LANGER
EMV-Technik

IC TEST SYSTEM

User manual

Probe set for RF field measurements on ICs

P1601, P1602 / P1702 set

Magnetic field:
P1601, 1602

Electric field:
P1702

For use with spectrum analyser

Table of contents: Page

1 Declaration of Conformity 4

2 Measurement systems for electric and magnetic field emissions from ICs 5

2.1 Introduction 5
2.2 Magnetic fields of ICs and how they are measured 7
2.3 Electric fields of ICs and how they are measured 8
2.4 Derivation of the measurement set-up 10

3 Magnetic field measurement with P1600 series 12

3.1 Design of the P1601, P1602 magnetic field probe 12
3.2 Function of the P1601, P1602 magnetic field probes 13
3.2.1 Equivalent circuit diagram and interactions of the magnetic field coupled out 14
3.2.2 Converting the measurement value U_{AV} of the spectrum analyser into EMC parameters 15
3.2.3 Correction curves and matching the P1601 and P1602 field probes 17
3.2.4 Parameters to describe the magnetic field excitation by ICs 21
3.3 Measurement with a spectrum analyser 23
3.3.1 Measurement set-up and measurement with the ChipScan-ESA software 23
3.3.2 Magnetic field measurement on the IC 26
3.3.3 Determining the IC emissions radiated in the worst case 27
3.3.4 Generating the excitation flux $\Phi(\omega)$ with the BPM 02 $\dot{B}$ field meter as a test source 31
3.3.5 Creating the correction factor K1600 38
3.3.6 Frequency response of the RF magnetic field probe 44
3.3.7 E-field suppression of the P1600 RF magnetic field probe 45

4 E-field measurement with P1702 47

4.1 Design of the P1702 E-field probe 47
4.2 Function of the P1702 E-field probe 48
4.2.1 Equivalent circuit diagram and interactions of the electric field coupled out 49
4.2.2 Converting the measurement value U_{AV} of the spectrum analyser into EMC parameters 51
4.2.3 Correction curves and matching of the P1702 probe 53
4.2.4 Parameters to describe electric field excitation by ICs 55
4.3 Measurement with a spectrum analyser 57
4.3.1 Measurement set-up and measurement with the ChipScan-ESA software 57
4.3.2 Measuring the electric field on the IC 60
4.3.3 Generating the excitation current I_P with the EPM 02 $\dot{E}$-field meter as a test source 61

4.3.4 Creating the correction curve K1702 70
4.3.5 Frequency response of the P1702 field probe 75
4.4 Set-up of the test bench / system set-up 77
4.5 Performance of the test 80
4.5.1 Test procedure 80
4.6 Verifying the waveform 80
5 Safety instructions 81
6 Warranty 81
7 Technical specifications 82
7.1 Characteristics 82
7.1.1 Characteristics of the field probes in the P1600 series 82
7.1.2 Characteristics of the P1702 E-field probe 1702 82
8 Scope of delivery 83
9 Information on Recycling and Disposal 84
10 Customer Service 84
11 Warranty 85

1 Declaration of Conformity

Manufacturer:
Langer EMV-Technik GmbH

Nöthnitzer Hang 31
01728 Bannewitz
Germany

Langer EMV-Technik GmbH herewith declares that the

P1601 / P1702 set, RF Field Emission up to 1 GHz including following products
- **P1601,** RF Magnetic Field Probe and
- **P1702**, RF E-Field Probe and

P1601 / P1702 set, RF Field Emission up to 3 GHz including following products
- **P1602,** RF Magnetic Field Probe and
- **P1702**, RF E-Field Probe

conforms with the following relevant regulations:
- EMC Directive 2014/30/EU
- Restriction of certain Hazardous Substances 2011/65/EU

The following applicable standards were used to implement the requirements specified by the aforementioned directives:
- DIN EN IEC 61000-6-1:2019-11 (EMC immunity)
- DIN EN IEC 61000-6-3:2022-06 (EMC emission)
- DIN EN IEC 63000:2019-05 (Restriction of hazardous substances)

Note: This product is not covered by the Low Voltage Directive (2014/35/EU), as its operating voltage is below 50 V AC / 75 V DC.

Name of the person authorized to compile the technical documentation

Katja Langer

Bannewitz, 2025-09-08

Signature:

K. Langer, Managing Director

2 Measurement systems for electric and magnetic field emissions from ICs

2.1 Introduction

The ***P1601, 1602*** and ***P1702*** probes are field probes. They are used to measure electric (E) or magnetic (H, B) RF fields which are emitted by ICs in the context of electromagnetic emissions from electronic devices (electrical equipment and facilities). The electronic devices are tested according to the relevant standards to determine their emissions. Limit values and basic standards can be found in the generic standards IEC (EN) 61000-6-3 and IEC (EN) 61000-6-4. These tests measure the radiation or transmission of electromagnetic fields from the electronic device via housings or connections.

Emissions from electronic devices are caused by switching operations, mainly in connection with the usual processes which take place on the electronic circuits inside them. Electronic switches are the responsible components. Integrated circuits (ICs) such as microcontrollers, memory circuits, etc. contain a large number of these switches. Due to high-frequency switching operations, they generate high-frequency electromagnetic voltages, currents and fields which are emitted into the electronic module via the IC's housing, pins and line connections. The electronic module, in turn, transmits them as electromagnetic emissions to the device's environment. Even FET switches or diodes can generate emissions on account of their switching operations.

While electromagnetic emissions from electronic devices (electrical equipment and facilities) have been governed by standards for years, such regulations do not exist for parts of devices such as modules. Increasing complexity and in particular increasing component (IC) integration density make it more and more difficult to comply with the standards which are specified for the devices if there are no suitable standardized requirements at the IC level.

There is thus an urgent need to specify and verify the EMC characteristics of ICs. This is the only way to limit substantial economical risks in the electronics industry and finally ensure the electronic device's reliable functioning.

The EMC standard for ICs (IEC 61967) already provides several measuring methods for the EMC characterisation of ICs: the 1 Ohm and 150 Ohm method for conducted emissions from ICs, the TEM (Transverse Electromagnetic Cell) method and the measurement with an IC stripline for the measurement of radiated emissions from ICs.

