Title: **Analysis on Feasibility of the CTA Internal RS Test Option**

DRD No.:

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1 Introduction

1.1 General

Doubt on sufficient representativity of the HERSCHEL instruments front-end structural/thermal/electrical environment during their qualification against RS led to wish to have a dedicated RS test of the instruments cold electronics on HERSCHEL PLM level.
Thinking about an RS test on HERSCHEL PLM level it must be noted that nominally the CVV cover is closed in order not to allow the operation of the cryostat on ground. In this nominal configuration it is possible to irradiate the cryoharness and the small (30mm) openings of the LO signals from LOU (HIFI); the impact of RF entering the cryostat via the telescope opening (280 mm) however cannot be verified.
During instrument performance verification and conducted susceptibility testing the cryostat is closed by a specific cryogenic test adapter (CTA). This adapter contains at least a specifically cooled black body (at 5K) and a reflector (80K) in order to simulate the correct thermal and optical environment for an accurate prediction of the instruments performance. Nominally it is not transparent for RF.
In order to allow statements about RS fields susceptibility of the cold electronic it was discussed to modify the CTA. Two solutions are considerable:

1. The CTA will be provided with an RF transparent opening which has nearly the same aperture size as the telescope opening in order to allow RS test fields to enter the cryostat via the CTA
2. The CTA will be equipped with some RF miniature antennas which shall allow to generate an RS test field representative under consideration of the attenuation for the CVV opening (RD2) and the limits applicable outside the cryostat for RS (RD1).

From RF technical point of view the implementation of the RF transparent window is not a problem. Anyhow it has to be stated that safety aspects as well as IR transmission restrictions for the window are of essential importance and cannot be ignored, whereas the feasibility to generate reliable fields by miniature antenna needs to be analysed in this study.

1.2 Objective

This study shall clarify the suitability of the idea to equip the CTA with miniature antennas for the aim to generate the electric fields representative w.r.t. the EMC specification on RS.
This study shall

1. propose principal suitable radiators, based on generic requirements, and then
2. test their suitability for the planned RS test together with the CTA.

An outlook shall be given on further activities necessary in order to establish a feasible configuration of the antennas within the test adapter and, in particular any possible difference to the standard RS test quality and performance shall be mentioned.

2 References

The following Documents are referred in this analysis:

RD1	EMC Requirements Specification	H-P-1-ASPI-SP-0037
RD2	Cryostat Shielding Efficiency	H-P-ASPI-TN-0177
RD3	EQM Test Plan Meeting 20.11.01	H-P-ASPI-MN-0297
RD4	HP List of Acronyms	H-P-ASPI-LI-0077

3 Description

3.1 Aspects

It follows a series of aspects to be considered for the definition of suitable antennas for the RS test.

3.1.1 Configurational Aspects

For this study we assume that the miniature antennas are have to be mounted inside the CTA anywhere but close to the CVV interface. The CTA is considered to have an inner available size of about 700 mm inner diameter and a height of about 900 mm (cylindrical shape) The miniature antennas share the area with at least a black body at 4 K for calibration purposes and an optical mirror with temperatures between 40 and 90 K. The temperature of the innermost surfaces will be around 5K. The necessary thermal gradient to the outer 300 K niveau will be established by 2 -3 radiation shields with MLI, Through these shields the feeding cables of the miniature antenna have to be routed before it can be connected to the SMA vacuum feedthrough of the CTA. Therefore we have to expect for every miniature antenna at least 1 metre of feeding cable. In the applicable frequency range the use of semi rigid cable is mandatory in order to save losses. The antenna will be operated under vacuum. A general simple test configuration of the CTA with 1 miniature antenna is shown in figure 3.1.1-1

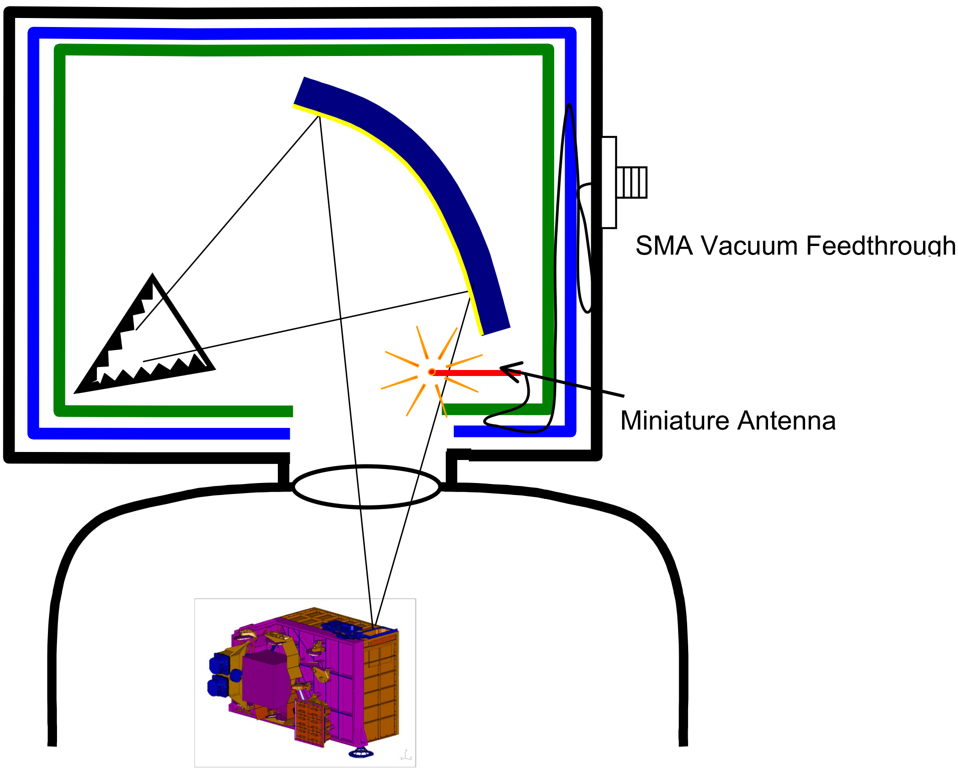


Fig. 3.1.1-1: RS Test General Configuration

The calibration of the CTA with radiating internal antennas will be done later. Hereto according to RD3 a receive antenna will have to be placed in representative distance to the CTA aperture (e.g. 1 metre) in order to measure the RS E-field.

