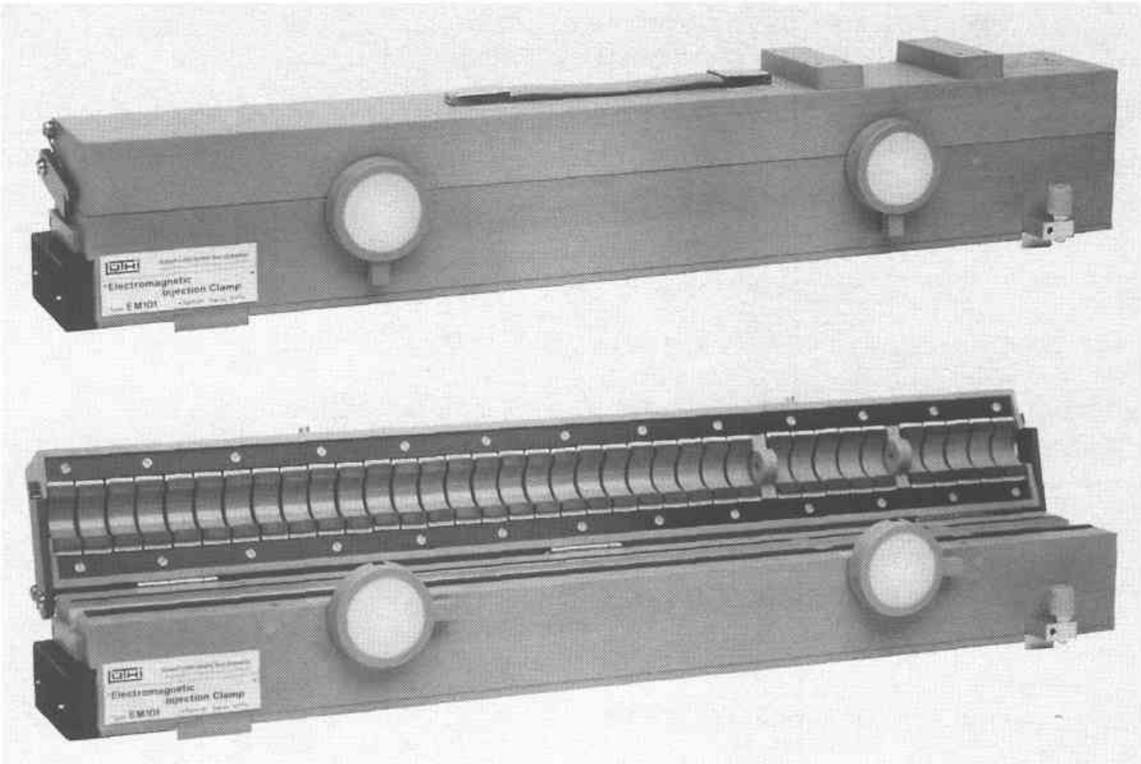
Lüthi Elektronik – Feinmechanik

RF CURRENT - INJECTION CLAMP TYPE EM 101

Electromagnetic Clamp, System Swiss PTT



Characteristics

Operating frequency range: 0,15 ... 1000 MHz

The correction factor " k " depend of the frequency
Guaranteed value: k = 0 dB ± 3 dB in the frequency range 0,3 ... 400 MHz
Typical min. value: k = - 5 dB by 0,15 MHz
k = - 5 dB by 1000 MHz

The correction factor k is defined with respect to a 150 Ω impedance system, in line with CISPR Publ. 20 (see also fig. 4)

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with I_{ind}: Current induced by the EM clamp into a cable having 150 Ω load at both ends. The clamp is hereby supplied from a 50 Ω- source having an electromotive force (e.m.f.) of the value U_o

I_{ref}: Nominal reference current from the same e.m.f. into 300 Ω (2 x 150Ω) total load : $I_{ref} = \frac{U_o}{300\ \Omega}$

RF-supply: RF-source of 50 Ω internal resistance

a) Sine-wave operation, maximum allowed e.m.f.:

0,15 ... 100 MHz : 140 V_{rms} (100 W source), max. 15 min.
100 ... 230 MHz : 140 V_{rms} (100 W source), max. 5 min.
230 ... 1000 MHz : 100 V_{rms} (50 W source), max. 3 min.

The severity of an immunity test with the above e.m.f. corresponds to an electromagnetic field-strength in the order of 100 V/m.

b) Pulse mode operation:
fast transients of 5ns / 50ns from a burst generator with a charging voltage up to 4 kV (IEC Publ. 801 - 4).

Directivity as current injection clamp: ≈10 dB beyond 25 MHz

Specifications:

Dimensions:	620 x 100 x 120 mm
Diameter of the window:	22 mm
Weight:	7,5 kg
Verification:	by Swiss Federal Office of Metrology CH - Bern

EM K-factor
in the frequency range 100 kHz to 1 GHz
in a test setup according to IEC 61000-4-6

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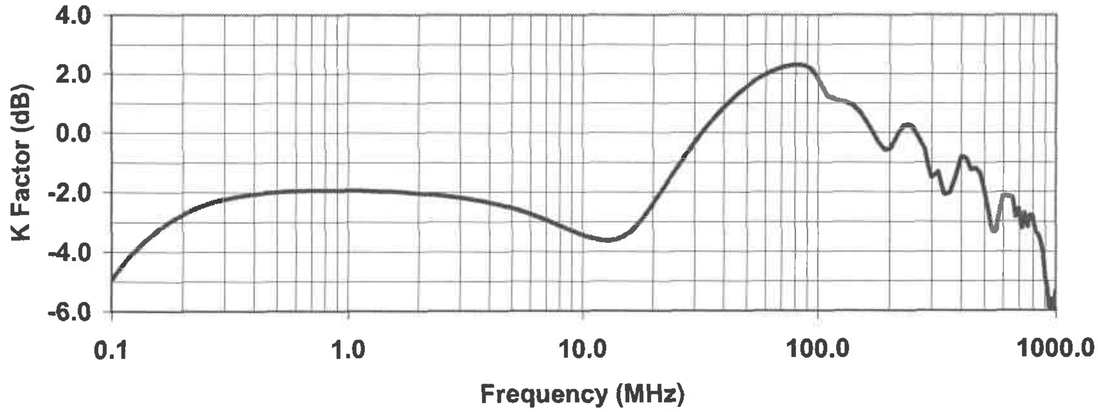
EM EM 101
Serie Nr. SN 35854



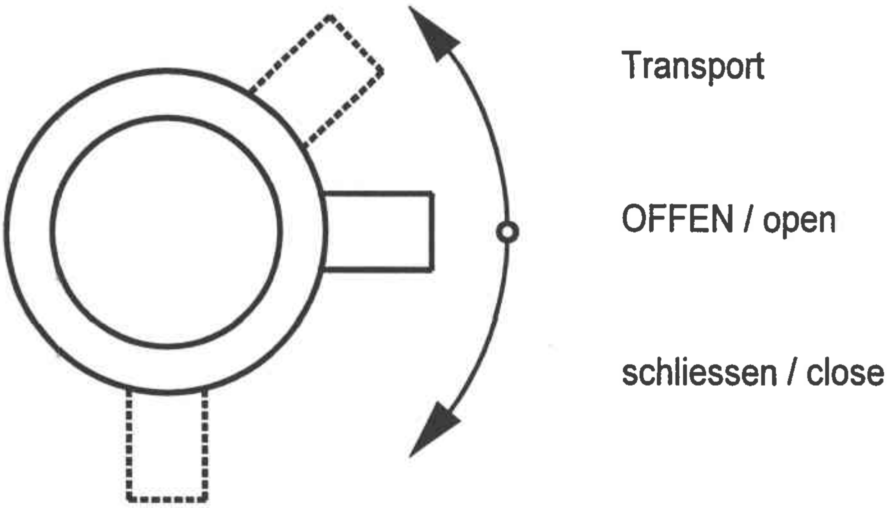
Equipment used

Network Analyzer Typ ZVR	MM Nr	4110	Date	28.06.2007
50 Ω to 150 Ω Adaptor	MM Nr	4159	Location	METAS
50 Ω to 150 Ω Adaptor	MM Nr	4160		

This is a computer created document and will not be signed.

Bitte beachten:

**Zum Transport, bei Nichtgebrauch oder zur Lagerung soll die Zange nicht geschlossen bleiben.
Die Verschlussknöpfe im Gegen-Uhrzeigersinn in die obere Nute einfahren.**



Attention:

***For transport or not in use, do not close the clamp.
The closing bottoms set left in the stop.***

Technical description of the EM clamp, type EM 101

Summary

The electromagnetic (EM) clamp is an RF current injection clamp, having inductive and capacitive coupling and allowing the induction of large currents on cables in the frequency range of 0.15 to 1000 MHz.

The EM clamp has been developed by the Swiss PTT *), basically in order to test the immunity against induced currents on the cables of installations containing information technology or telecommunication equipment. This test is the most important elementary RF immunity test. The EM clamp shall be used whenever the coupling units, according to the CISPR Publication 20 [1], cannot be realized or applied (either due to the number of conductors in one cable or due to the size of the installation or for other reasons).

With respect to the injection of currents, the EM clamp has similar properties as the 150 Ohm coupling unit. It may be supplied from an RF generator with 100 W or more power in the frequency range 0.15 - 230 MHz or from a burst generator with a charging voltage up to 4 kV, allowing tests on special equipment with high immunity level.

1. Introduction

Whenever an RF-electromagnetic field acts on a real installation (equipment with cables), the basic interference agents are, to our experience, the common mode currents, induced on the cables. These currents enter in the apparatus at the connecting points of the cables and circulate through the chassis. This effect may be simulated in an elementary immunity test by injecting, with an appropriate injection device, common mode currents on the cables.

We note however that, existing injection devices, other than the EM clamp, are not convenient for information technology or telecommunication equipment because of the following reasons:

- The construction of the coupling units [1] is not possible for cables having a large number of conductors.
- The capacitive IEC coupling clamp [IEC Publ. 801-4] has not enough coupling at frequencies below 5 MHz (fig. 7).
- The absorbing MDS clamp and other current probes have poor efficiency, when used as current injection devices (fig. 7).

The EM clamp has been developed in order to eliminate these drawbacks.

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*) Swiss PTT, General Directorate, Research and Development, VD 24, CH-3000 Berne 29.

[1] CISPR Publication 20, 1985: Measurement of the immunity of sound and television broadcast receivers and associated equipment in the frequency range 1.5 MHz to 30 MHz by the current-injection method.

2. Description of the EM clamp

The principle of the construction is shown in the fig. 2 and 3.

The EM clamp induces a current on a cable by using inductive and capacitive coupling at the same time; the designation "EM" (electromagnetic) comes from this feature. The fig. 2 illustrates the inductive coupling: An RF transformer having a one turn primary circuit uses the clamp's ferrite tube of 60 cm length as magnetic core. The fig. 3 represents the capacitive coupling between the cable under test and the primary turn (semi cylinder of a metal foil in the groove of the clamp).

The resistance R2 in the impedance Z2 enhances the directional effect and diminishes the influence of the load at the "back side" of the clamp.

Thanks to the precise mechanical construction of the clamps (tight electrical tolerances) it was possible to suppress the series impedance Z1 in the model EM 101. It was also possible to improve the frequency range up to 1000 MHz, by modifying the primary winding.

