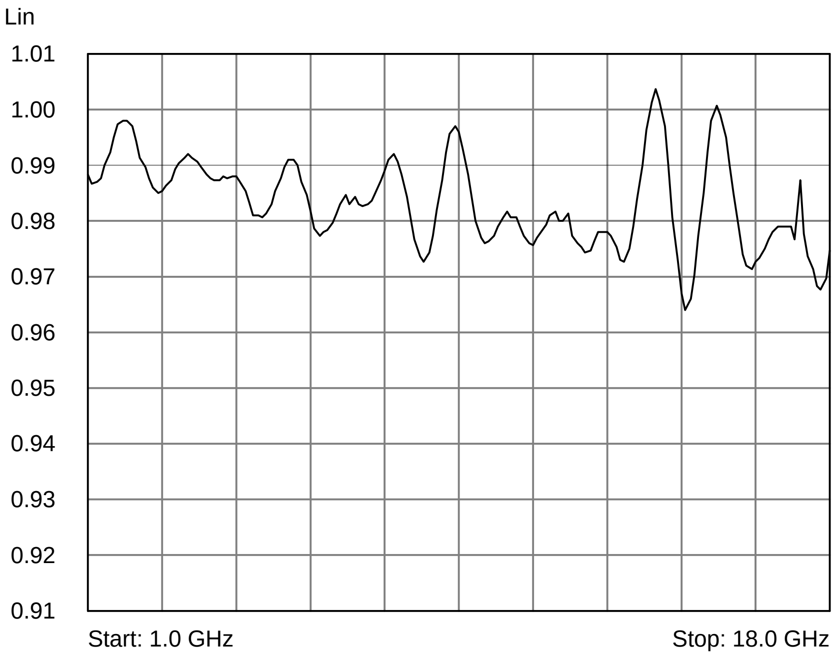

Fig 19. Short-circuit No 2 connected to the first 100 mm air line

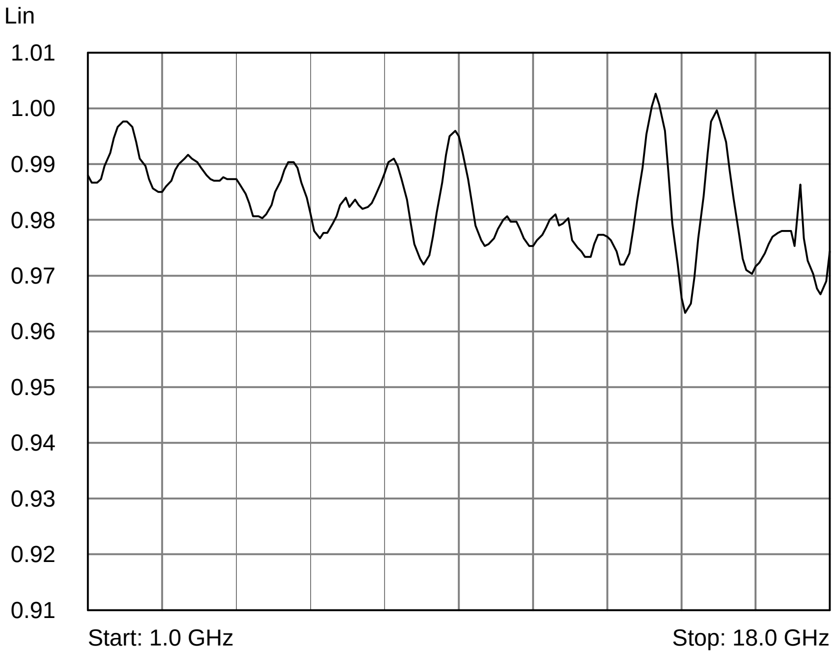

Fig 20. Short-circuit No 2 connected to the second 100 mm air line

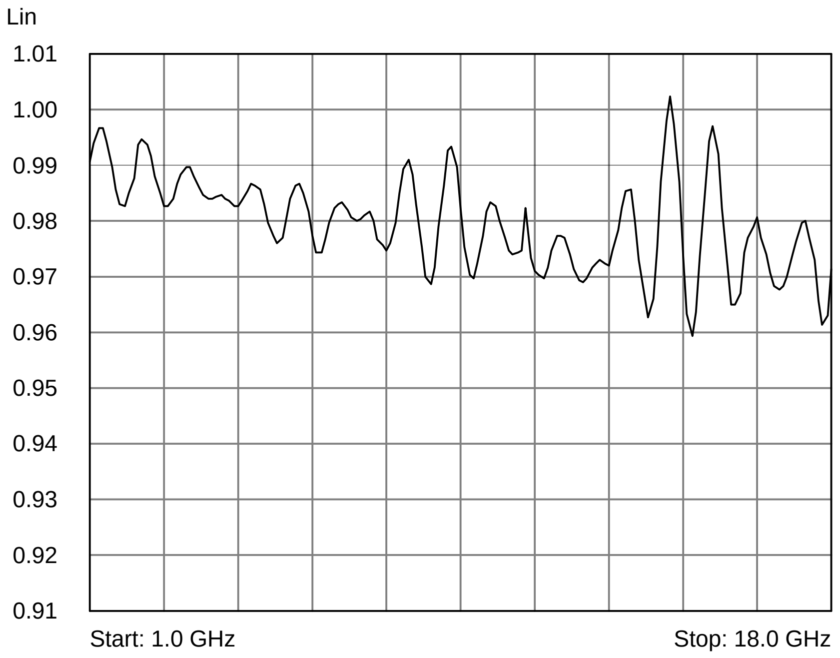

Fig 21. Short-circuit No 2 connected to the 150 mm Rosenberger air line

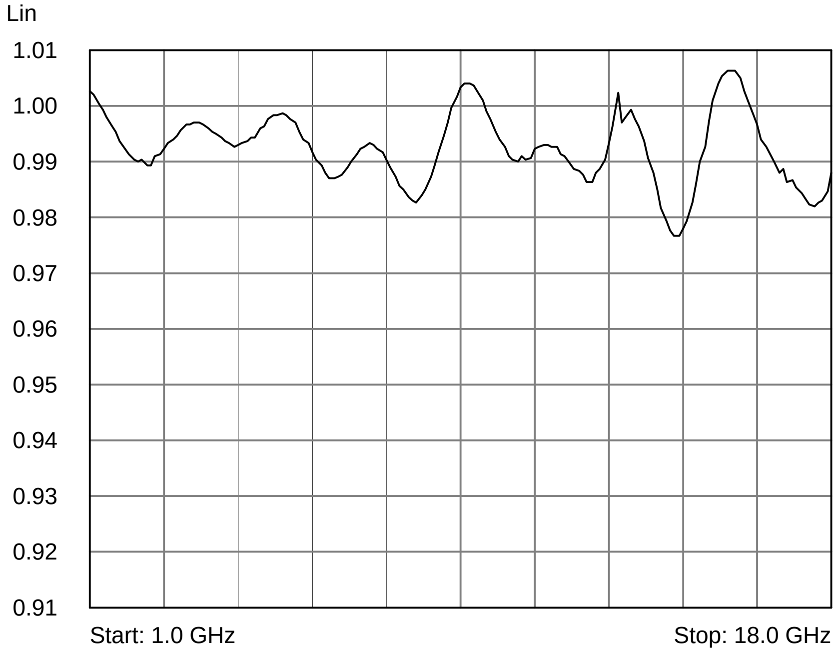

Fig 22. Short-circuit No 2 connected to the 50 mm Rosenberger air line