The job of an IC test system (www.langer-emv.com) is to integrate the existing measuring methods and develop them further if and when necessary. The aim is to create a uniform test environment for all IC EMC measurements and enable the automation of the measurements. Another important task is the further development of test methods. The measurement of electromagnetic field emissions from ICs which is described in this manual is just one example.

The TEM cell or IC stripline measure the electric and magnetic field of the IC together in a single measurement. Both effects overlap at the septum of the TEM cell or in the IC stripline (**Figure 1** and **Figure 2**) and are measured as a joint value.

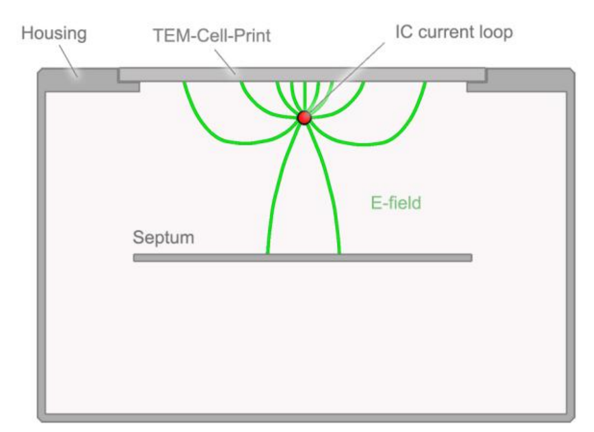

Figure 1 Development of the electric field of an IC current loop in a TEM cell or IC stripline.

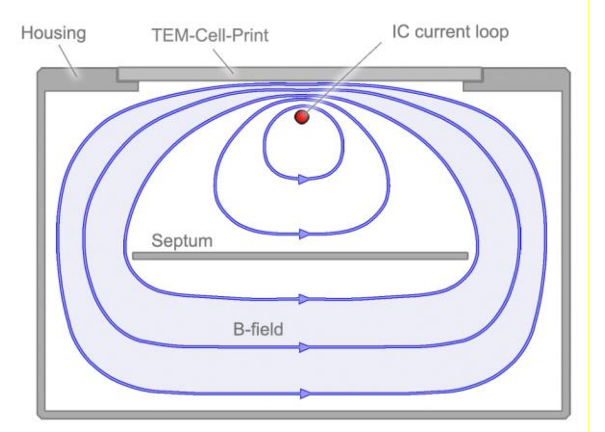

Figure 2 Development of the magnetic field of a current loop in a TEM cell or IC stripline.

The joint value of the measurement is a voltage which can be measured as $U_{AV}(\omega)$ with a spectrum analyser. The voltage $U_{AV}(\omega)$ is the EMC parameter of the IC. The concrete electric or magnetic field quantity which is generated by the IC is not determined on the basis of the voltage $U_{AV}(\omega)$ in practice.

This procedure is adequate for a global evaluation of the field emissions from an IC. A comparison of the voltage $U_{AV}(\omega)$ is sufficient here. Information on the real field strength is not necessary for such a comparison.

Precise information on the electric or magnetic field emissions from the IC, however, is necessary if technically sound, physical root-cause analyses are performed or values have to be provided for EMC simulations. This means that the fields have to be measured separately with appropriate measuring devices. The result of such separate measurements is not a voltage $U_{AV}(\omega)$ but the electric field strength $E(\omega)$ or the current $I_P(\omega)$ which is coupled out capacitively or the magnetic flux $\Phi(\omega)$.

The ***P1601*** and ***P1602*** field probes measure magnetic RF fields and the ***P1702*** field probe measures electric RF fields.

The field probe dimensions depend on how RF fields are coupled out from the ICs. The design of the field probes is based on the respective field orientation and the operational principles behind these coupling processes.

2.2 Magnetic fields of ICs and how they are measured

Figure 3 and **Figure 4** show the field orientations and operational principles for IC current loops and magnetic fields.

The metallic structure of the printed circuit board mainly determines the form of the IC's magnetic fields. Printed circuit boards usually contain continuous copper layers which shape the fields.

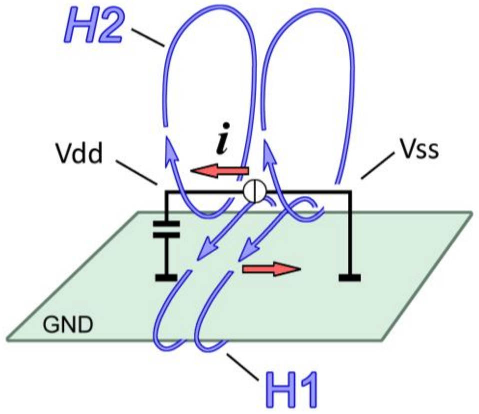

Figure 3 Magnetic fields H1 and H2 of the IC caused by a current loop of the IC responsible.

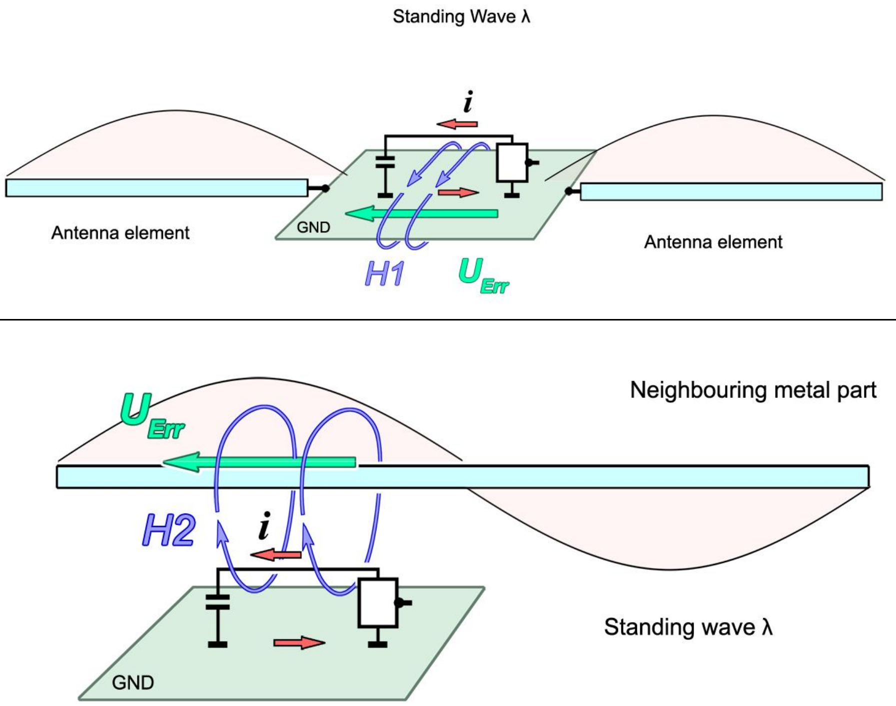

Figure 4 Coupling path of the magnetic fields H1 and H2 to generate radiated emissions from ICs.