3. Calibration

The EM clamp is provided to replace a "150 Ohm coupling unit", therefore such a unit is used as calibration reference.

The calibration procedure is illustrated in the fig. 4. The fig. 4a shows the reference set up, containing two resistive 150 Ohm coupling units, connected together and being used as transmitter and load units respectively. In the second calibration step the transmitter unit is replaced by the EM clamp according to fig. 4b.

A correction factor "k" in function of the frequency shall be determined, being defined as:

$$k\ (\text{dB}) = \underset{(\text{level "4b" in dB}(\mu V))}{\text{reading with clamp}} - \underset{(\text{level "4a" in dB}(\mu V))}{\text{reference reading}}$$

The typical correction factor for a clamp EM 101 is given in the fig. 5 for the frequency range 0.1 to 1000 MHz.

The induced current "I_{ind}" by the EM clamp in a cable with a 150 Ω termination at both ends may be calculated as follows:

$$\underset{\text{dB}(\mu A)}{I_{ind}} = \underset{\text{dB}(\mu A)}{I_{ref}} + \underset{\text{dB}}{k}$$

Reference current from fig. 4a: $I_{ref} = \dfrac{U_o}{300\ \Omega}$

$$\underset{\text{dB}(\mu A)}{I_{ref}} = \underset{\text{dB}(\mu V)}{U_o} - 50\ \text{dB}$$

U_o = eletromotive force (e.m.f.) of the RF generator

4. Expression of the immunity

Similarly to the current injection method described in the CISPR Publication 20, the immunity of an equipment under test (EUT) shall be expressed in terms of the e.m.f. of the 50 Ohm source, supplying the EM clamp and just not causing an intolerable interference to the EUT. The correction factor k is respected as follows:

$$\begin{pmatrix}\text{Immunity}\\ \text{of the EUT}\\ \text{dB}(\mu V)\end{pmatrix} = \begin{pmatrix}\text{e.m.f. applied}\\ \text{to the clamp}\\ \text{dB}(\mu V)\end{pmatrix} + \begin{matrix}k\\ \text{dB}\end{matrix}$$

5. Relation between the e.m.f. and the interference field

For large installations this relation should be established on a statistical basis.

Derived from experience of the Swiss PTT, the following provisional relation is proposed for testing equipment with small and medium dimensions:

E.m.f. to be applied to the clamp:

from 1.5 to 30 MHz: e.m.f. ≅ interference field + 7 dB - k
from 30 to 230 MHz: e.m.f. ≅ interference field - k
dB(μV) dB(μV/m) dB

By these relations the EM clamp induces a current of similar intensity as the specified field would induce on the cables of an installation.

6. Limits of the use

In continuous sine-wave operation the EM clamp has been tested in the frequency range 0.15 - 230 MHz with an e.m.f. of 140 V and in the range 230 - 1000 MHz with an e.m.f. of 100 V; the corresponding power into 50 Ω of the RF generator is 100 W, respectively 50 W. No saturation effect of the ferrites has been observed in the whole frequency range. Thus the EM clamp has a large margin of linearity for usual immunity tests. For special applications, the given e.m.f. values could be exceeded for a short time, especially in the range 0.15 - 100 MHz. The upper limit of use has not been determined.

The temperature rise of the ferrites at the front side of the clamp in the frequency range 100 - 1000 MHz limits the duration of the application of the maximum voltages as follows:

Frequency range:	0.15 - 100 MHz	100 - 230 MHz	230 - 1000 MHz
E.m.f. of the source:	140 V_{rms}	140 V_{rms}	100 V_{rms}
Corresponding source power into 50 Ω:	100 W	100 W	50 W
Maximum duration:			
a) at a fixed frequency:	15 min	5 min	3 min
b) in sweep mode operation:	≈ 30 min	≈ 10 min	≈ 6 min

Note: The above e.m.f. allow to reproduce the interfering effects of an electromagnetic fieldstrength in the order of 100 V/m.

In pulse mode operation, fast transients of 5 ns/50 ns [IEC Publ. 801-4] from a burst generator with a charging voltage up to 4 kV may be applied: no saturation is observed and the pulse shape is better reproduced than with the capacitive IEC coupling clamp (fig. 6). Thus the EM clamp may favourably replace the IEC capacitive clamp; further on, the EM clamp is less bulky than the capacitive clamp.

7. Use of the EM clamp for immunity tests
(Test method proposed by the Swiss PTT)

To equipment with small or medium dimensions (max ~ 0.8 m size), the current injection method may be applied in the frequency range of 0.15 ... 230 MHz with a similar measurement set-up as described in the CISPR Publication 20 [1]. On cables with multiple conductors, the EM clamp shall be applied instead of a coupling unit.

The fig. 8 gives an example of such a measurement set-up. In order to define the load at the rear side of the clamp, a capacitive coupling has been realized between cable and ground plane (10 m of cable wound up on a metal plate placed on the ground plane).

Note: The better definition of load impedance on the rear side is recommended, because an auxiliary equipment, connected directly to the rear side of the EM clamp, will be less effectively decoupled than an auxiliary equipment that is connected through a coupling unit. In the calibration set-up (fig. 4b) the current, injected to the rear side, is ≈ 10 dB lower at frequencies beyond 25 MHz than the current on the front side. For lower frequencies, the currents on the front and rear side have nearly the same magnitude.

In large installations (groups of racks with a dense network of cables), the EM clamp shall be placed, successively, on each of the representative cables of the specific system racks (type tests).

Fig.2: Circuit équivalent simplifié du couplage inductif
Simplified equivalent circuit of the inductive coupling

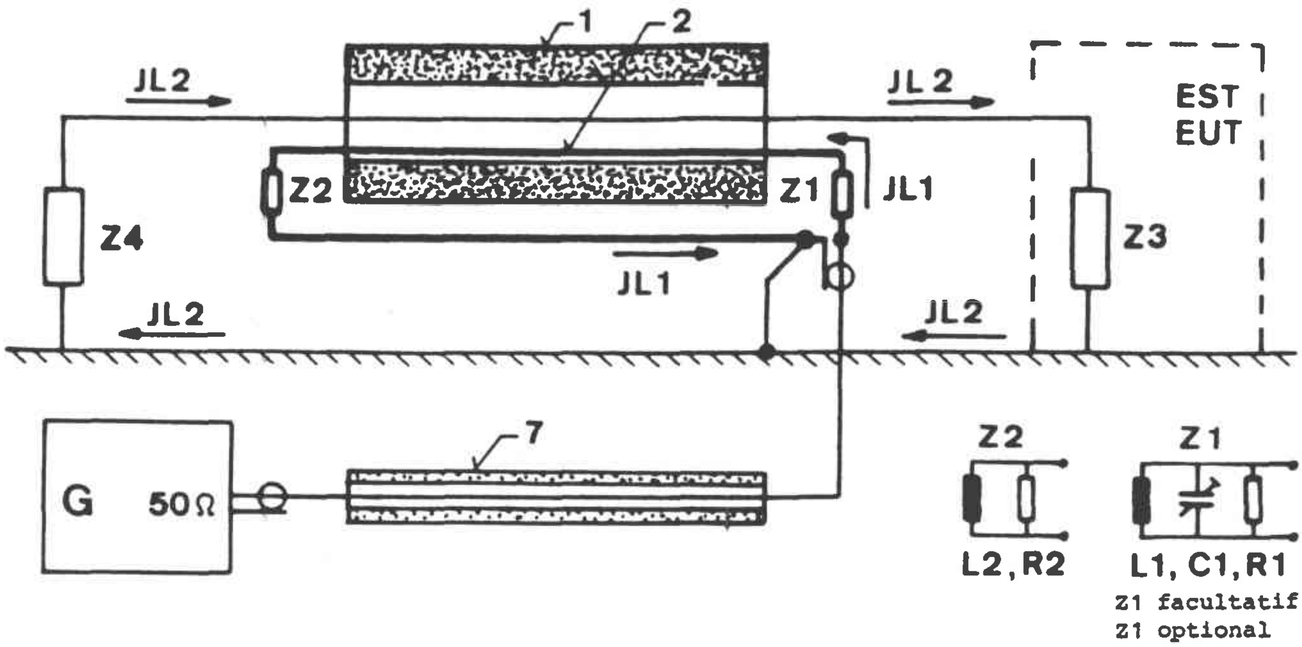
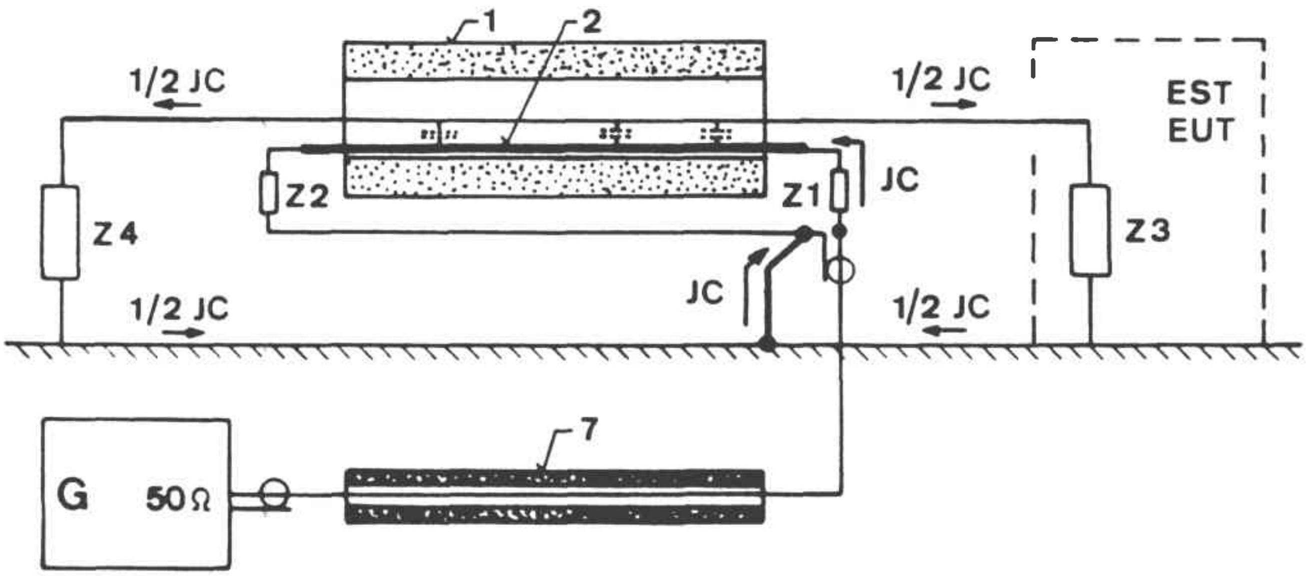


Fig.3: Circuit équivalent simplifié du couplage capacitif
Simplified equivalent circuit of the capacitive coupling



Z1 - Z2 : Impédances en série dans la spire primaire
Z3 : Impédance de l'équipement sous test
Z4 : Impédance du câble à l'arrière de la pince
JL1 : Courant inductif primaire
JL2 : Courant inductif secondaire
JC : Courant capacitif
G : Générateur du signal HF

1-7: Tube de ferrite, longueur 60 cm
2 : Demi-cylindre en tôle de cuivre

Les éléments importants de chaque circuit sont représentés en traits forts.