3.1.2 Thermal Aspects

Due to the considerable change of dielectric losses over temperature it will be necessary either to have calibrated antenna measurement under representative thermal environment or to have a good knowledge about the change in electrical properties of the materials used for the antenna and feeding cable over the temperature and do, then, the calibration in ambient temperature. The latter we do not have due to the unconventional design of proposed the miniature antenna (see following chapters) and due to the rather low temperature (< 80 K), where secondary effects may exist, the general change of the conductivity across temperature.
For reduction of the cold-leak it may be necessary to construct the semi rigid RF feeding cable of Stainless Steel (SS) instead of copper with, however, impacts on cable losses. The adequacy of such material therefore, depends on the margin available on feeding power in order to generate the RF field with the necessary amplitude. If a RF field calibration of the CTA with the internal antennas is done, the CTA interface to the CVV must be closed by a vacuum tight but RF transparent (at least electrically characterised) cover.

3.1.3 Optical Aspects

Miniature antennas inside the CTA must not disturb the field of view of the focal plane equipment. Moreover even if placed directly on the inner thermal shield, they may still impact the straylight. The rule of the thumb is therefore: The smaller the antennas, the better.

3.1.4 Mechanical Aspect

The miniature antenna needs a stiff mouting plate with a size of about 100 x 100 mm the innermost shield. In case that several antennas are to be used within the CTA their vacuum feedthroughs should be places close together for simplification of the adaptation of an optional RF distribution network (e.g. in order to be able to radiate with several antennas the same time).

3.1.5 Electrical Aspects

The lower frequency range limit is given by the so-called cut-off characteristics of the upper CVV aperture (RD2). The higher frequency range limit as well as the field level itself is given by the EMC specification (RD1). In order to avoid oscillations within the feeding cable due to worse antenna VSWR, it is important to avoid „cable interruptions“. I.e. connector brackets shall be avoided. It would be the best to have only one single semi rigid cable from the antenna bracket to the CTA feedthrough. This cable would have to be integrated during CTA manufacturing.

3.2 Requirements on the Miniature Antenna

In the following, short term requirements for such a miniature antennas have been elaborated under consideration of the aspects above:

1. The performances are applicable at about 4 K as well as around 290 K, in vacuum as well as under ambient conditions
2. Frequency range 600 MHz to 18 GHz, antennas close to isotropic radiation characteristics under all conditions
3. E-field 2V/m in 1 metre distance
4. VSWR small
5. Small size (e.g. < 2cm * 2cm * 2cm).
6. Mounting by screwing preferred

7. Connection to a semi-rigid or flexible coax cable which has to be well characterised over frequency for ambient temperature and representative temperature with low heat conductivity
8. Connectors: SMA male

4 Evaluation

4.1 Antenna Selection

Due to the fact that one of the dominating requirement is the small antenna size, standard antennas, e.g. used to verify EMC in accordance to the MIL STD, are considered not suitable.
Short loop antennas fulfil the requirements on size. They suitability w.r.t. the other requirements, especially in respect to the field strengths shall be checked in frame of dedicated antenna tests.
The proposed miniature antenna is basically a SMA feedthrough connector as used for e.g. feeding a RF signal into an e.g. filter box. On the inner connector of this SMA transition, one end of a wire loop is soldered. The other end of the wire loop is soldered to the bracket of the SMA feedthrough connector. This loop antenna radiates electric fields polarised parallel to the loop area plane. The radiation pattern is dipole-like; In parallel to the loop area vector there is only low or no radiation expected (ref. Fig. 4.1-1).

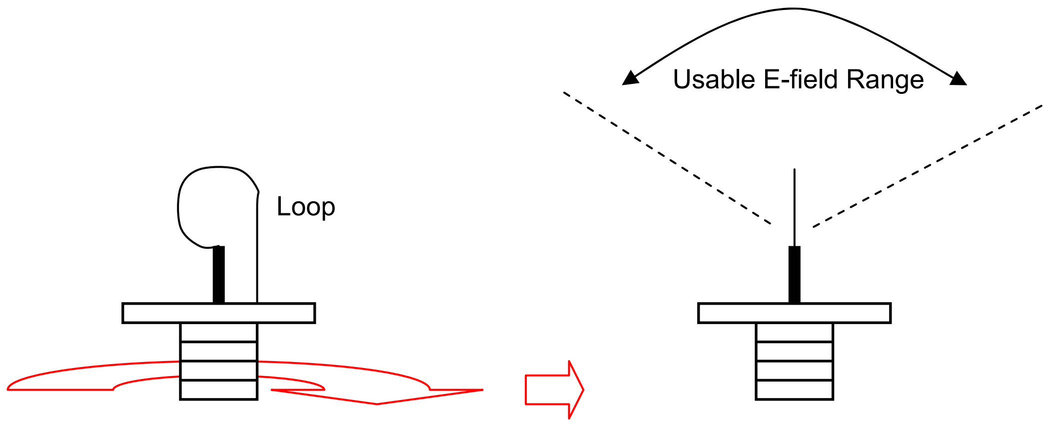


Figure 4.1-1: Expected radiating Pattern for the Loop Antenna

The suitable loop diameter for the antenna was predicted by R.L. measurements. The goal hereby was to have an R.L. of better than 3 dB. An antenna with a loop diameter of 7 mm was by this method identified to be suitable between 4 and 8 GHz. By roughly scaling we chose 10 mm for a lower frequency range and 4 mm for an upper.

4.2 Test Description

The tests were done in an anechoic chamber with the miniature antenna set as radiating antenna. We measured the field from this miniature antenna in 1 metre distance. The distance was considered to be roughly the same we would have "in reality" between the antenna in the CTA and the FPUs on the optical bench of the CVV.
The driving amplifiers were set to 10 dBm constant power at their output and were swept over the applicable frequency range. With the receive antenna we measure the E-field corresponding to the drive power. Then, based on the measure field we calculate the drive power necessary to generate the required E-field.
The receiving antenna is positioned in the same polarisation as the drive antenna.
The set-up has been illustrated in figure 4.2-1.

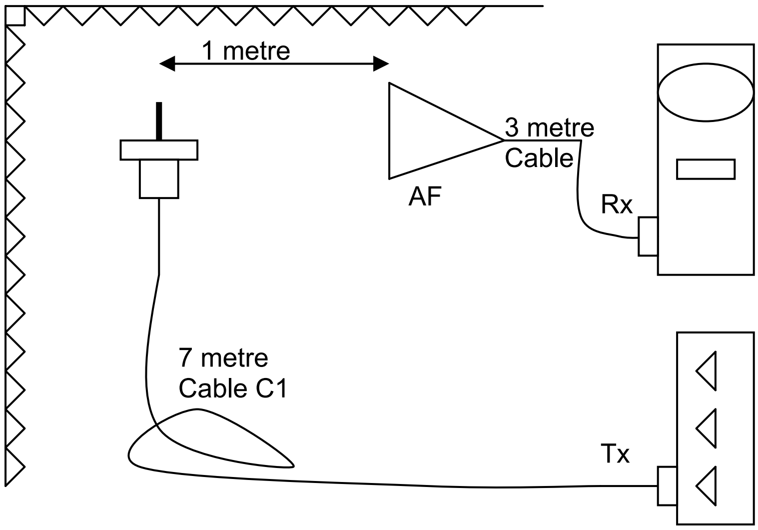


Fig. 4.2-1: Test Set-up Description

The field at the receiving antenna is calculated as follows:

E(@1metre distance)[dBµV/m] = AF[dB] + C2[dB] + Rx[dBµV]

Whereas C2 are the cable losses, Rx the voltage measured with the spectrum analyser and AF the antenna factor of the receive test antenna. The antenna factor includes both, the antenna gain and the conversion factor for the conversion to E-field to line voltage. AF can be treated like a damping factor, i.e. the lower the value in [dB] the higher the gain of the antenna.