Figure 3 shows a Vdd/ Vss IC current loop. The strongest magnetic fields are produced by the supply current ***i*** of the IC. The current ***i*** flows from the Vdd pin to the Vss pin via the back-up capacitor through the copper layer of the printed circuit board and back into the IC. The current ***i*** generates the magnetic fields H1 and H2. The field H2 develops around the electric conductor of the IC and the field H1 around the copper layer of the printed circuit board (**Figure 3**).

The spatial configuration of the fields H1 and H2 around the copper layer of the printed circuit board and the IC can be measured with the magnetic field probes in the ***RF 1*** and ***RF 2*** sets from Langer EMV-Technik GmbH.

Figure 4 shows how the radiated emissions are produced. The magnetic field H1 induces the excitation voltage U_{Err} in the GND surface of the printed circuit board. This voltage drives an excitation current in the connecting lines of the printed circuit board, for example. The length of the connecting lines should correspond to half the wavelength of the excitation current frequency if possible. Standing waves can then form on the lines. The connecting lines act like an antenna in conjunction with the standing waves.

Standing waves can also form and cause emissions on the printed circuit board if this is large enough and the frequency is high enough.

The diagram at the bottom of **Figure 4** shows how field H2 can generate radiated emissions. A voltage U_{Err} is induced in a neighbouring metal part if this is encircled by the field. This voltage produces standing waves on this metal part. The standing waves in conjunction with the neighbouring metal part produce radiated emissions like a sending antenna. Field H2 cannot produce any radiated emissions if there is no neighbouring metal part.

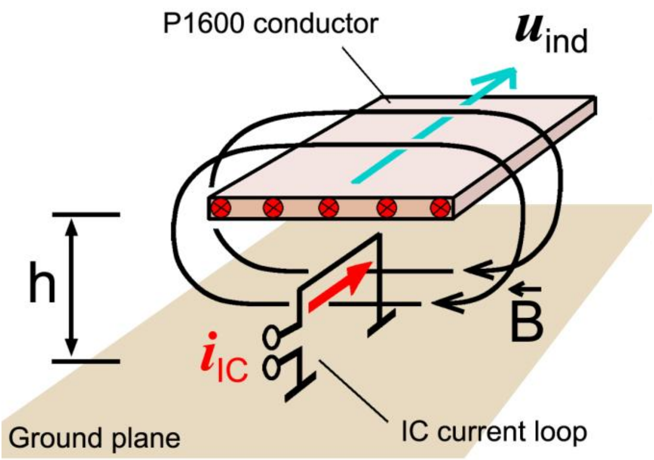

Figure 5 Operational principle of the electric conductor of the magnetic field probe in the P1600 series.

The design of magnetic field probes must allow them to pick up the magnetic flux Φ(ω) which is led around the neighbouring metal part by field H2 (**Figure 4**). The ***P1601*** and ***P1602*** probes (**Figure 5)** have an electric conductor which simulates the neighbouring metal part at the defined distance h.

2.3 Electric fields of ICs and how they are measured

An IC's electric fields are caused by RF voltages which are generated inside the IC. These voltages are present between the IC's line network and GND of the printed circuit board. A continuous copper layer usually forms the GND of the printed circuit board. The electric field develops between the line network and the copper layer of the printed circuit board (**Figure 6**).

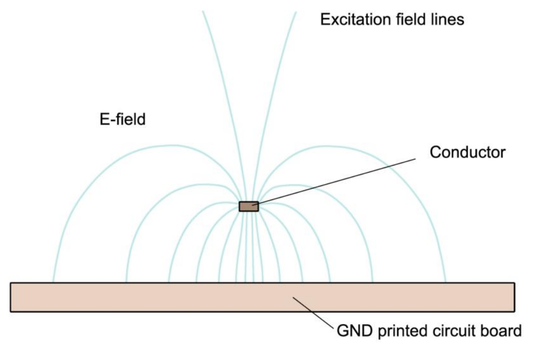

Figure 6 Electric field generated by an IC's electric conductor.

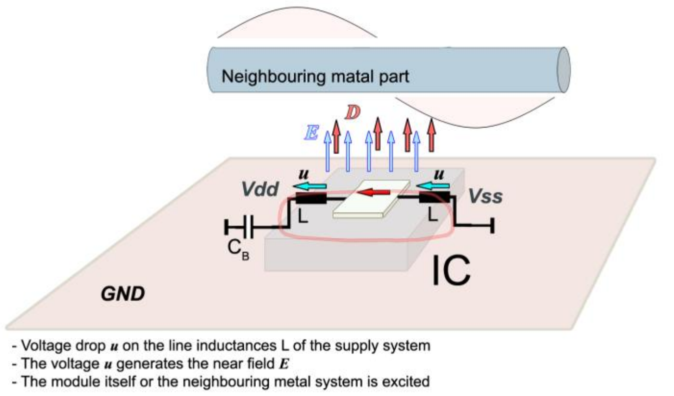

Figure 7 An IC's electric field couples to a neighbouring metal part and stimulates this to radiate emissions.

The field lines which return to the printed circuit board do not produce any emissions. The field lines which leave the module and penetrate into the environment may stimulate emissions. They are called excitation field lines. These excitation field lines transmit an excitation current capacitively into the module's environment. The excitation current can produce standing waves on neighbouring metal parts when they enter them. These standing waves cause radiated emissions.

The capacitance which couples the excitation current out is approx. 5 fF (Femtofarad). Depending on the distance (h = 3 mm or 10 mm), the electrode picks up more or less excitation current from the electric field (**Figure 6**).