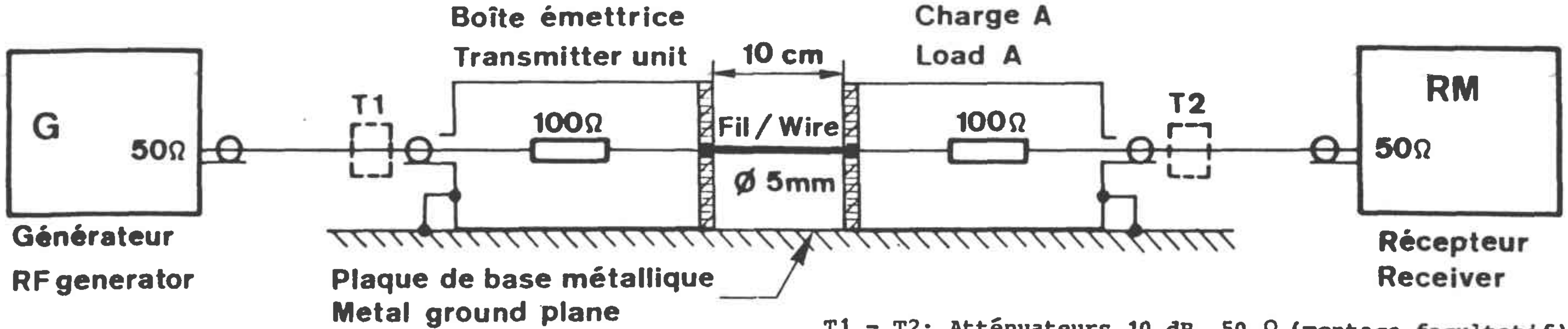
Z1 - Z2 : Series impedances in the primary turn
Z3 : Impedance of the EUT
Z4 : Impedance of the cable on the rear side of the clamp
JL1 : Inductive primary current
JL2 : Inductive secondary current
JC : Capacitive current
G : RF signal generator

1-7: Ferrite tube, total length: 60 cm
2 : Semi cylinder of copper foil

The important elements of each circuit are drawn in heavy lines.

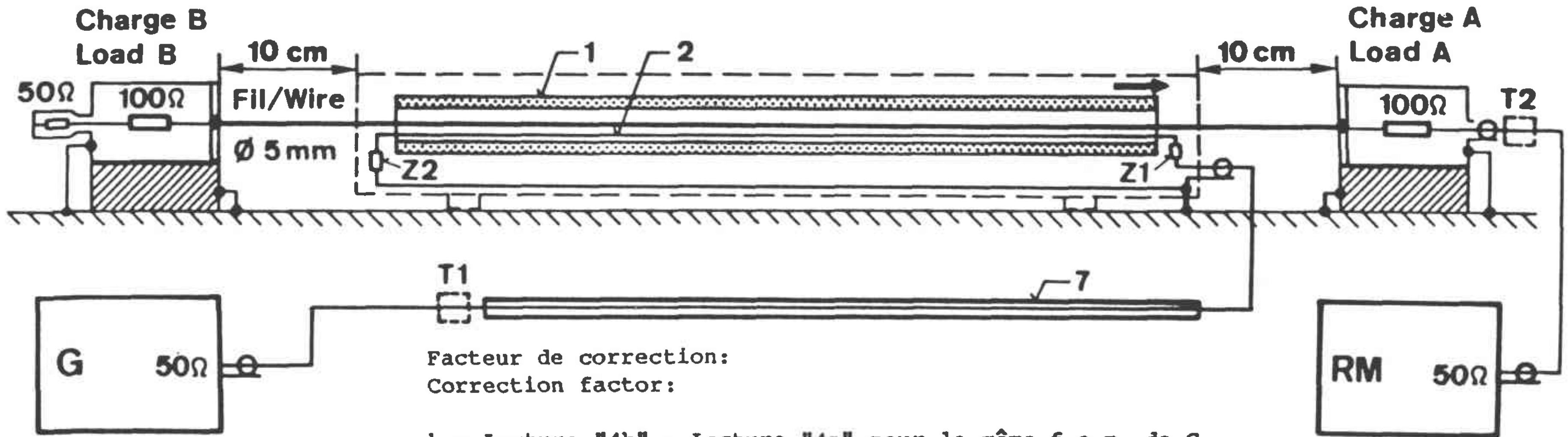
Fig.4: Etalonnage de la pince EM
Calibration of the EM clamp

Fig.4a: Dispositif de référence avec 2 boîtes de couplage à 150Ω (type Sr, Publ. CISPR 20)
Reference set up with two 150 Ohm coupling units (type Sr, CISPR Publ. 20)



T1 - T2: Atténuateurs 10 dB, 50 Ω (montage facultatif)
Attenuator 10 dB, 50 Ω (optional)

Fig.4b: Etalonnage par comparaison: La boîte émettrice est remplacée par la pince EM
Calibration by comparison: The transmitter unit is replaced by the EM clamp

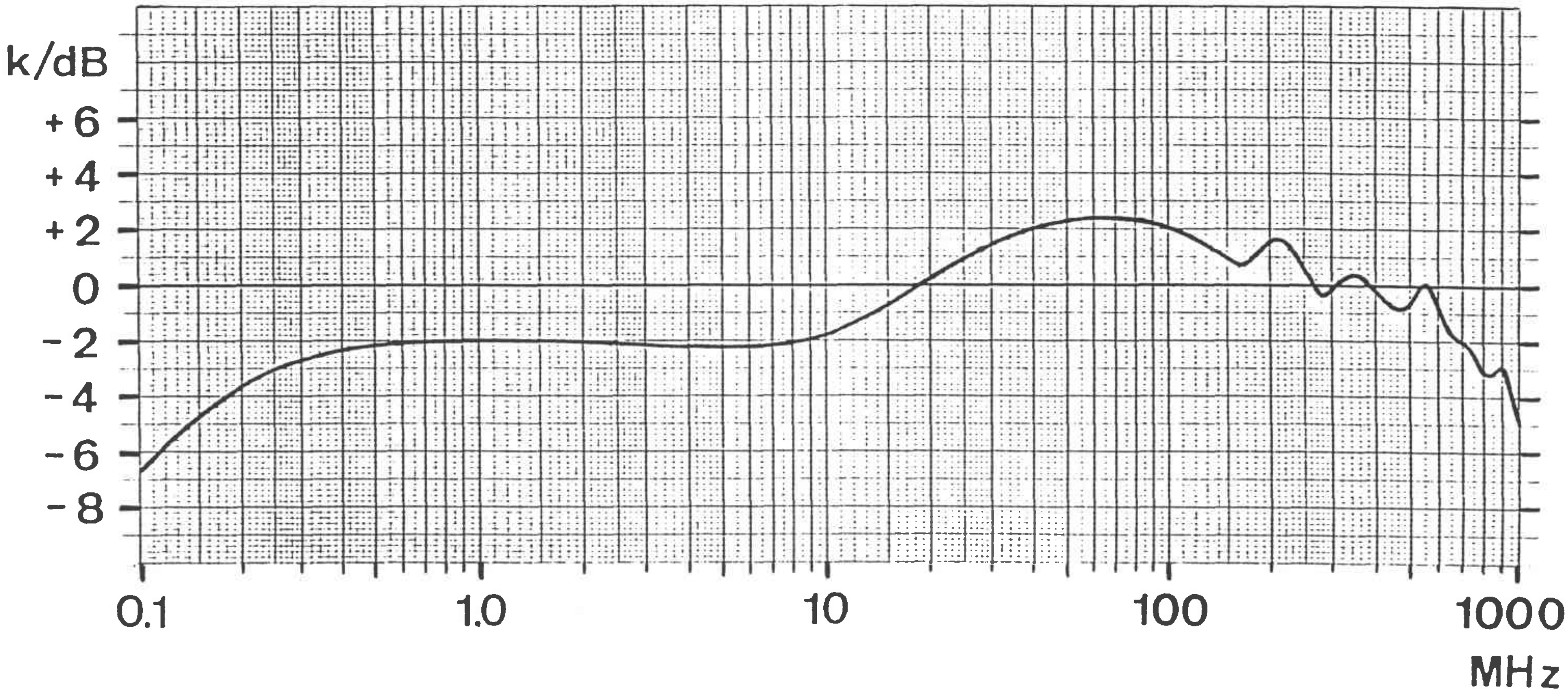


Facteur de correction:
Correction factor:

k = Lecture "4b" - Lecture "4a" pour la même f.e.m. de G
k = Reading "4b" - Reading "4a" for the same e.m.f. of G
dB dBμV dBμV

Fig.5: Facteur de correction de la pince EM
Correction factor of the EM clamp

EM 101



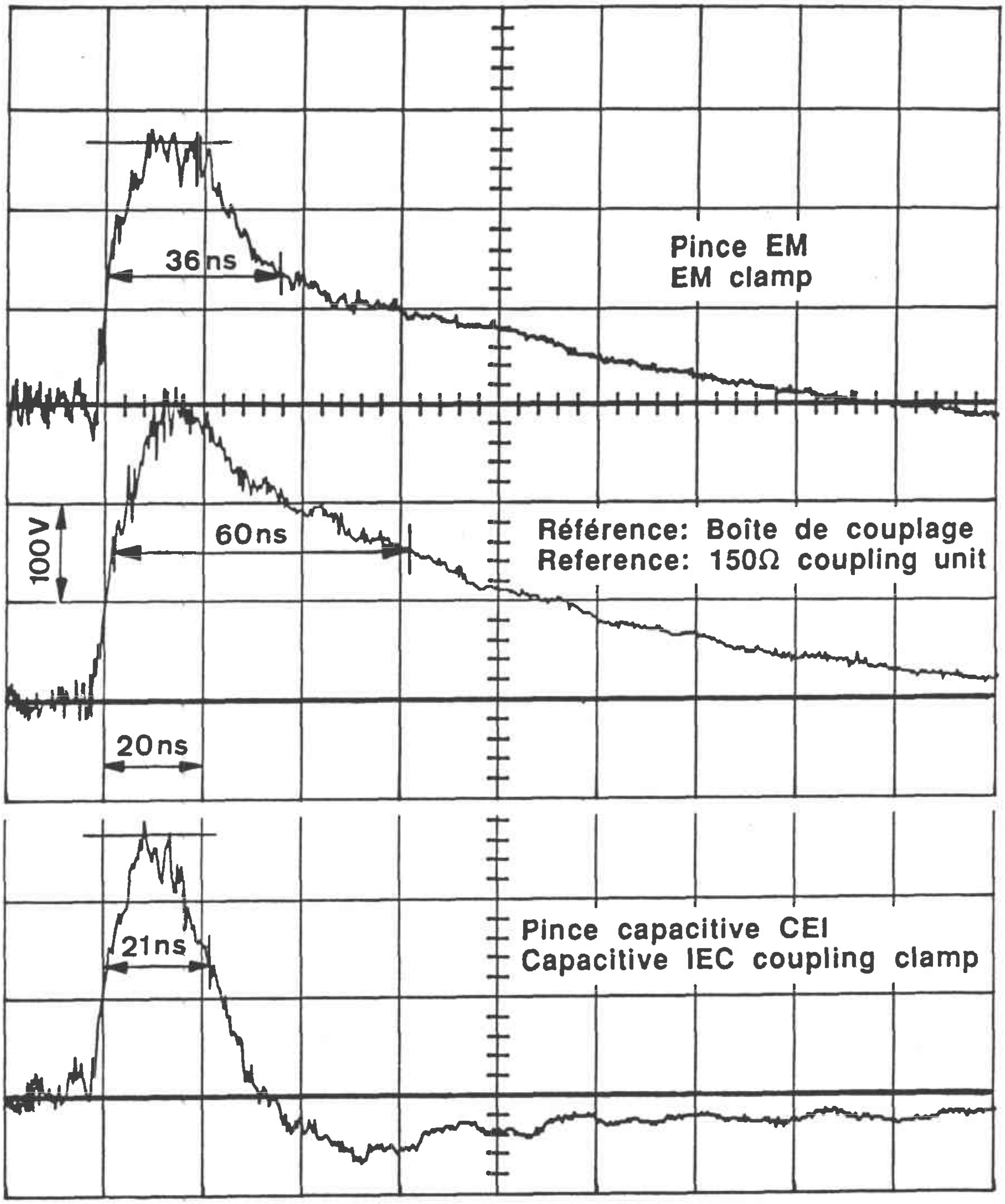


Fig.6 Injection d'impulsions brèves 5ns/50ns (salve) avec la pince EM et la pince capacitive CEI.