By knowledge of the field we would have to measure, i.e. 126 dBµV/m (= 2V/m), we can calculate the factor by which we would have to increase the Tx amplifier power to reach the RS level necessary. This required Tx level can be compared with the amplifier specified performance to estimate the feasibility of the RS test with such miniature antenna (ref. §1.1).
The tests were done over the frequency range 1 GHz to 18 GHz. 3 antennas where used to cover this range,

- 10 mm loop diameter,
- 7 mm loop diameter, and
- 4 mm loop diameter

The test results where plotted and a table was generated to summarise the show the results.

4.3 Results Discussion

4.3.1 General

The following table Tab. 4.3.1-1 summarises the results. The corresponding measurement plots can be found attached.

Freq.	Rx Meas.	Rx Cable C2_Loss	AF	E-field @ Rx Ant. (1m dist. to probe)	delta to 2V/m @ 1 m dist. to probe	Tx Cable Loss (3 metre SR inside CTA)	Add. Tx cable ext. (6 metre)	Req. Tx Power to drive CTA probe	Tx Probe Loop diameter	Plot
[GHz]	[dBµV]	[dB]	[dB]	[dBµV/m]	[dB]	[dB]	[dB]	[dBm]	[mm]	
1	57	0,7	24,5	82,2	43,8	1	1	54,8	10	16
1,3	62	0,7	25,3	88	38	1	1	49	10	16
1,6	67	0,7	26,3	94	32	1	1	43	10	16
1,9	70	1,2	28	99,2	26,8	1	1,14	37,8	10	16
2,2	67	1,2	28,9	97,1	28,9	1	1,32	39,9	10	16
2,5	60	1,2	29,6	90,8	35,2	1	1,5	46,2	10	16
2,5	60	1,2	29,6	90,8	35,2	1	1,5	46,2	10	17
3	55	1,5	31,3	87,8	38,2	1	1,8	49,2	10	17
3,5	52	1,5	32,7	86,2	39,8	1,05	2,1	50,85	10	17
4	57	1,7	34	92,7	33,3	1,2	2,4	44,5	10	17
4,5	57	1,7	33,4	92,1	33,9	1,35	2,7	45,25	10	17
5	65	2,2	35,2	102,4	23,6	1,5	3	35,1	10	17
4	85	1,7	34	120,7	5,3	1,2	2,4	16,5	7	6
4,4	84	1,7	38,4	124,1	1,9	1,32	2,64	13,22	7	6
4,8	84	2,1	34,3	120,4	5,6	1,44	2,88	17,04	7	6
5,2	86	2,2	35,2	123,4	2,6	1,56	3,12	14,16	7	6
5,6	87	2,2	35,4	124,6	1,4	1,68	3,36	13,08	7	6
6	89	2,3	35,4	126,7	-0,7	1,8	3,6	11,1	7	6
6,4	92	2,3	35,6	129,9	-3,9	1,92	3,84	8,02	7	6
6,8	92	2,3	36,3	130,6	-4,6	2,04	4,08	7,44	7	6
7,2	92	2,4	36,9	131,3	-5,3	2,16	4,32	6,86	7	6
7,6	92	2,4	37,6	132	-6	2,28	4,56	6,28	7	6
8	91	2,5	38	131,5	-5,5	2,4	4,8	6,9	7	6
10	90	3	38,6	131,6	-5,6	3	6	7,4	7	15
10,4	59	3	38,7	100,7	25,3	3,12	6,24	38,42	7	15
10,8	58	3,1	39,1	100,2	25,8	3,24	6,48	39,04	7	15
11,2	57	3,2	39,3	99,5	26,5	3,36	6,72	39,86	7	15
11,6	52	3,2	39,4	94,6	31,4	3,48	6,96	44,88	7	15
12	45	3,2	41,8	90	36	3,6	7,2	49,6	7	15

Freq.	Rx Meas.	Rx Cable C2_Loss	AF	E-field @ Rx Ant. (1m dist. to probe)	delta to 2V/m @ 1 m dist. to probe	Tx Cable Loss (3 metre SR inside CTA)	Add. Tx cable ext. (6 metre)	Req. Tx Power to drive CTA probe	Tx Probe Loop diameter	Plot
12,4	52	3,2	41,4	96,6	29,4	3,72	7,44	43,12	7	15
12,8	55	3,3	40,5	98,8	27,2	3,84	7,68	41,04	7	15
13,2	49	3,4	41	93,4	32,6	3,96	7,92	46,56	7	15
13,6	47	3,4	41,7	92,1	33,9	4,08	8,16	47,98	7	15
14	47	3,5	41,7	92,2	33,8	4,2	8,4	48	7	15
14	55	3,5	41,7	100,2	25,8	4,2	8,4	40	4	11
14,4	55	3,5	41,5	100	26	4,32	8,64	40,32	4	11
14,8	55	3,4	40,8	99,2	26,8	4,44	8,88	41,24	4	11
15,2	55	3,5	39,4	97,9	28,1	4,56	9,12	42,66	4	11
15,6	55	3,5	38,1	96,6	29,4	4,68	9,36	44,08	4	11
16	55	3,6	38,4	97	29	4,8	9,6	43,8	4	11
16,4	55	3,6	40,2	98,8	27,2	4,92	9,84	42,12	4	11
16,8	54	3,7	41,2	98,9	27,1	5,04	10,08	42,14	4	11
17,2	53	3,8	42,6	99,4	26,6	5,16	10,32	41,76	4	11
17,6	51	3,8	44,6	99,4	26,6	5,28	10,56	41,88	4	11
18	49	3,9	44,3	97,2	28,8	5,4	10,8	44,2	4	11

Tab. 4.3.1-1: Evaluation of the Required Tx Power

The first column contains the frequency, the second the voltage as measured with the 50 ohms input of the spectrum analyser. Next column contains the cable loss of cable C2, followed by the antenna factor (AF). In the next column E(@1metre distance)[dBµV/m] has been calculated, and then, the difference of this result to the required 2 V/m (126dBµV/m).
The set-up shown in figure 4.2-1 is not already fully representative. In the CTA configuration we would have an additional semi rigid cable from the CTA feed through connector to the antenna, and maybe the 7 metre outside the CTA is also not sufficient. Here we include 6 metre additional RF in series to the 7 metre one in order to be on the safe side. Then, one can calculate how much the Tx output power of the RF source amplifiers have to be increased in order to generate the required 2V/m in the CTA configuration. We calculate the corresponding values in the column „Req. Tx Power to drive CTA Probe".