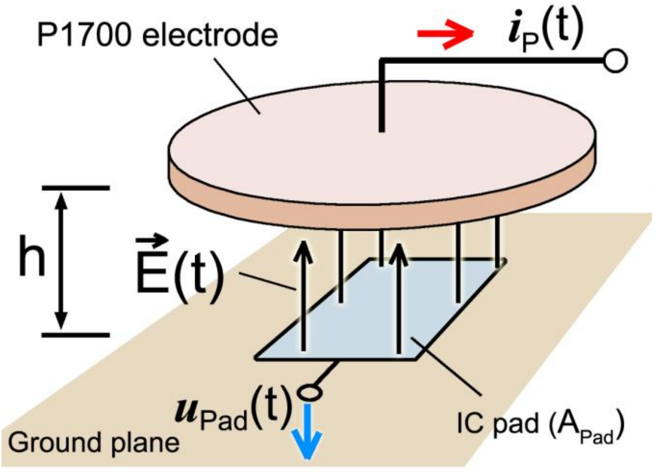

Figure 8 Operational principle of the electrode of the E-field probe in the P1700 series.

The design of E-field probes must allow them to pick-up the excitation current (**Figure 9**). The E-field probes have an electrode for this purpose (**Figure 8**). The E-field probe with its electrode is arranged at a defined distance h above the IC.

The ***RF-E 02***, ***RF-E 05*** or ***RF-E 10*** E-field probes from Langer EMV-Technik GmbH can be used to measure the IC's local electric RF fields.

2.4 Derivation of the measurement set-up

The test equipment (**Figure 9**) comprises the measurement set-up which has been derived from **Figure 5** and **Figure 8.** It includes the test-IC, test board, ground adapter, spacer ring and the bottom of the field probe together with the electrode and/or electric conductor. These components form a shielded space which is also called a field chamber.

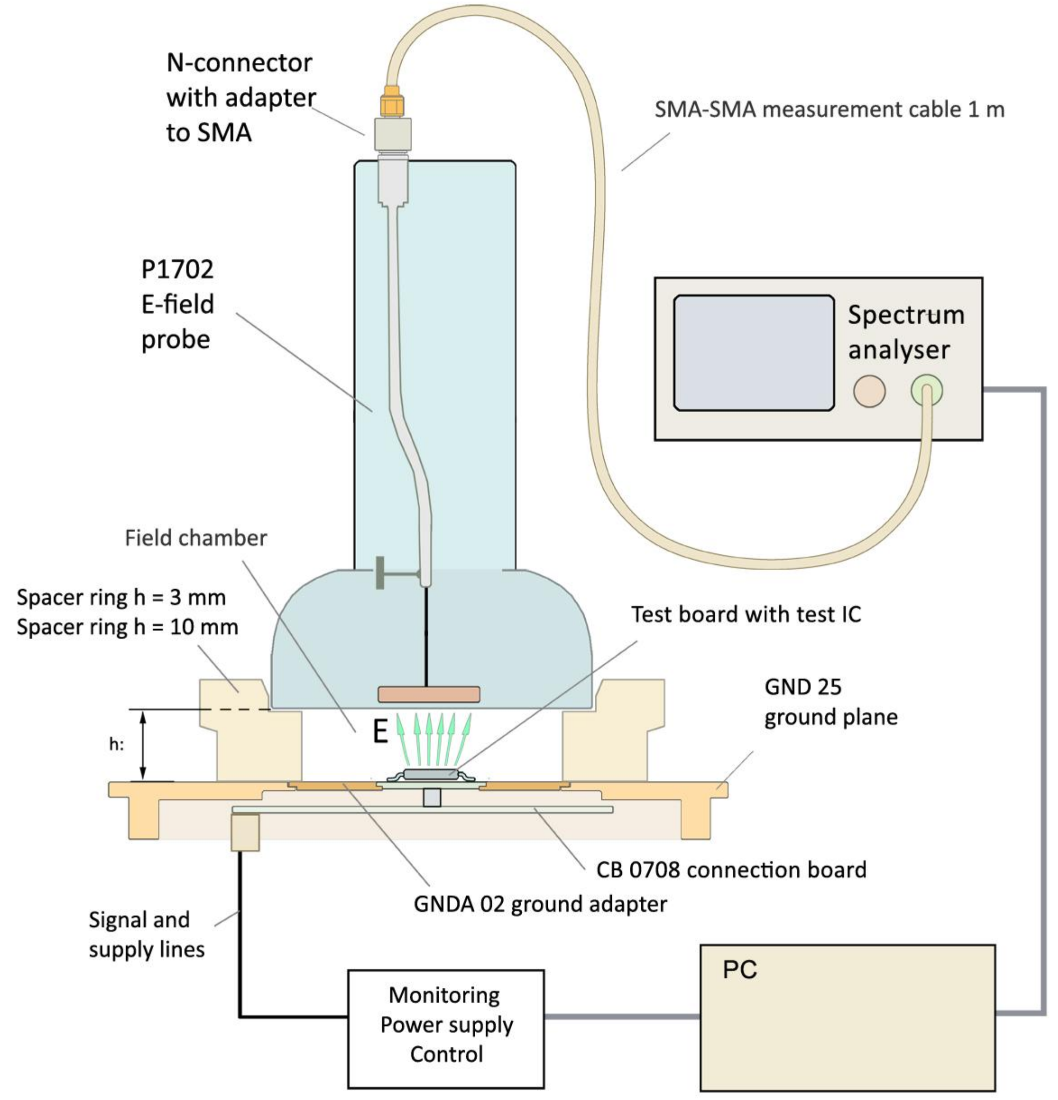

Figure 9 Test equipment: ***ICE1***[1] test environment with the ***P1702*** field probe and measuring instruments.

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[1] ***GNDA 02*** ground adapter,***GND 25*** ground plane and ***CB 0708*** connection board are included in the ***ICE1*** IC test environment set www.langer-emv.de. The test board is described in the ***IC test instructions manual***, mail@langer-emv.de.

The test equipment comprises a field probe from the RF-field measurement probe set, the ***ICE1***[2] IC test environment set and measuring instruments.