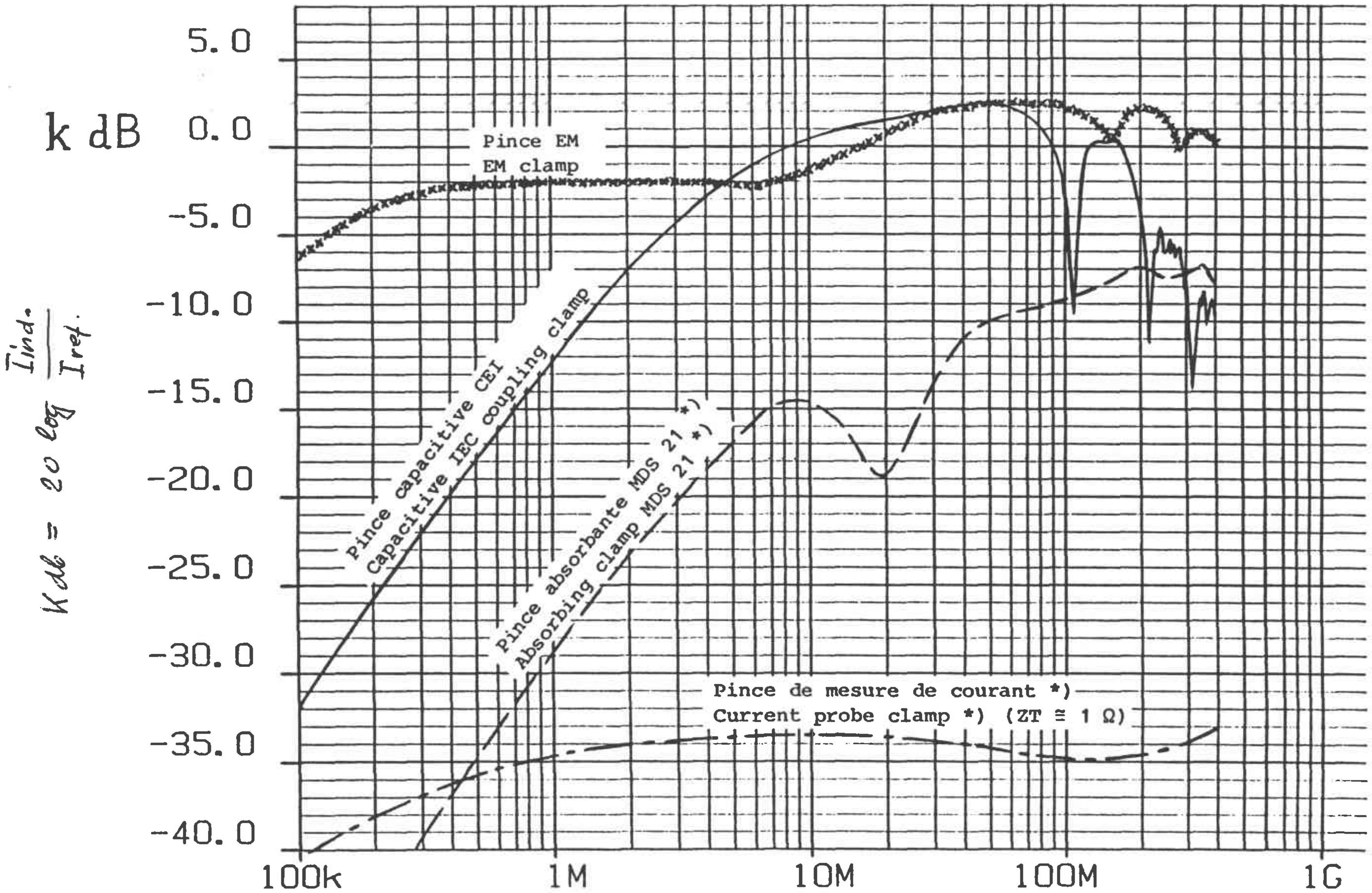
Injection of fast transients 5ns/50ns (burst) with the EM clamp and the capacitive IEC coupling clamp.

Montage selon fig. 4b: Tension mesurée sur la charge A (150 Ω).
- Référence: Boîte 150 Ω, fig. 4a.
- Tension de charge du générateur de salves: 1 kV

Test set-up according to fig. 4b: Voltage measured across the load A (150 Ω).
- Reference: 150 Ω coupling unit, fig. 4a.
- Charging voltage of the fast transient generator: 1 kV

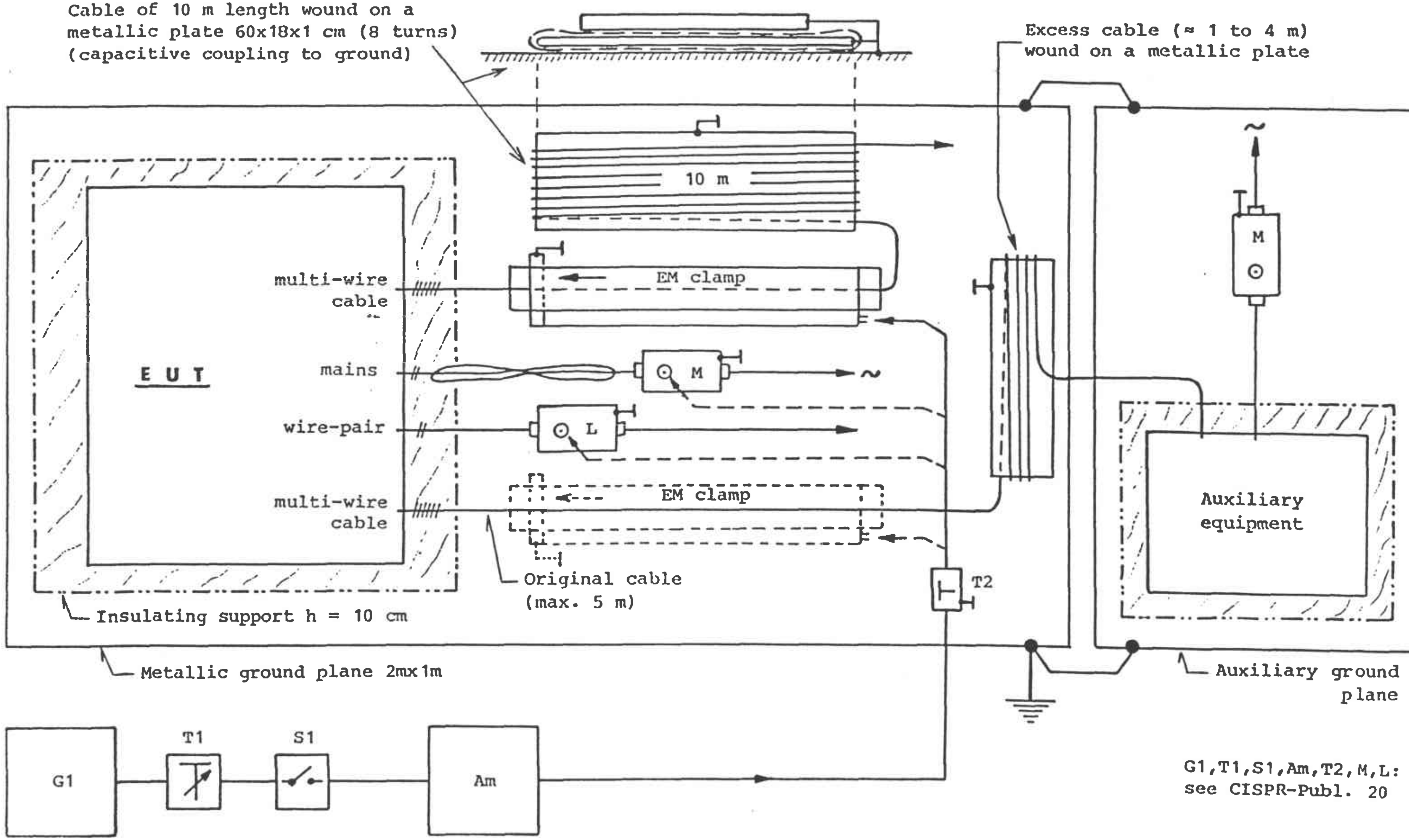
<u>Fig. 7</u> : Comparaison des facteurs de correction de divers dispositifs établis selon le procédé de la fig. 4

<u>Fig. 7</u> : Comparison of the correction factors of various devices, established according to the procedure of fig. 4



*) utilisation en injecteur de courant
*) used as current injection device

Fig. 8: Proposed set-up for the current-injection method



G1,T1,S1,Am,T2,M,L:
see CISPR-Publ. 20

CORRELATION between the field's method and the current injection's method effect (EM 101 or CDN) on the EUT

The developpers (Mr. Bersier and Ryser, General Directorate Swiss PTT)of the EM Clamp have given us the following explanation:

See fig.8 (proposed set-up for the current-injection method)

1 Volt (source voltage) at output T_1 corresponds to a field strength of about 1 V/meter

The correction values given in the measured curve enclosed with the EM 101 are to be taken in account as follows:
In the case of negative values the source voltage is to be incrased by the values as per the curve; when positive, it is to be decreased accordingly.

Injection with a CDN (Coupling-decoupling Network) requires no correction.

SC 65A/WG4 (CH-Bersier, Szentkuti)2
CISPR/A/WG1 (Bersier)18
CISPR/G/WG3 (Bersier, Ryser)6
March 1991

Practical application of the EM clamp:

New test setup yielding better reproducibility of the tests and better decoupling of the auxiliary equipment

Investigations performed at the Swiss PTT show that a ferrite tube of high permeability, placed directly at the rear side of the EM clamp, improves the reproducibility of the immunity tests and efficiently decouples the auxiliary equipment (AE). This setup is shown in figures 1 and 1a.

However, the application of this tube increases the impedance of the injection setup in the frequency range 0.5...5 MHz, i.e. the injected current will be decreased in this frequency band. Therefore the whole "combination" [EM clamp + ferrite tube] must be considered as the injection system , rather than the EM clamp alone, when calibrating for the correction-factor; see fig. 2.