EMC facility amplifiers have a power capability of typical 10 W to 100 W. Therefore, there is a potential problem seen in the lower frequency range of about 1 GHz where the required power cannot be generated. At higher frequencies the feasibility is confirmed; It should not be forget here the impact of the additional 6 metre cable, i.e. if in the higher frequency range a problem would exist to generate the fields required, there is still the possibility to improve the set-up by a better cable (e.g. semi rigid or a shorter one) in order to reduce the losses and increase the radiated power.

4.3.2 Frequency Responses

From first view on the plots got from measurements with the 10 mm loop we see already that we measure everything else than a continuos field over the frequency range. It is to assume that the radiating element have some resonant behaviour. It is also considerable that, in the lower frequency range resoncances are

built up between the output impedance of the amplifier and the radiator. This problem could be overcome with the implementation of an passive output isolator.
Looking on Plot 6 we see that the 7 mm loop antenna becomes suitable for frequencies higher than about 6 GHz. Below it shows sharp resonances comparable with them of the 10 mm loop. Maybe this is an indication for that

1. the 7 mm loop should have been used not below 6 GHz (although the R.L. measurements showed it suitable between 4 and 8 GHz)
2. the 10 mm loop is underestimated, it should be increased to tbd(> 10mm) diameter.

As already expected, the 4 mm loop continuos with the good results we have achieved already with 7 mm loop for the higher frequency range (refer to PLOT11)

4.3.3 Requirements Discussion

Here we can go throughout the electrical requirements applicable for a miniature antenna (ref. § 3.2) and check the adequacy of the proposed miniature antennas to them (ref. § 3.2). We can shortly summarise the result as follows:

1. It is expected that temperature decrease and vacuum will only marginal change the radiated power. To overcome this issue, it is proposed to characterise in CTA configuration with the prposed miniature antennas under cold conditions with He inside the CTA
2. The radiation pattern is expected to be close to isotropic (dipole like), due to the simplicity of the miniature antenna geometry, the frequency range lower limit however is not 600 MHz but about 1 GHz
3. The proposed antenna is suitable to generate the required field as shown in table 4.3.1-1.
4. VSWR is rather bad. It must be compensated by lossy SMA feeding cable and/or (at lower frequencies) matched amplifier outputs in order to avoid resonances.
5. Miniature antenna size is less than 2cm * 2cm * 2cm
6. Mouting of the antenna can easily be performed by screwing or other means.
7. Antenna is compatible for interfacing a semi rigid or flexible coaxial cable.
8. The miniature antenna is fully SMA compatible. Impacts coming from the feeding cable are already considered in table 4.3.1-1 and could be confirmed later by a dedicated CTA level test.

4.3.4 Differences to Quality and Performance of a standard RS test

This chapter summarises the differences we will have with the proposed test solution compared with a standard RS test (e.g. as per MIL 462).

As said above, the field level across the area of interest may not be sufficiently constant. The RS test with the specifically equipped CTA would required to set the radiating antenna to the level which coresponding to the minimum the required E-field level at representative distance for a particular illuminated area. At some locations however, the E-field level might be higher. Therefore, a specific characterisation of the radiation from the CVV interface of the CTA in representative distance (e.g. 1 metre) over the spatial area corresponding to 45° opening angle from centre of the CTA aperture would be necessary. This would allow a verification of the correct E-field at particular locations of the optical bench. In case of susceptibility, a complementary test could follow with reduced levels for those locations where susceptibility has been detected and the level is higher than the specified. By this test either recovery of compliance can be confirmed or susceptibility thresholds can be predicted (as applicable for the particular location).

4.4 Outlook

We saw that the 7 mm loop showed bad results below 6 GHz. Most probably the 10 mm loop could bring here better results. If the 7 mm loop is perfect between 6 GHz and 12, then, as can be calculated by downscaling, a 14 mm loop would be suitable from 3 GHz to 6 GHz, and a 28 mm loop from about 1 GHz to 3 GHz. With the 28 mm loop we get maybe also a better gain with the result to be able with standard amplifier (< 100W) to drive the antenna up to the level necessary.
A delta test could be performed therefore below 6 GHz to confirm that the results will be improved when the loop diameters are increased from 10 mm to 14mm and 28 mm respectively.
Once implemented in the CTA, the behaviour of the antenna will change. Then, one have to expect multiple resonance's that can lead to a field increase by up to 6 dB or a decrease down to zero. Assuming an inner min. diameter of 300 mm, at least every 500 MHz would vanish. The situation becomes further changed once the CTA is mounted on the CVV, then the additional standing waves between the CTA and the CVV have to be considered. With a distance of 1 metre between the probe and the bottom of the optical bench every 150 MHz a total vanish of the field is to be expected.
From the plots we see over the frequency a short term and long term variation of the field. The short term variation is about +/- 2 dB (no resonance's assumed, i.e.). The same variances (short term and long term) can be expected for one particular frequency over the spatial area at defined distance to the probe, which is in any case quite small compared to the applicable RF wavelengths. A correction of those variations is not possible, because power adjustments will affect the complete illuminated area as such. To get knowledge about the fields we may have at the spatial illuminated area is however possible by a specific measurement of the CTA within a antenna measurement facility over the complete illuminated area in defined distanced to the CTA.