The test IC is located on the test board. The field probe is arranged above the test IC at a defined distance h = 10 mm or 3 mm with a spacer ring. The measurement signal is led to the spectrum analyser via a measuring cable. The measurement signal is converted into the electric excitation current or magnetic flux by means of a correction factor. The ***ChipScan-ESA*** software is used for this measurement and conversion. The only distinguishing feature of the measurement set-up for the measurement of RF magnetic fields is the respective field probe used for this purpose.

Notation:

- u, $u(t)$, $E(t)$: Variation over time
- U, E: Effective values
- U_{MAX}, $\hat{U}$: Peak values
- dB / dt: $\dot{B}$
- $U(\omega)$, $E(\omega)$: Effective values, variation with frequency

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[2] www.langer-emv.com

3 Magnetic field measurement with P1600 series

3.1 Design of the P1601, P1602 magnetic field probe

Figure 10 Design of ***P1601*** with a 4 cm long electric conductor.

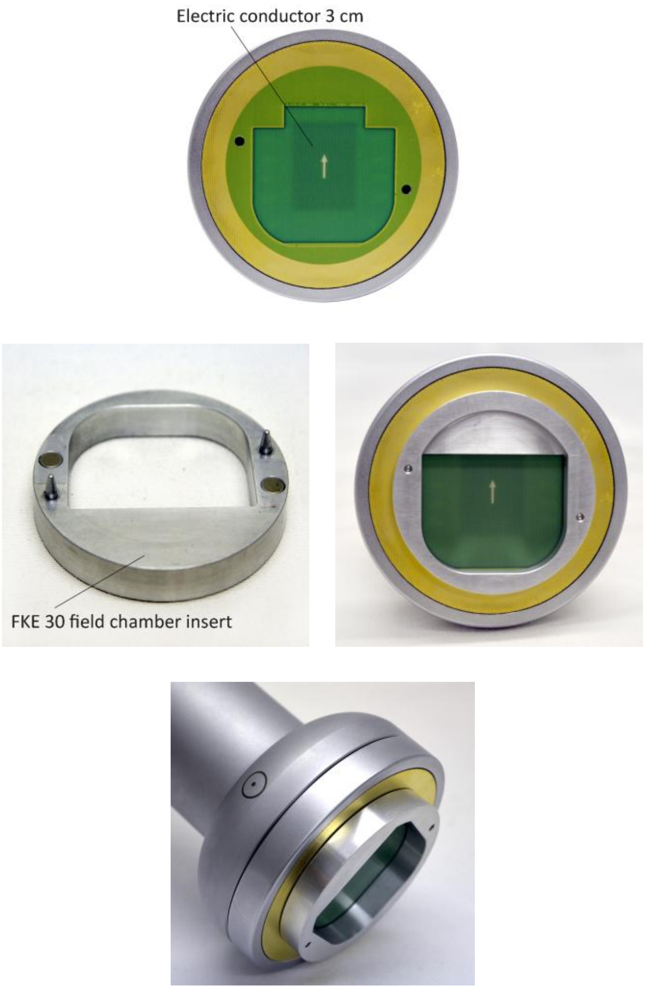

Figure 11 Design of ***P1602*** with a 3 cm long electric conductor and the ***FKE 30*** field chamber insert attached.

The field probe has a measurement output (N-connector) at its top. The measurement output is connected to the electric conductor inside the field probe (**Figure 10**). The electric conductor is at the bottom of the field probe. The end of the electric conductor is connected to GND of the field probe and thus causes a short circuit in the RF current path. The magnetic field of the IC enters the field probe at its bottom and whirls around the electric conductor.
The magnetic field (**Figure 12)** which is generated by the IC is enclosed by the field chamber which comprises the bottom of the field probe, the spacer ring and the ground plane. The test IC is located inside the field chamber. It is mounted on the test board (**Figure 9**). The test board is inserted into the corresponding ground adapter such as ***GNDA 02***. The ground adapter fits into the respective recess of the ***GND 25***[3] ground plane. A (100 x 100) mm TEM-cell print can be inserted instead of the ground adapter.
The ***P1601*** field probe (**Figure 10**) has a 4 cm long electric conductor and is provided for measurements up to 1 GHz.

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[3] ***GNDA 02*** ground adapter and ***GND 25*** ground plane are included in the ***ICE1*** IC test environment set www.langer-emv.com. The test board is described in the "IC test instructions manual".

The ***P1602*** field probe (**Figure 11**) has a 3 cm long electric conductor and the ***FKE 30*** field chamber insert. The ***FKE 30*** is used to prevent cavity oscillation above 1 GHz. Thus its recommended to use the field chamber insert for measurements above 1 GHz to 3 GHz. The field chamber insert is connected to the field probe through guide pins and magnets.