With the setup of fig. 1 the influence of the rear circuit (AE impedance, length and layout of the cable) on the injection to the EUT-side does usually not exeede ± 3 dB, with respect to the values during calibration, in the frequency range 1 MHz...400 MHz (see fig. 3 and 4). Consequently in this frequency range the setup of fig. 1 may be used for any type of AE and cabling.

In the frequency range 150 kHz...1 MHz the strongest influence from the rear circuit is obtained, whenever the cable is short and the common mode impedance of the AE is high. This is the situation when the AE input-circuits are insulated from the AE-earth.

For the tests in the frequency range 150 kHz...1 MHz the reproducibility may be improved through the following measures:

- Connect a 150 Ω resistor between the ground point of the AE input-circuits (generally the ground pin of the input connector) and the GRP.
- If this is not feasible than increase the capacitance between the cable and the GRP at the rear side of the injection system, as much as possible (10 m cable placed in zig-zag on the GRP or capacitive winding on a metallic plate).

Fig. 5a shows the decoupling obtained for the AE using the setup of fig. 1 in the case of a short cable. This decoupling may be increased by using a long cable and, if necessary, an additional ferrite tube, directly at the AE (fig. 5b).

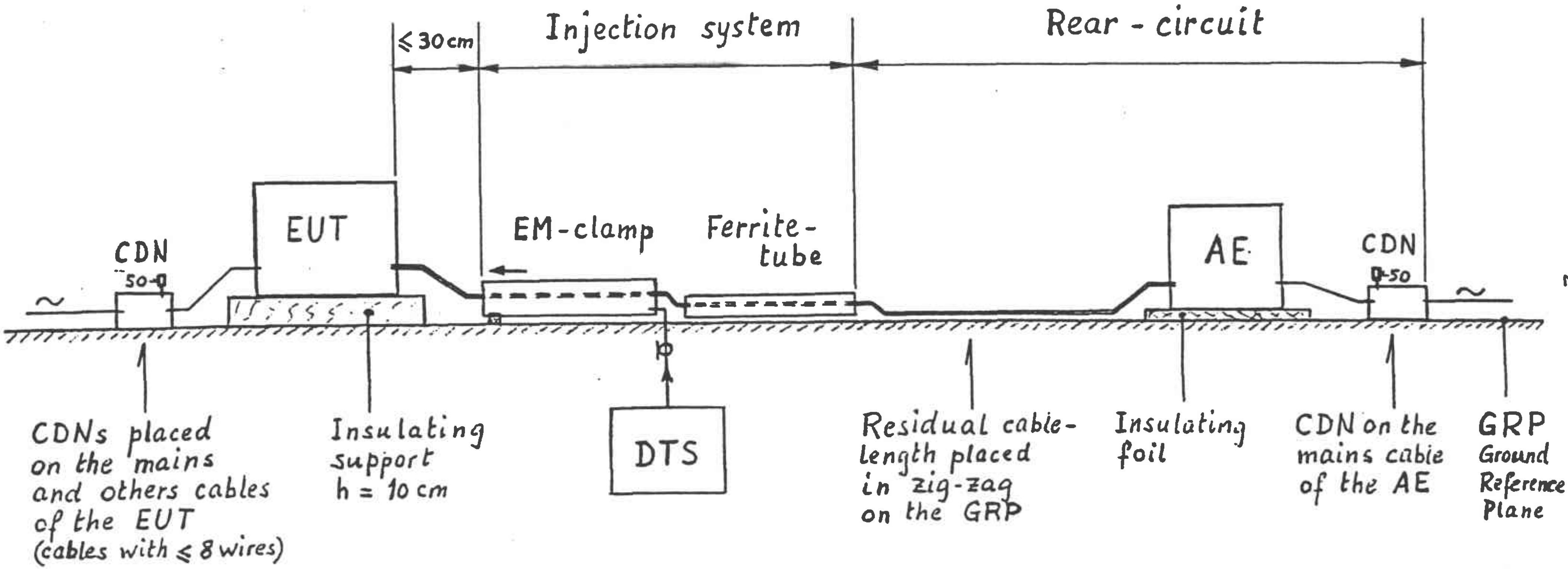


Fig. 1: Test set-up applicable for all immunity tests using the EM-clamp, in the frequency range 1 MHz to 400 MHz.

For the tests in the frequency-range 0,15...1 MHz it is recommended to stabilise the common-mode inpedance of the AE to 150 Ω, in order to provide reproducible test-conditions.

The correction factor k_{cf} of the whole injection system comprising the EM-clamp and the ferrite tube shall be taken into account.

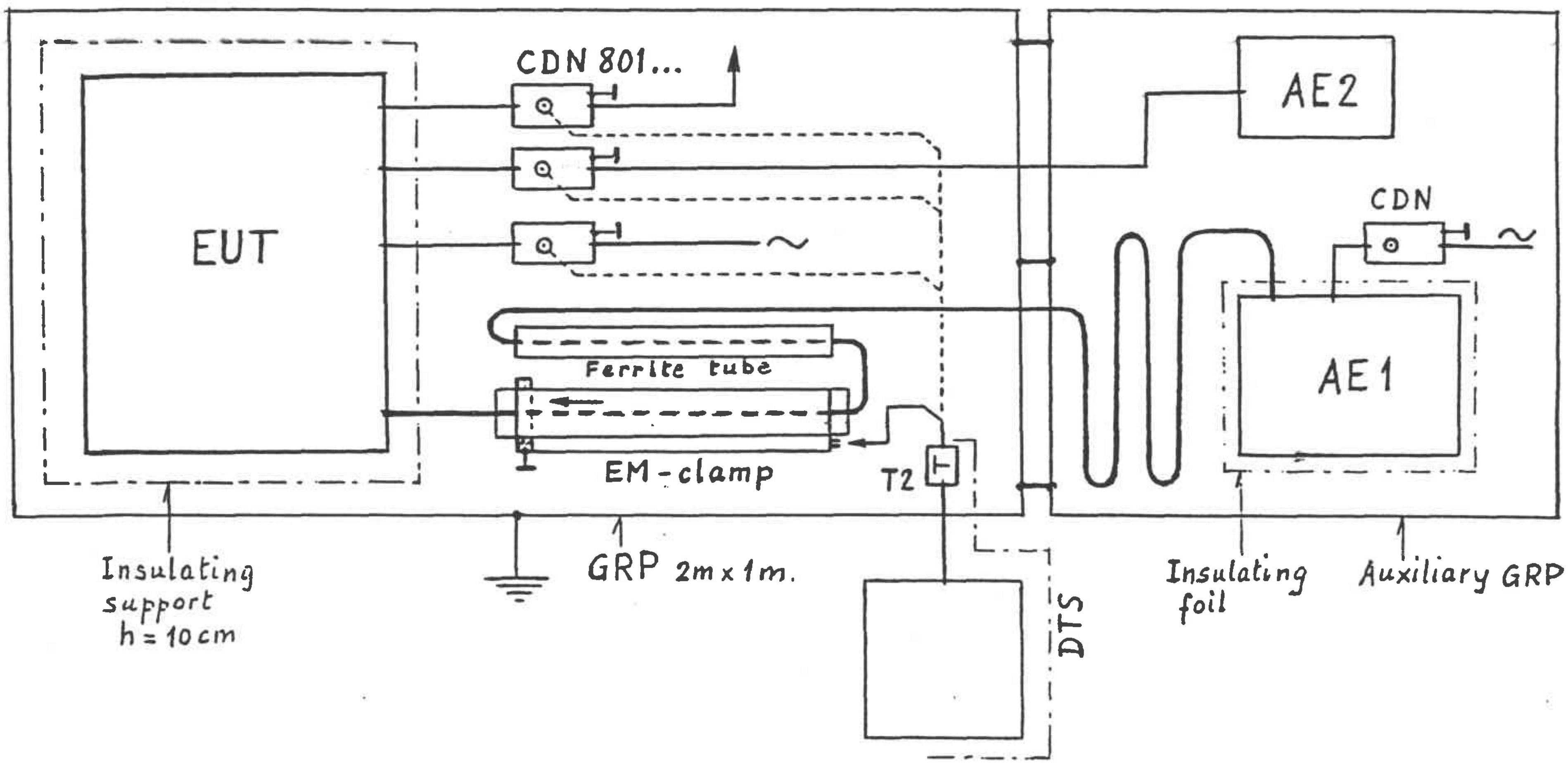
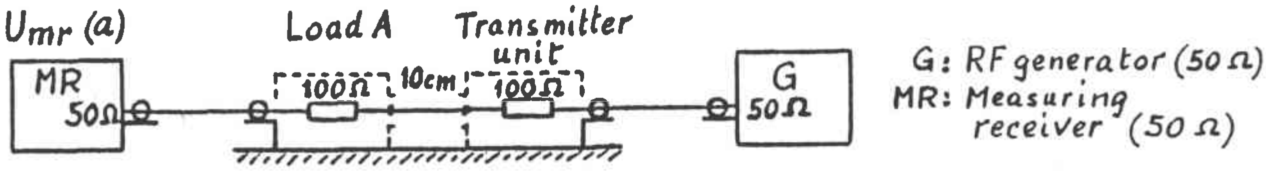


Fig. 1a: Example of test unit locations on the ground plane (upper viewl)

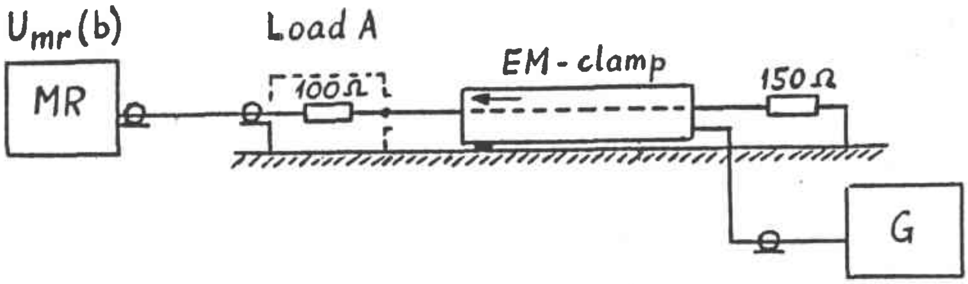
Fig. 2: Calibration of the injection system

a) Reference set - up with two 150 Ω coupling units



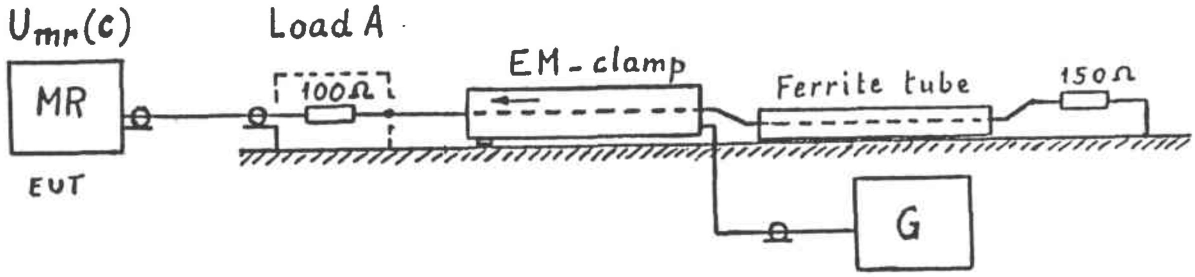
b) The transmitter unit is replaced by the EM - clamp
Correction factor of the EM - clamp:

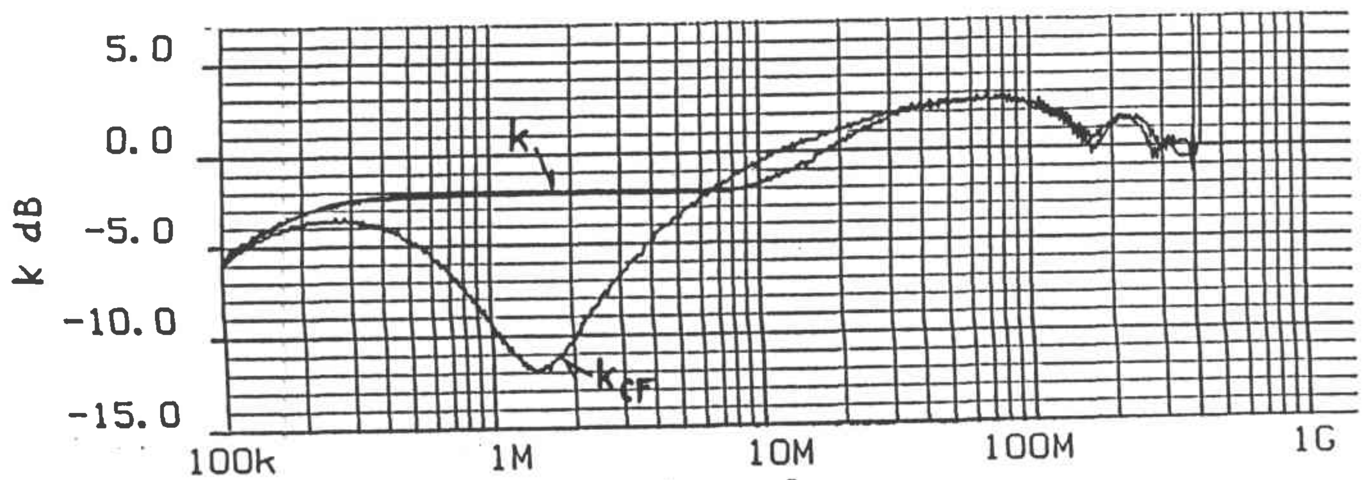
$$\underset{dB}{k} = \underset{dB(\mu V)}{U_{mr}(b)} - \underset{dB(\mu V)}{U_{mr}(a)}$$ for the same e.m.f. of G



c) The transmitter unit is replaced by the injection system [EM - clamp + ferrite tube]
Correction factor of the injection system:

$$\underset{dB}{k_{cf}} = \underset{dB(\mu V)}{U_{mr}(c)} - \underset{dB(\mu V)}{U_{mr}(a)}$$ for the same e.m.f. of G





k = correction factor for the clamp EM 101
k_{cf} = correction factor for the injection system EM 101 + ferrite tube

Fig. 3 + 4: Influence of the AE - impedance and cable layout on the injected level to the EUT.

EUT simulated by typical impedance 150 Ω.

Injection system: EM - clamp + ferrite tube

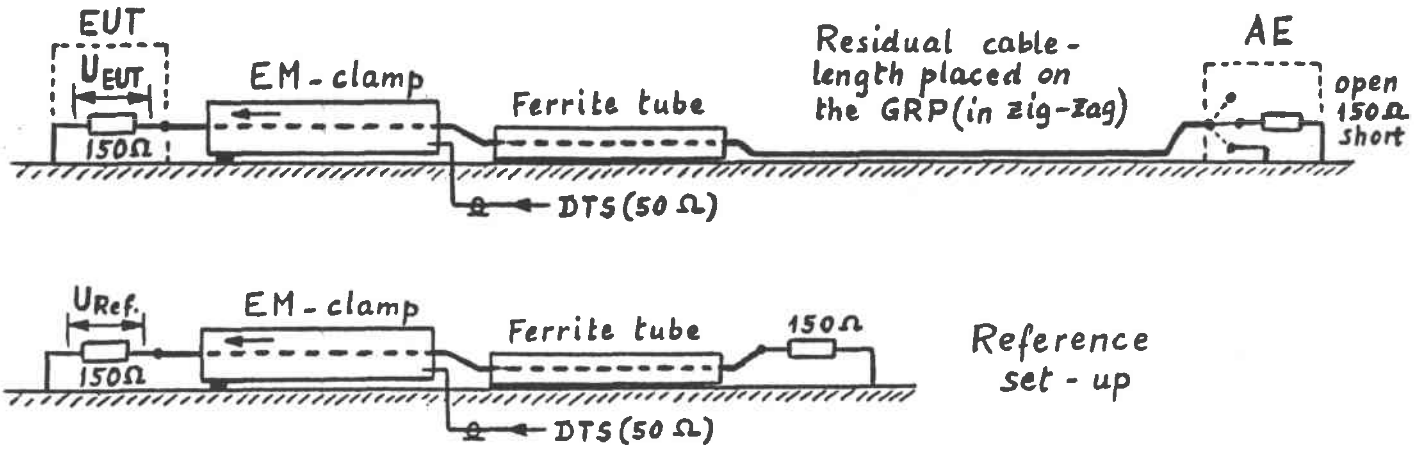


Fig. 3: Total cable - length: 12 m (~ 10,4 m in zig - zag on the GRP)

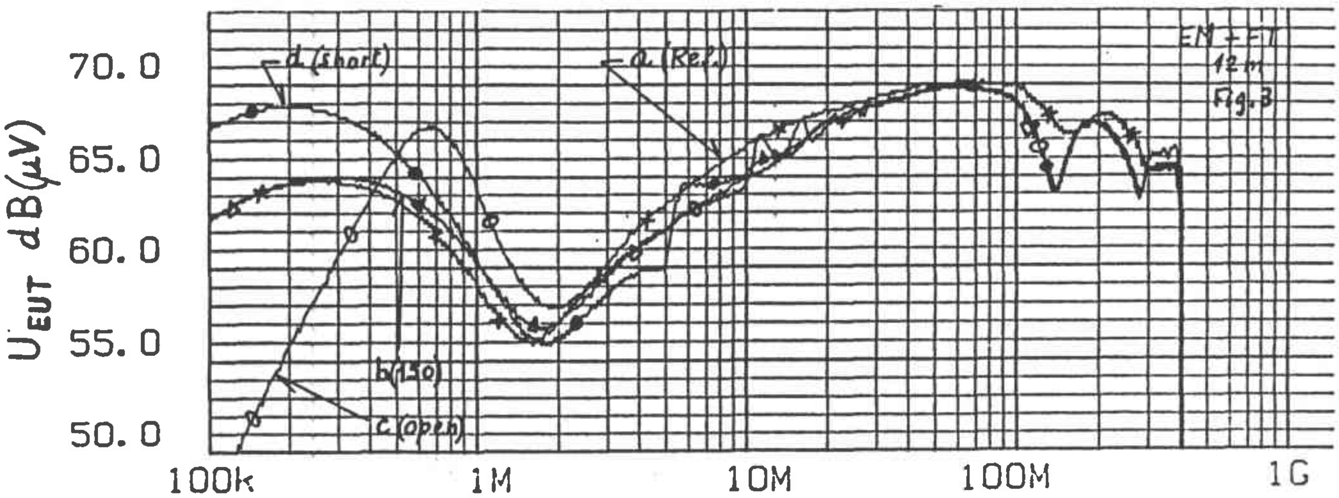
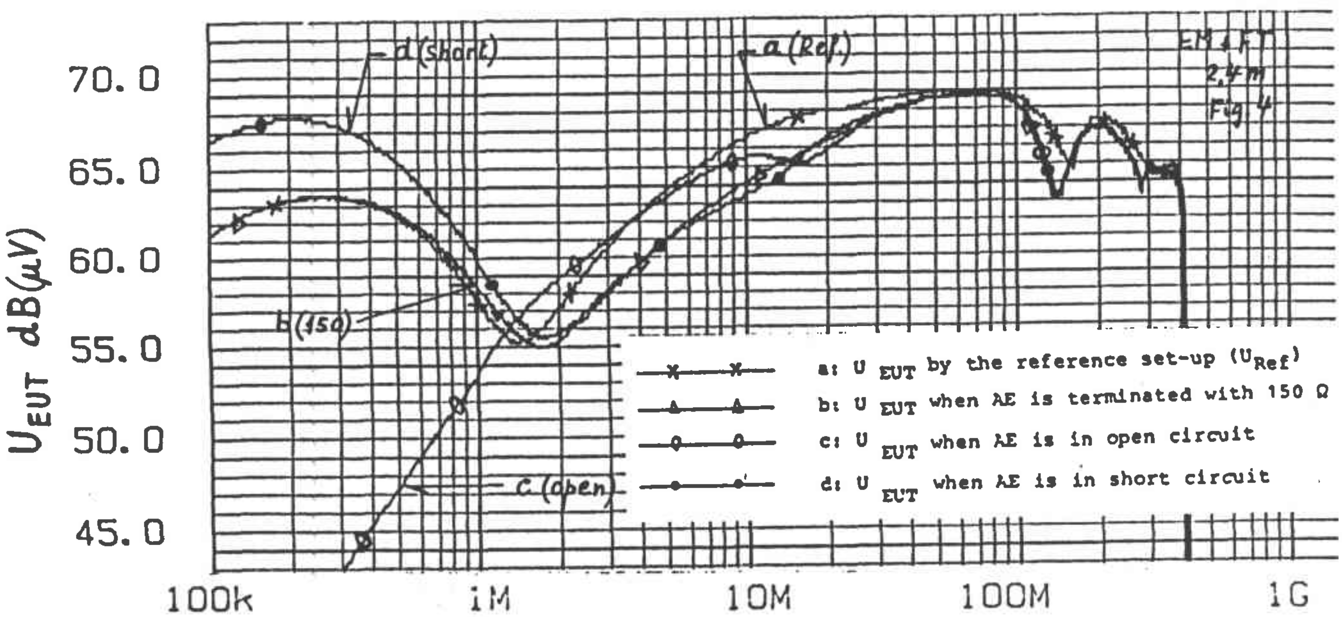


Fig. 4: Total cable - length: 2,4 m (~ 0,8 m on the GRP)



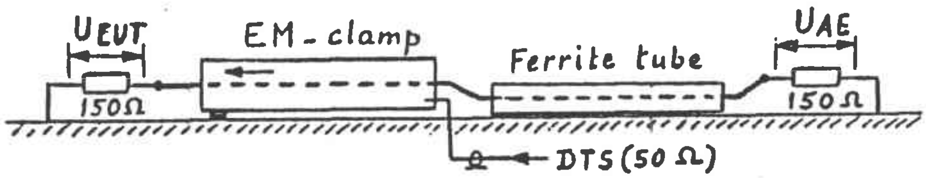
<u>Fig. 5:</u> <u>Protection of the auxiliary equipment (AE)</u>