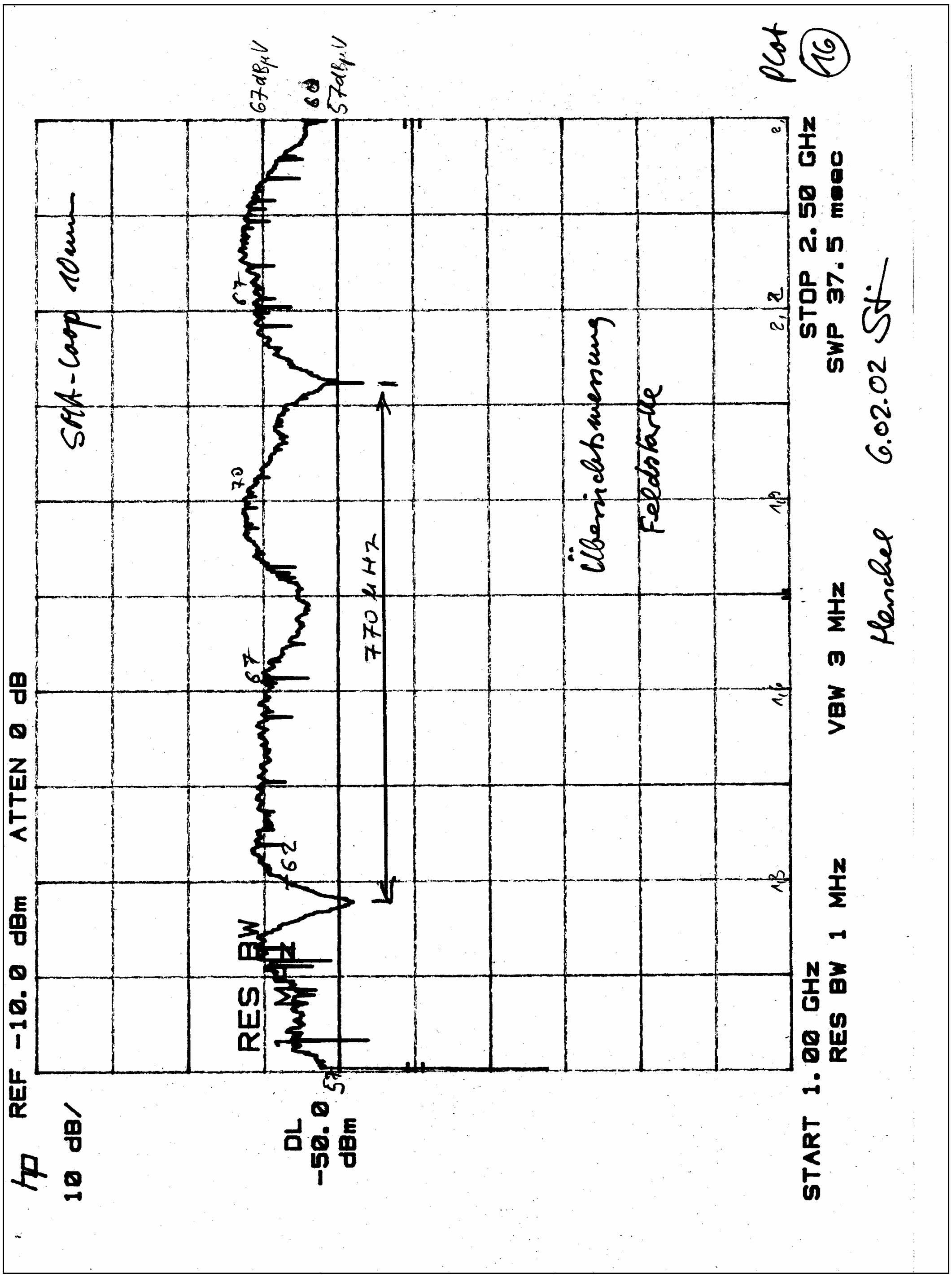
5 Conclusion

In the test programme as described above it has been demonstrated that:

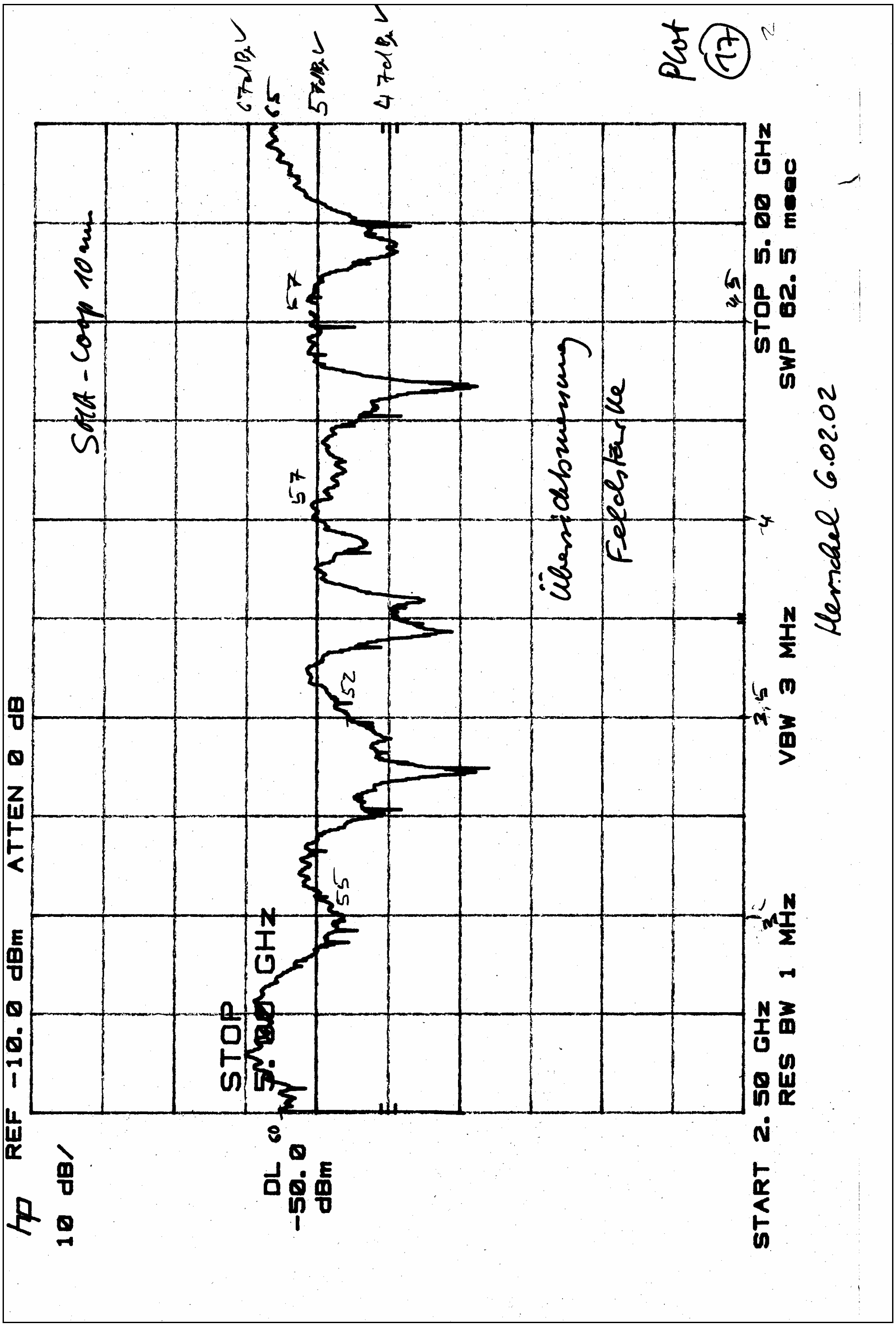
- The use of miniature tests antennas for the RS test option (CTA internally) is in general feasible.
- Field fluctuations are to be expected, both over frequency and illuminated area that cannot probably be fully compensated. The effect of reflections inside the CTA need also to be considered in addition with the corresponding effects on e.g. field fluctuations. A calibration run (CTA cooled to operational temperatures with test antenna at foreseen FPU location) seems therefore necessary.