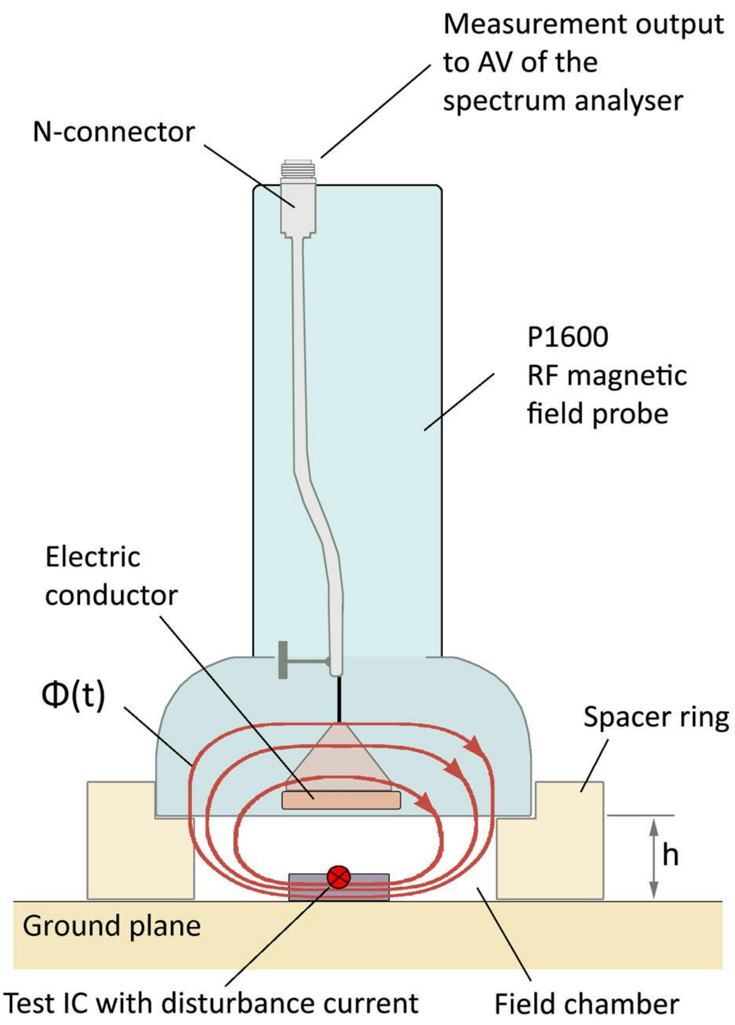


Figure 12 Design and function of the magnetic field probes in the P1600 series.

3.2 Function of the P1601, P1602 magnetic field probes

High-frequency operating currents flow in the test IC (interference current **Figure 12**). These currents may flow in the Vdd / Vss supply loop, for example. The current ($I_{ic}(\omega)$) which flows in the IC generates the magnetic field H2 (**Figure 3**). Field H2 spreads in the space above the IC. It can induce the interference voltage $U_{ind}(\omega)$ in a neighbouring metal part (**Figure 4**). The electric conductor of the field probe (**Figure 12**) simulates the neighbouring metal part. The distance to the electric conductor (metal part) is defined by the spacer ring and may be 10 mm or 3 mm. Field H2 drives the magnetic flux. The flux portion $\Phi(\omega)$ which flows above the electric conductor induces a voltage $U_{ind}(\omega)$ in the electric conductor (**Figure 5**). The IC would induce a voltage of the same amount in a metal part which is arranged identically. The induced voltage is led to the AV input of a spectrum analyser via the measurement output, an N-SMA adapter and the SMA-SMA 1 m cable (**Figure 9**). The spectrum analyser measures the induced voltage $U_{ind}(\omega)$ as a function of frequency.

3.2.1 Equivalent circuit diagram and interactions of the magnetic field coupled out

The flux portion Φ(ω) **Figure 5** and **Figure 12** encircles the electric conductor of the ***P1601*** or ***P1602*** field probe and induces the voltage $U_{ind}(\omega)$. The voltage $U_{ind}(\omega)$ is provided as $U_{AV}(\omega)$ on the 50 Ohm internal resistor of the spectrum analyser and is measured there.
The IC's most effective current loops usually include the IC pins (**Figure 13**). Particularly high currents flow in the Vdd/Vss supply systems. The interference current loop is closed outside the IC via the Vss pin and the Vdd pin of the test board, for example. The interference current flows in a closed loop.

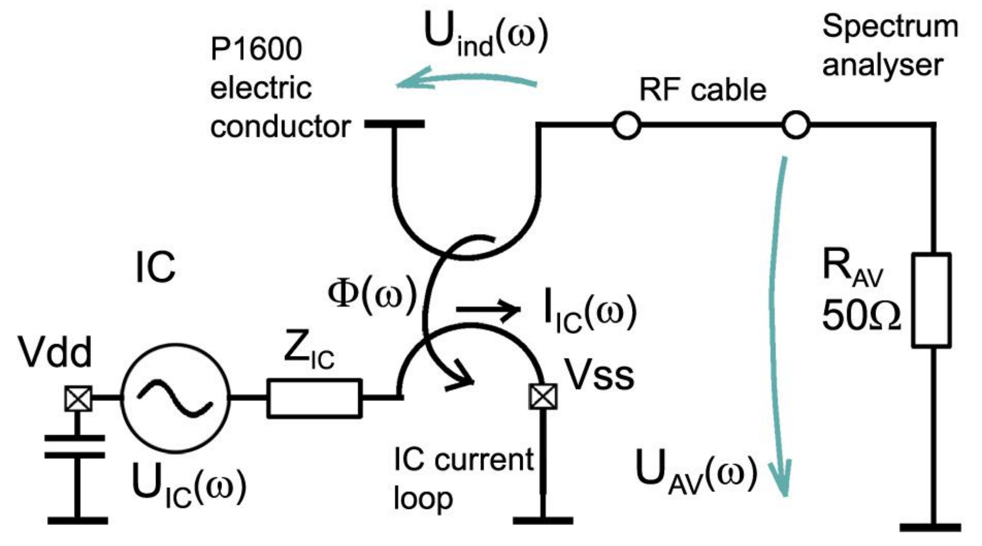


Figure 13 Equivalent circuit diagram with the P1600 field probe in conjunction with a Vdd/Vss current loop of a test-IC and spectrum analyser.

The IC current loop generates the magnetic flux Φ(ω) in connection with the current $I_{IC}(\omega)$.
Only the flux portion Φ(ω) which encircles the electric conductor of the ***P1601*** or ***P1602*** field probe is considered.

$$\Phi(\omega) = L_h * I_{IC}(\omega) \qquad \text{Eqn 1}$$

In a logarithmic form:

$$20 \text{ Log } \Phi(\omega) = 20 \text{ Log } L_h + 20 \text{ Log } I_{IC}(\omega) \qquad \text{Eqn 2}$$

In a reduced logarithmic form where 20 log is omitted in front of electric quantities:

$$\Phi(\omega) = 20 \text{ Log } L_h + I_{IC}(\omega) \qquad \text{Eqn 3}$$

L_h is the coupling inductance between the IC current loop and the electric conductor of the ***P1601*** or ***P1602*** field probe. The coupling inductance L_h can be calculated from:

$$L_h = L_h' * A_{IC} \qquad \text{Eqn 4}$$

Where L_h' is the coupling inductance per unit length between the IC current loop and the electric conductor of the field probe. The IC current loop is vertical to GND of the test board (**Figure 5**). A_{IC} is the cross-section of the IC current loop. **Table 2** shows the inductance per unit length L_h' for h 10 mm and 3 mm.