Injection system: EM - clamp + ferrite tube

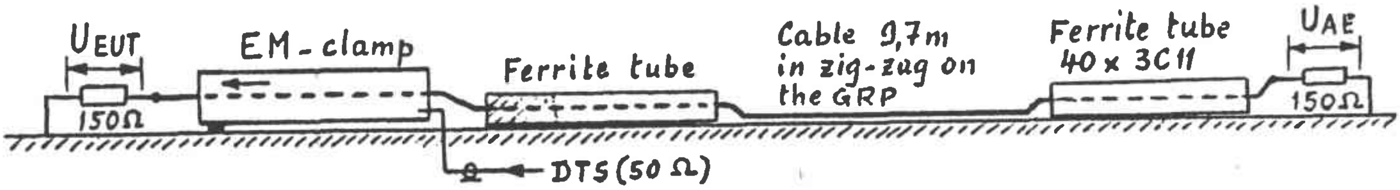
EUT = 150 Ω ; AE = 150 Ω

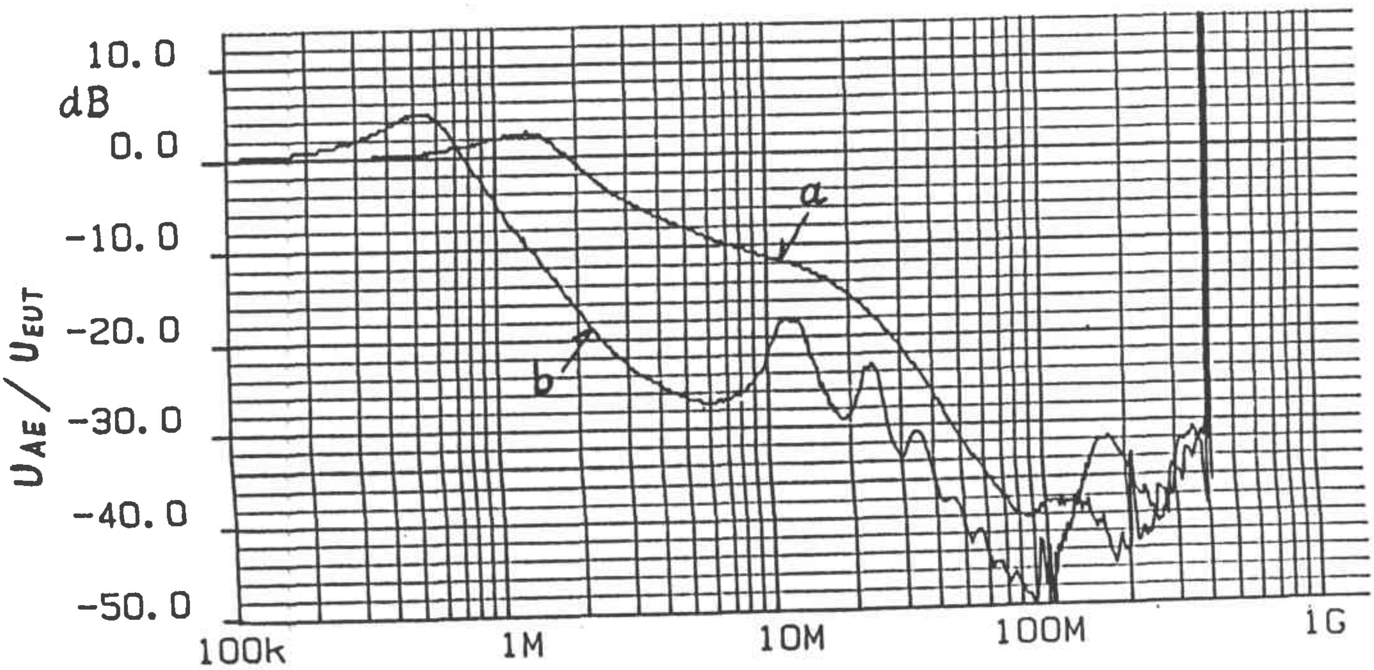
$$\underset{\text{dB}}{\text{Protection of the AE}} = \underset{\text{dB}(\mu\text{V})}{U_{AE}} - \underset{\text{dB}(\mu\text{V})}{U_{EUT}}$$

a) Total cable length: 1,8 m



b) Total cable length: 12 m (~9,7 m in zig - zag on the GRP)





Reference level and required HF power of the power amplifier PA in the frequency range 0.15 ... 230 MHz

Table 1 Test levels

Frequency range	.15 MHz - 80 MHz	
Level	Voltage level (e.m.f.) U_o [dBuV]	U_o [V]
1	120	1
2	130	3
3	140	10
X[1]	special	

The prescribed voltage test levels are shown in item 5, table 1.

This is the not direct measurable EMF at the exit of T2.

For HF current injection either a CDN or a **Current Injection Clamp** (**EM 101** or Current Clamp 5:1) can be used, depending on the number of leads.

The decoupling against the AE is contained in both the CDN and the EM 101. In order to obtain a well reproducible result below 20 MHz, it is advisable to use an additional decoupling (FTC Clamp). In this connection please note that the Current Clamp 5:1 without decoupling does not produce reproducible results.

The required output power of the PA for testing at level 3 (10 $V_{e.m.f.}$) and 80 % amplitude modulation depth is shown in table D.1.

The available output power of the power amplifier PA, figure 3 can be determined by taking into account the attenuator T_2 (6 dB), the amplitude modulation depth (80 %), see figure 4 and the minimum coupling factor of the used CDN or clamp.

Table D.1 Required power amplifier output power to obtain a test level of 10 $V_{e.m.f.}$

Injection device	Minimum coupling factor ± 1.5 [dB]	Required power at output of PA [Watt]
CDN	0	7
Current clamp winding ratio 5:1	-14	176
EM-clamp	-6	28

Determination of the power required for measuring by means of the EM 101:
At 150 Hz k equals -5 dB; the ratio is 3.16 (see table in annex 2)
P_{PA} = 3.16 * 7 = 22 W.

If the FTC 101 is used as an additional decoupling in order to guarantee reproducibility below 20 MHz, more power is required in the hatched frequency range. At the most unfavourable frequency of 1.5 MHz k equals -12 dB; the ratio is 15.85
P_{PA} = 15.85 * 7 = 111 W.
If the range between 1 and 1.5 MHz is not relevant, 90 W are sufficient, etc.

Annex
1 coupling factor of EM 101 + FTC 101
2 table dB / Watt
3 measuring of the reference
4 substitute circuit diagram with CDN
5 substitute circuit diagram with EM 101

Lüthi Elektronik-Feinmechanik AG
CH-4402 Frenkendorf

Verification of the system EM101 + FTC101 in the frequency range 150 kHz - 1000 MHz with reference to a 150Ω source / load system

Swisscom CT-EEC Ry

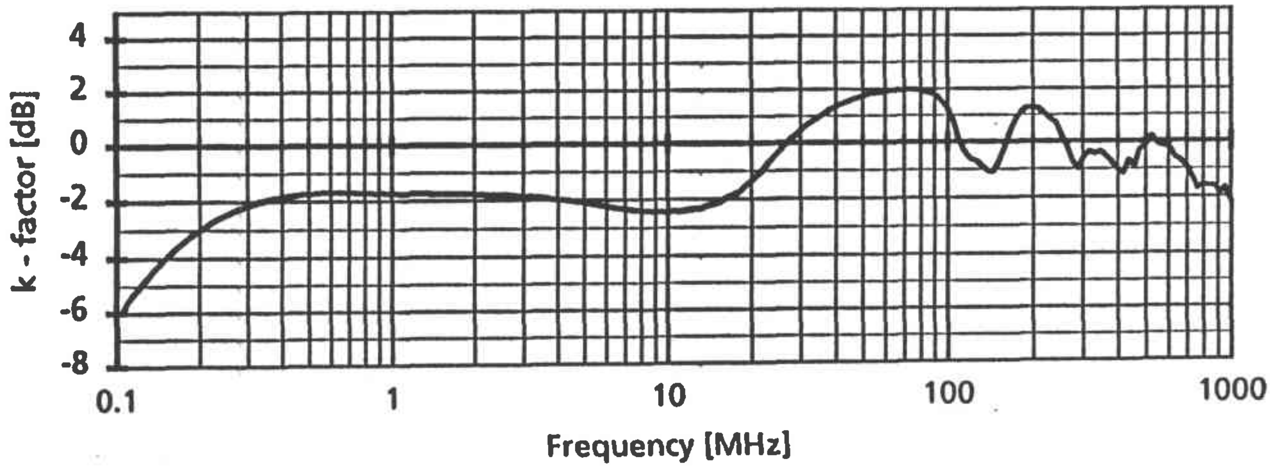
Date 07.04.1999

EM101 Ser. Nr.: 35555

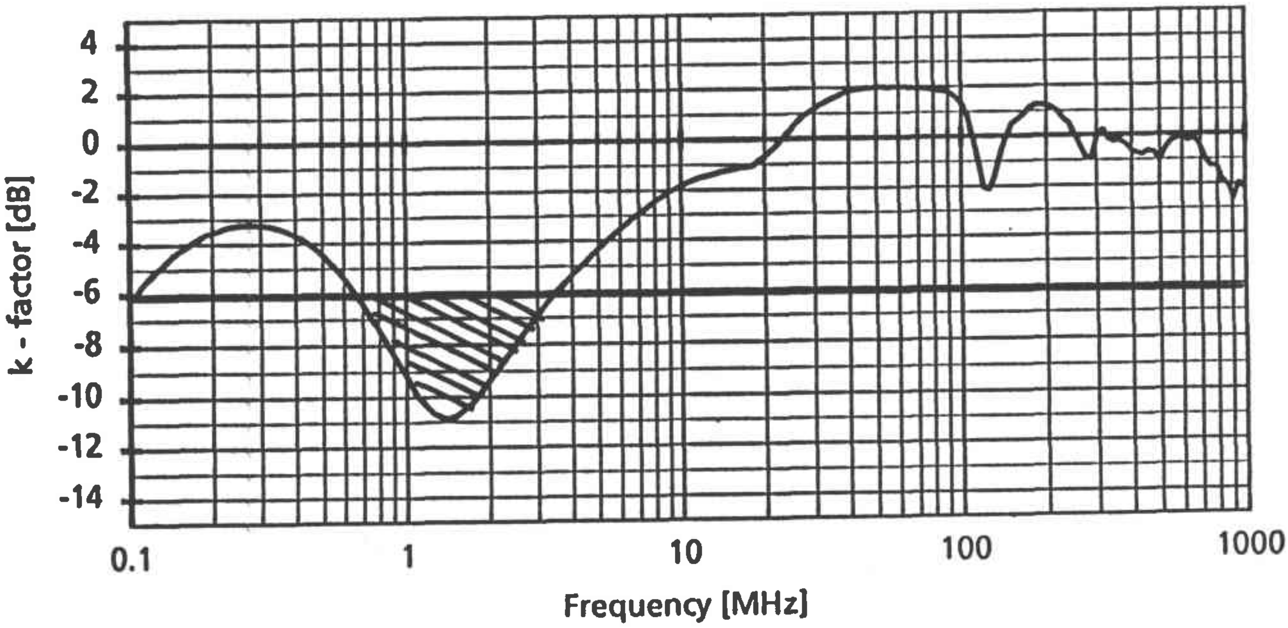
FTC 101 Ser. Nr.: 4631

Made by: Lüthi Elektronik-Feinmechanik AG
CH 4402 Frenkendorf

EM101 (without FTC)