The connection of the CTA to the CVV will lead to further standing waves which cannot be controlled. One could perform a kind of worst case level test which ensures that at all locations are illuminated with at least the required E-field and, later correct the field level in case of suceptibility.

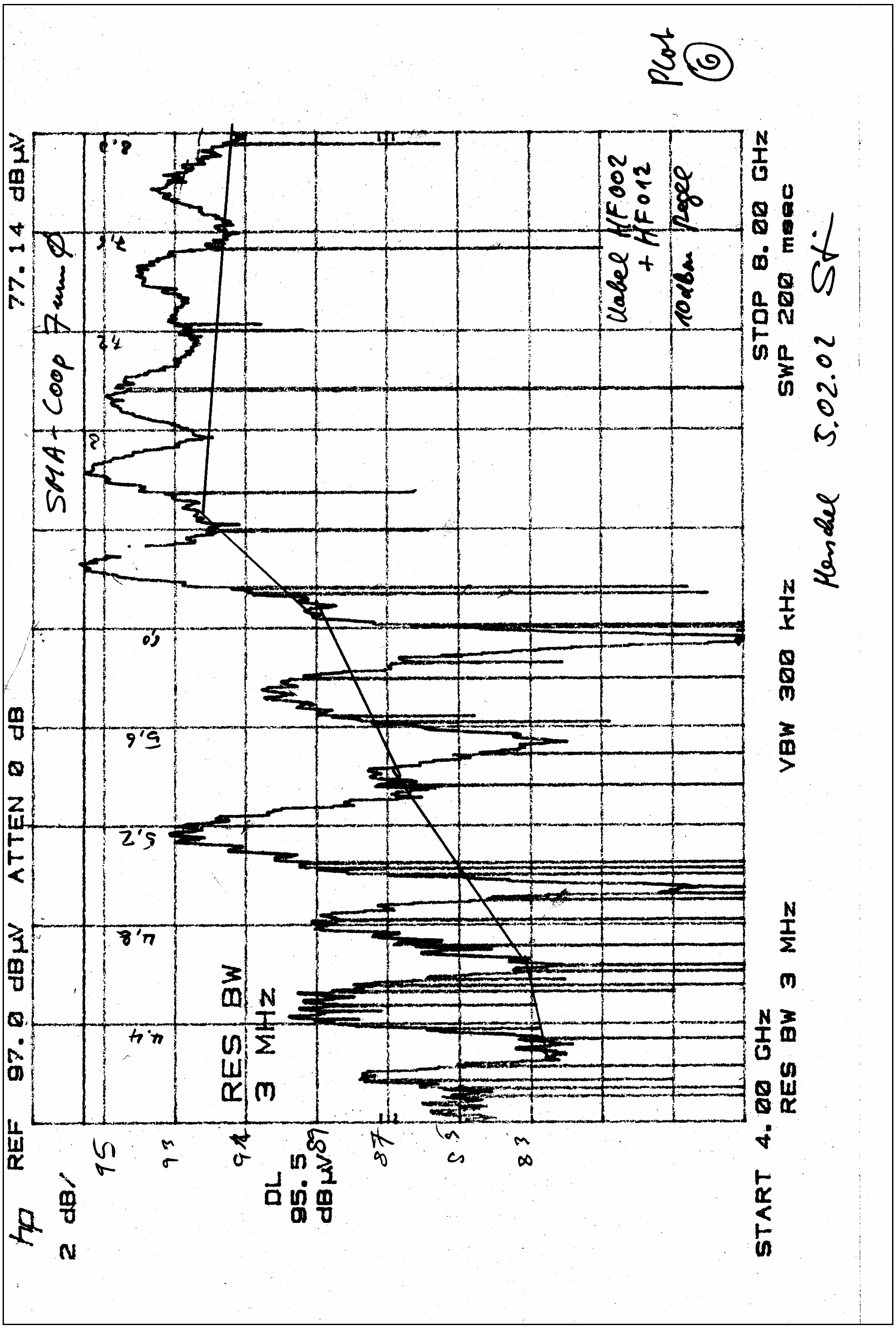
6 Measurement Plots from the Miniature Antennas



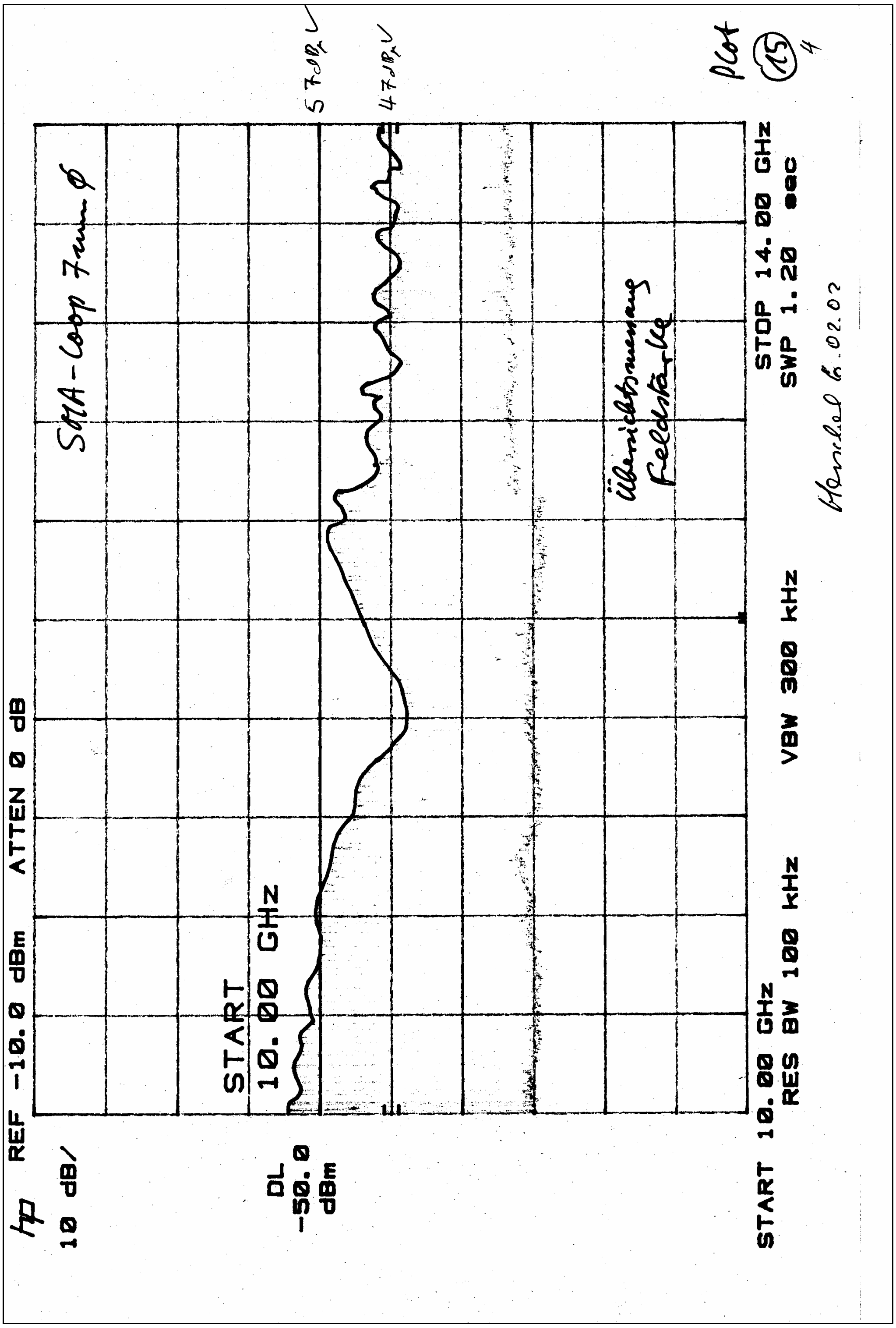
Plot 16: 10 mm Loop from 1 GHz to 2,5 GHz