Example: A (1.5 x 7.8) mm IC current loop has a cross-section A_{IC} of 1.5 mm x 7.8 mm = 11.7 mm². L_h' from **Table 2** is 12.4 pH / mm² for a spacer ring height of 10 mm. It follows from **Eqn 4** that:

$L_h = L_h' * A_{IC} =$ 12.4 nH / mm² * 11.7 mm² = 0.145 nH * Eqn 5

The way in which L_h is determined here assumes ideal conditions and does not take side-effects into account. The actual value may deviate, see **Eqn 24** L_h = 0.108 nH. L_h = 0.108 nH is used in the following considerations.
A magnetic flux coupling of $\Phi(\omega)$ = 81 fVs (-141.8 dB µVs) to the electric conductor of the ***P1601*** or ***P1602*** the field probe follows according to **Eqn 1** with the inductance L_h = 0.108 nH if the current $I_{IC}(\omega)$ is constant over frequency and is 0.75 mA (57.5 dBµA). The flux $\Phi(\omega)$ is then, like the current, constant.

The interaction chain can be pursued in the equivalent circuit diagram **Figure 13**. The induced voltage $U_{ind}(\omega)$ in the electric conductor of the probe follows from the correspondingly linked flux $\Phi(\omega)$ in accordance with the law of induction.

Time domain: $U_{ind}(t) = d\Phi(t) / dt$ Eqn 6

If Φ (t) is divided into harmonics, the following notation results for the frequency domain:

Frequency domain: $U_{ind}(\omega) = \omega * \Phi(\omega)$ Eqn 7

Frequency domain, in a logarithmic form: $20 \text{ Log } U_{ind}(\omega) = 20 \text{ Log } \omega + 20\text{Log } \Phi(\omega)$ Eqn 8

This notation can be reduced by agreement by omitting 20 Log in front of the electric quantities.

$U_{ind}(\omega) = 20 \text{ Log } \omega + \Phi (\omega)$ Eqn 9

The induced voltage increases proportionally to the frequency ω. $\Phi(\omega)$ is the proportionality factor. If $\Phi(\omega)$ is constant over frequency in special cases, $U_{ind}(\omega)$ rises linearly as a function of frequency or logarithmically in the logarithmic form.
The equivalent circuit diagram **Figure 13** reveals that the voltage at the input of the spectrum analyser is equal to the induced voltage $U_{ind}(\omega)$ (**Eqn 10**). The spectrum analyser records the voltage $U_{AV}(\omega)$.

$U_{AV}(\omega) = U_{ind}(\omega)$ Eqn 10

$I_{IC}(\omega)$s, L_h, $\Phi(\omega)$ and $U_{ind}(\omega)$ are EMC parameters of the IC.

3.2.2 Converting the measurement value U_{AV} of the spectrum analyser into EMC parameters

The voltage $U_{AV}(\omega)$ is generated on R_{AV} of the spectrum analyser (**Figure 13**). It is measured and displayed by the spectrum analyser. According to **Eqn 10,** $U_{AV}(\omega)$ is equal to the voltage $U_{ind}(\omega)$ which is induced in the electric conductor of the probe.
The flux portion $\Phi(\omega)$ can be calculated from $U_{AV}(\omega)$ after transposition of Frequency domain: (**Eqn 11**). $\Phi(\omega)$ is the flux portion that is driven by IC field H2 (**Figure 3** and **Figure 4**) and encircles the electric conductor of the ***P1601*** or ***P1602*** field probe.

$\Phi(\omega) = U_{AV}(\omega) / \omega$ Eqn 11

The logarithm can be taken of (**Eqn 11)** to provide a logarithmic form:

$20\ \mathrm{Log}(\Phi(\omega)) = 20\ \mathrm{Log}(\ U_{AV}(\omega)) - 20\ \mathrm{Log}\ \omega$ Eqn 12

This notation can be reduced by agreement by omitting 20 Log in front of the electric quantities.

$\Phi(\omega) = U_{AV}(\omega) - 20\ \mathrm{Log}\ \omega$ Eqn 13

Figure 14 shows the voltage U_{AV} that was measured with the spectrum analyser U_{AV} and the flux $\Phi(\omega) = U_{AV}(\omega) - 20\ \mathrm{Log}\ \omega$ that was calculated from **Eqn 13.**