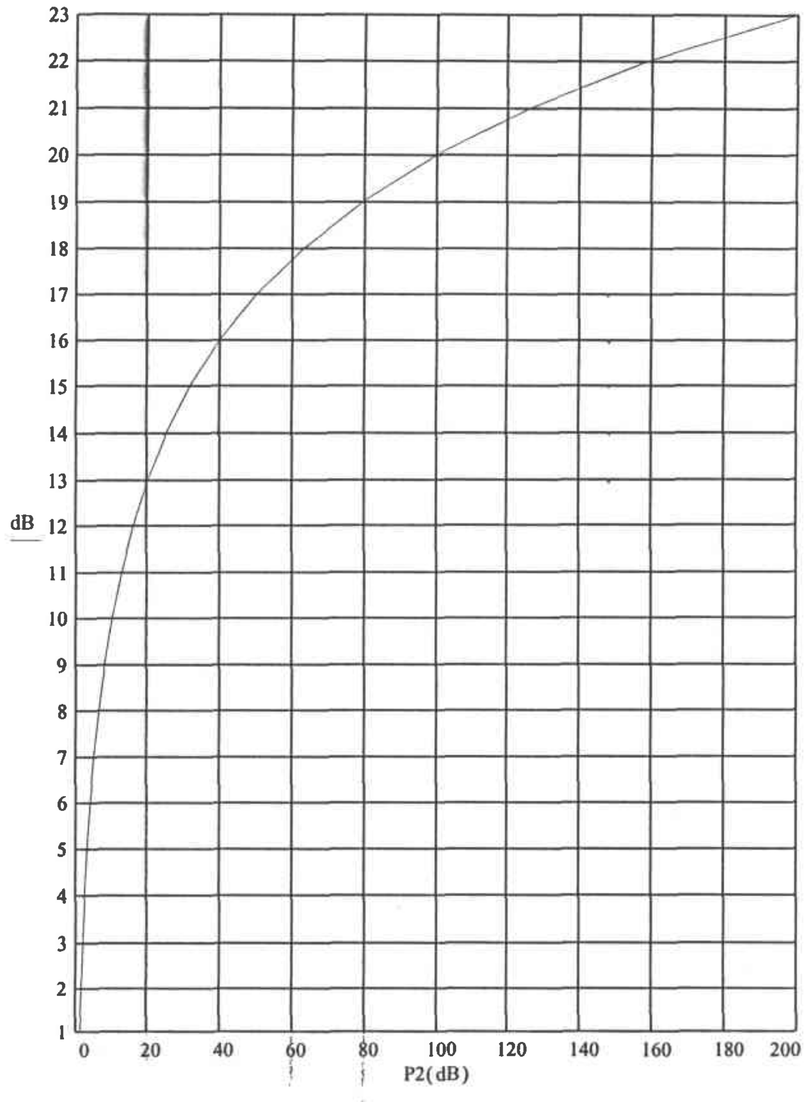
System EM101 + FTC 101



Prüfleistung des PA
Output power of the PA

$dB := 1, 2 .. 23 \qquad P1 := 1$

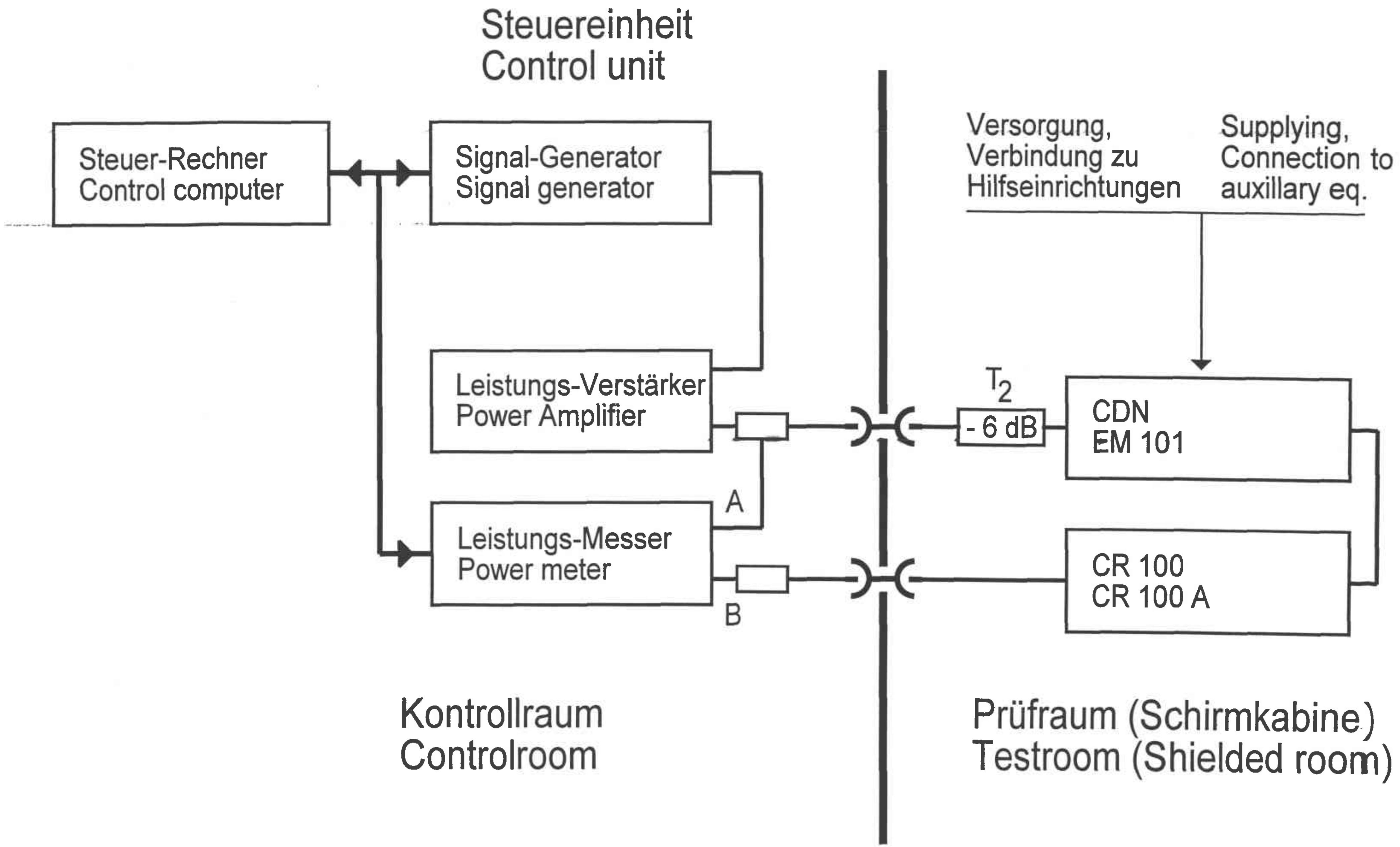
$$dB := 10 \cdot \log\left(\frac{P2}{P1}\right) \qquad P2(dB) := \exp\left(\frac{1}{10} \cdot dB \cdot \ln(10)\right) \cdot P1$$



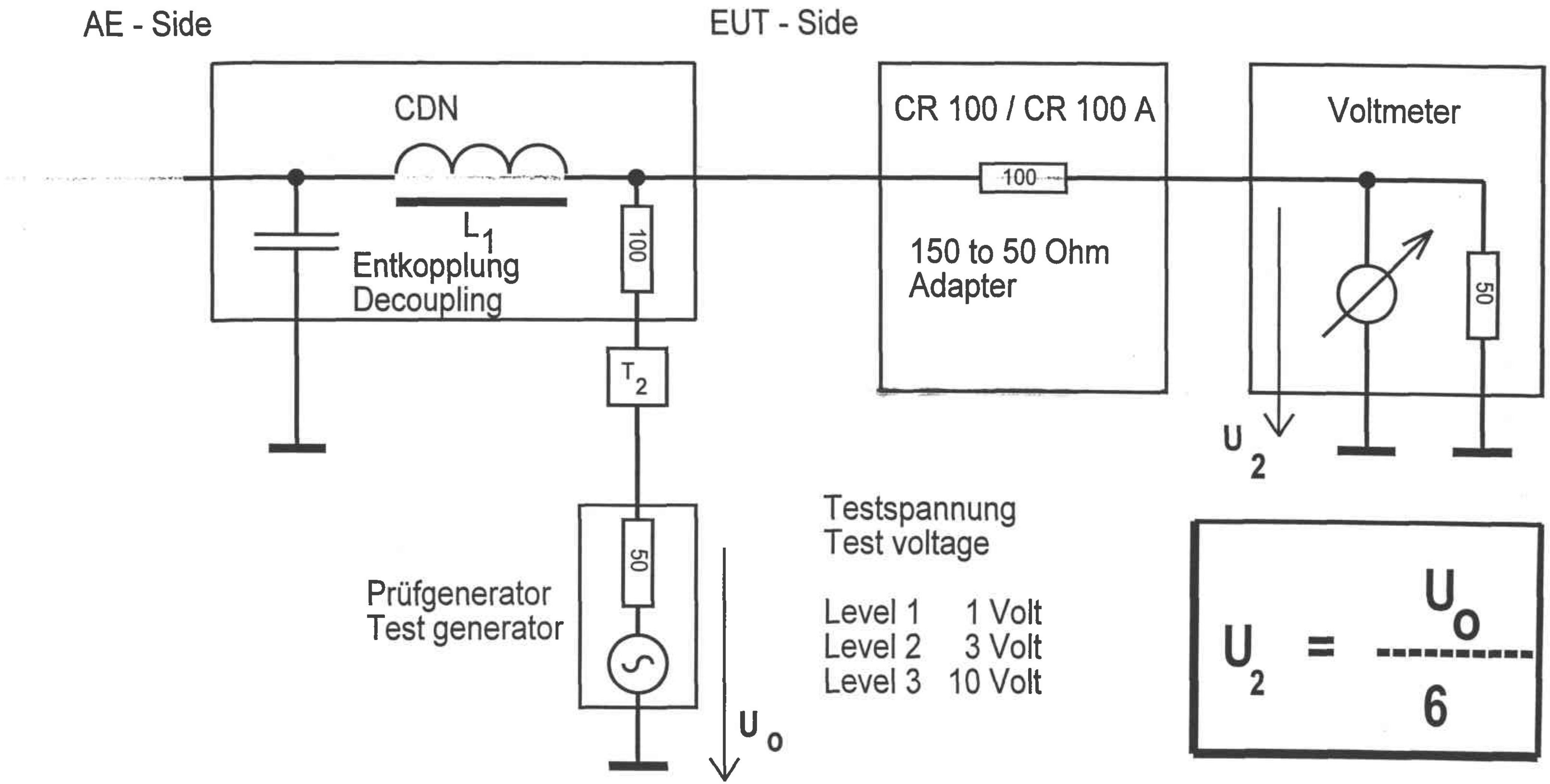
dB	P2(dB)
1	1.259
2	1.585
3	1.995
4	2.512
5	3.162
6	3.981
7	5.012
8	6.31
9	7.943
10	10
11	12.589
12	15.849
13	19.953
14	25.119
15	31.623
16	39.811
17	50.119
18	63.096
19	79.433
20	100
21	125.893
22	158.489
23	199.526

P2 [W]

Referenzmessung / Reference measurement



Referenzmessung : Ersatzschaltbild CDN
Reference measurement : Basic circuit CDN



Testspannung
Test voltage

Level 1	1 Volt
Level 2	3 Volt
Level 3	10 Volt

$$U_2 = \frac{U_o}{6}$$

IEC 1000-4-6

Referenzmessung : Ersatzschaltbild EM 101
Reference measurement : Basic circuit EM 101