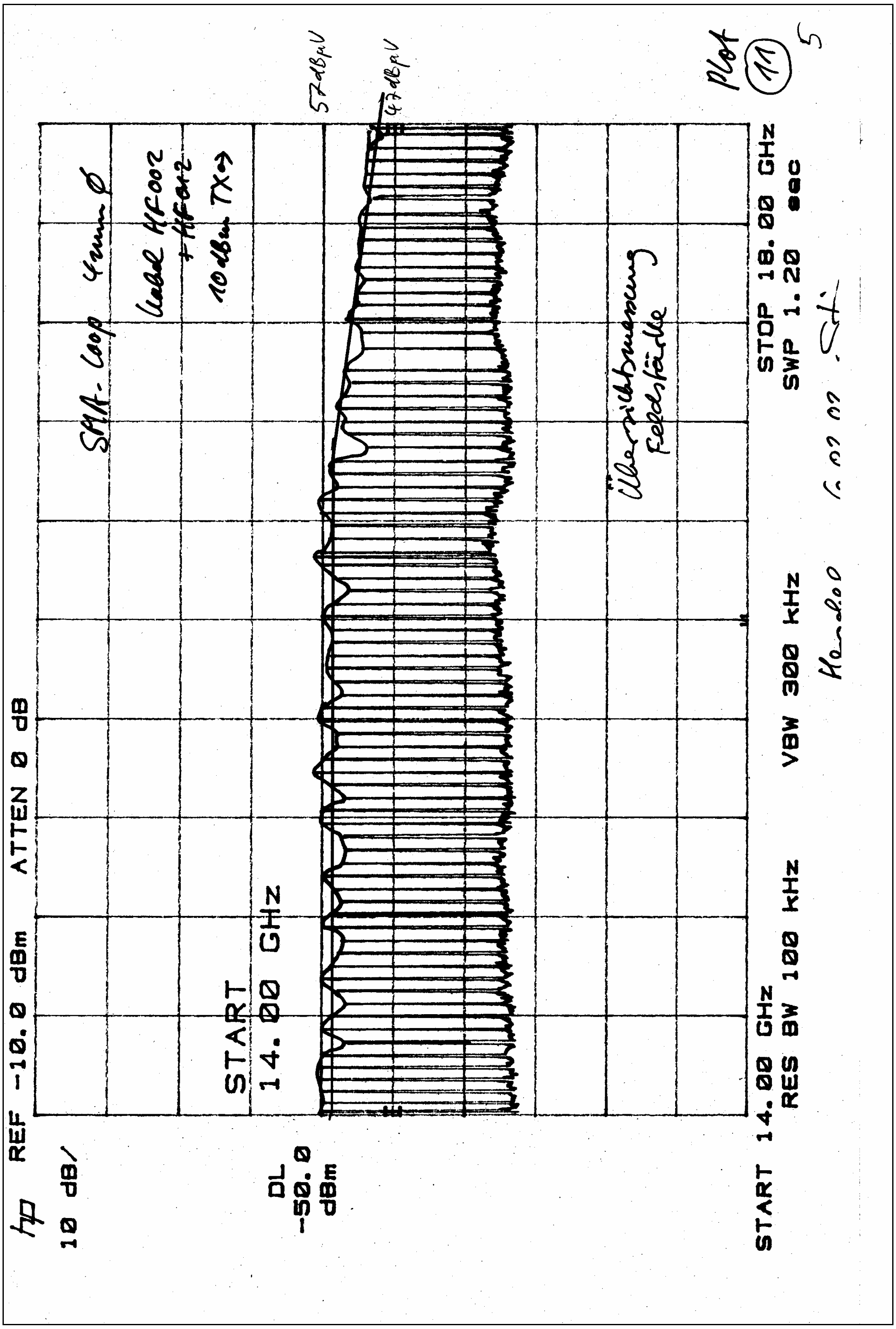
Plot 17: 10 mm Loop from 2,5 GHz to 5 GHz



Plot 6: 7 mm Loop from 4 GHz to 8 GHz



Plot 15: 7 mm Loop from 10 GHz to 14 GHz



Plot 11: 4 mm Loop from 14 GHz to 18 GHz

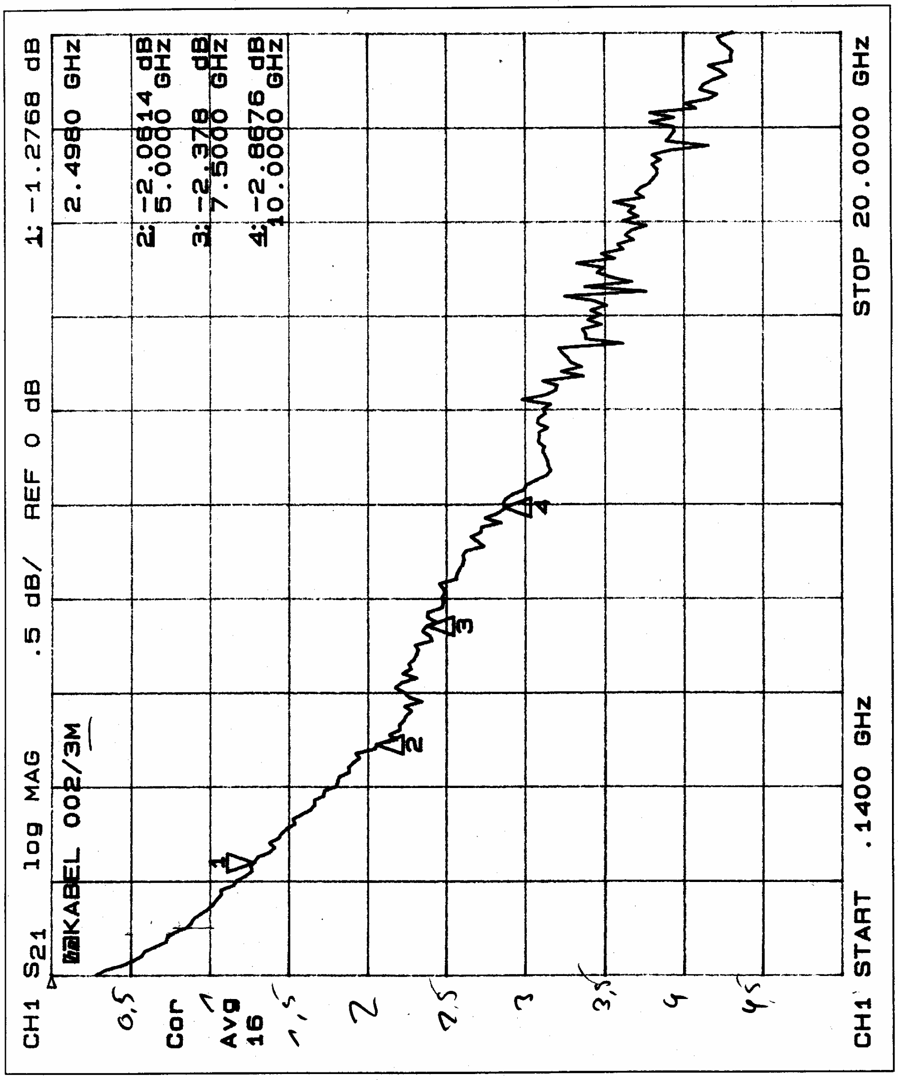
6.1 Cable C1 and C2 calibration curves

astrium — EMV und Messtechnik

Titel: / Title: **Messdaten, Leitungsdämpfung**

Nr.: / No.:	HF002	Leitung/Typ: / Cable/Type:	Sucoflex 104A	Ausgabe: / Issue:	1	Datum: / Date:	04.07.00

1.2 Frequenzbereich 1,2GHz – 20GHz



Filename: Messdaten Leitungsdämpfung 'HF002' — *Blatt/Sheet:* 2 von/of 2

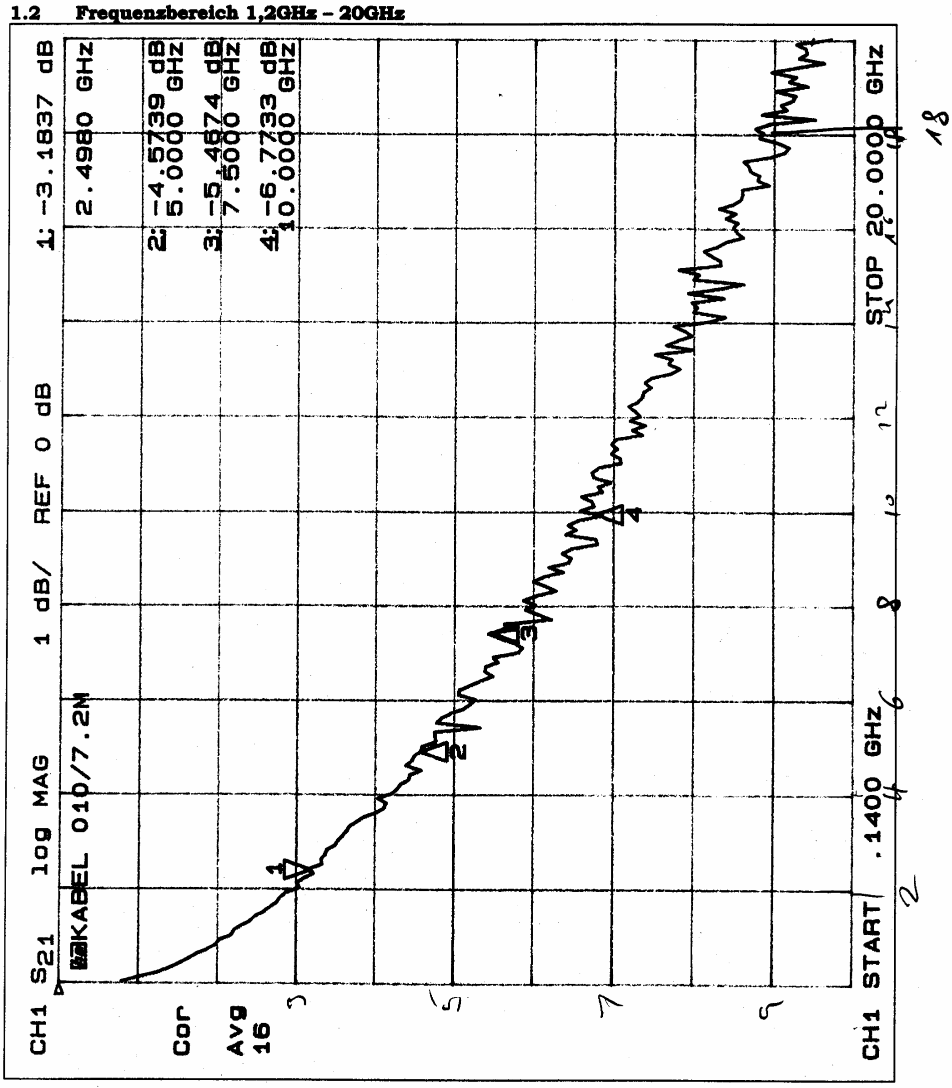
Calibration Curve for Cable C1

astrium — EMV und Messtechnik

Titel: / Title: **Messdaten, Leitungsdämpfung**

Nr.: / No.: **HF010** — Leitung/Typ: / Cable/Type: **Sucoflex 104A** — Ausgabe: / Issue: **1** — Datum: / Date: **04.07.00**

1.2 Frequenzbereich 1,2GHz – 20GHz



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Calibration Curve for Cable C1