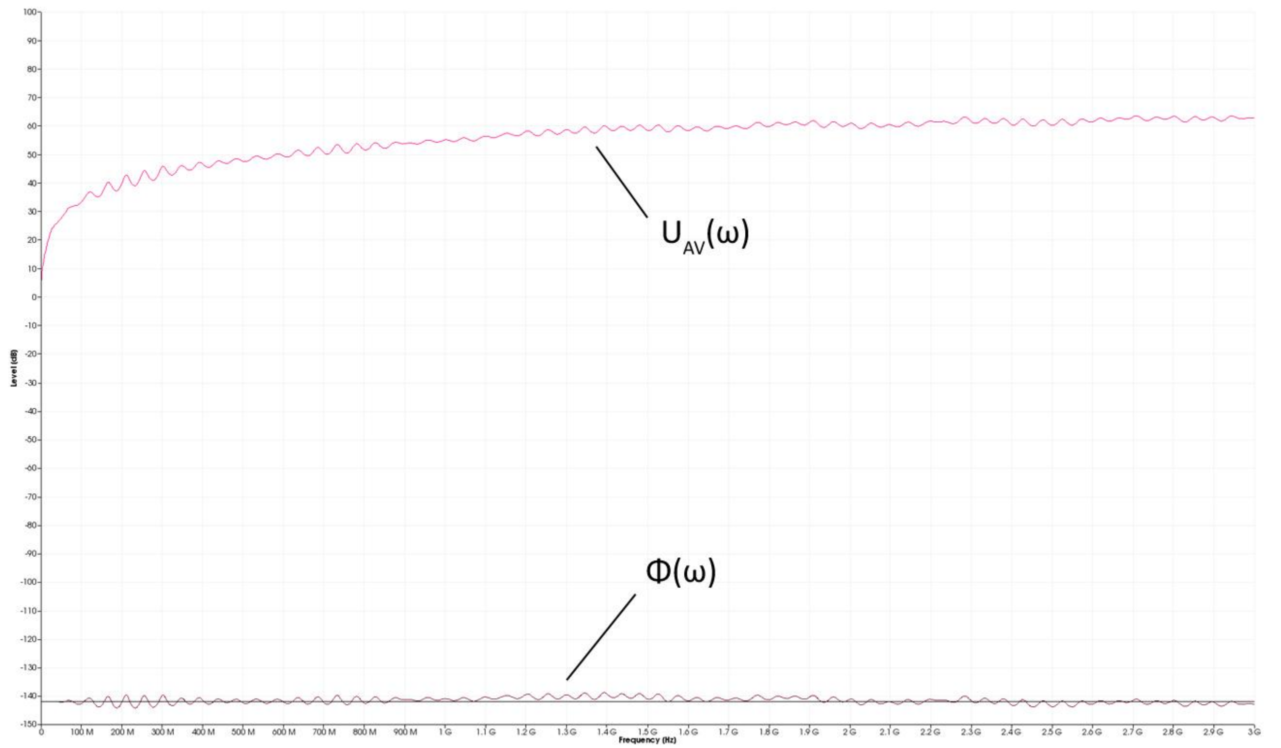


Figure 14 $U_{AV}(\omega)$ measured with the spectrum analyser (at $I_{IC}(\omega)$ = 57 dBµA (0.75 mA) constant, L_h = 0.108 nH), calculation of the flux $\Phi(\omega)$ with Eqn 13 resulting in -141.8 dB µVs.

The measurement is performed on the model of an IC current loop with the ***P1602*** field probe. The current $I_{IC}(\omega)$ = 57 dBµA is constant over frequency. The coupling inductance between the IC current loop and the electric conductor of the ***P1602*** field probe is approx. L_h = 0.108 nH.

The flux portion $\Phi(\omega)$ is produced by the current $I_{IC}(\omega)$ in conjunction with the coupling inductance L_h (**Eqn** 1) in the equivalent circuit **Figure 13.** This assumes that $R_{AV} >> \omega\ L_h$.
The flux $\Phi(\omega)$ is constant since a constant current $I_{IC}(\omega)$ is fed into the IC current loop. The voltage $U_{AV}(\omega) = U_{ind}(\omega)$ is induced in the probe's electric conductor.
$U_{AV}(\omega)$ rises linearly as a function of the frequency ω **Frequency domain**: or logarithmically in the logarithmic form (**Eqn 8, Figure 14**).
Figure 14 shows that the flux portion $\Phi(\omega)$ deviates slightly from the linear constant curve (-141.8 dBµVs). The voltage $U_{AV}(\omega)$ also has ripples. The ideal values of $U_{AV}(\omega)$ (**Figure 15)** can be calculated from **Eqn 1** and **Eqn 7** and the values $I_{IC}(\omega)$ = 57 dBµA constant and L_h = 0.108 nH.

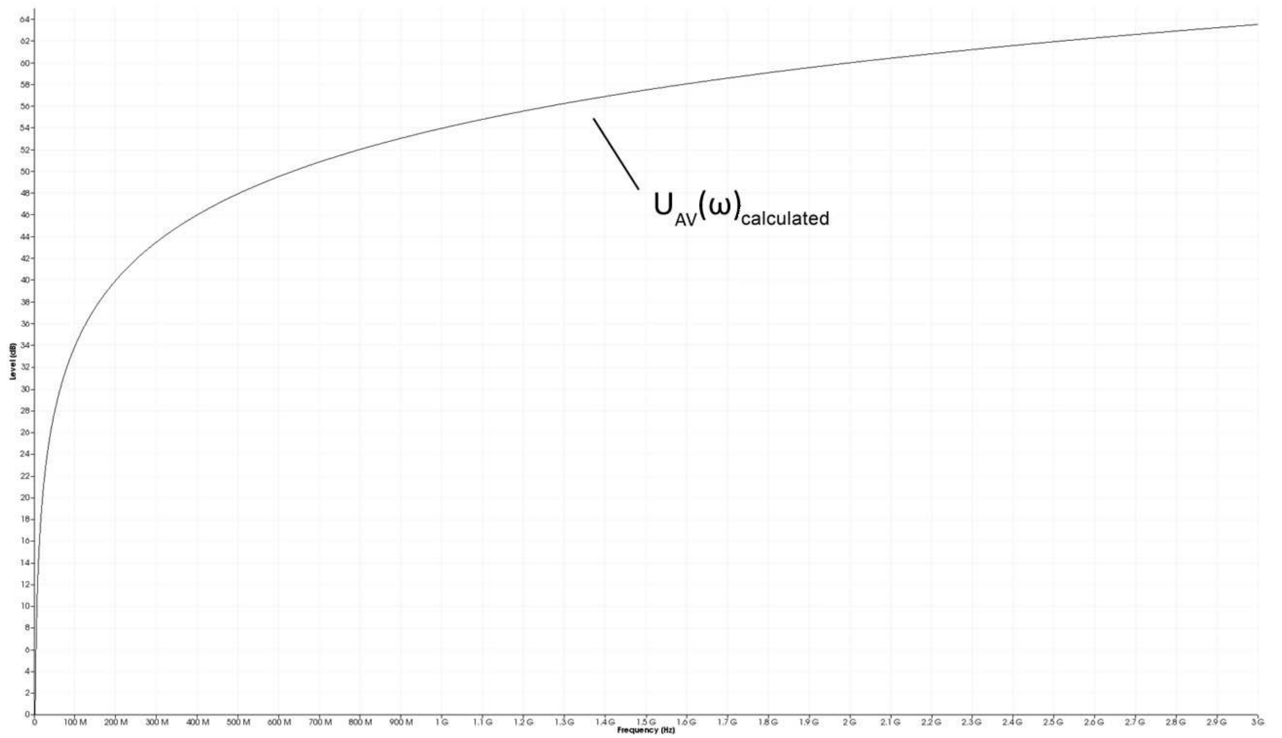


Figure 15 $U_{AV}(\omega) = U_{ind}(\omega)$ calculated from Eqn 1 and Eqn 9 and the values $I_{IC}(\omega)$ = 57 dBµA constant and L_h = 0.108 nH.

3.2.3 Correction curves and matching the P1601 and P1602 field probes

Figure 16 shows both the measured flux and voltage curve from **Figure 14** and the calculated flux and voltage curve from **Figure 15.** Unlike the calculated curve, the measured curve shows standing waves. The standing waves (2 dB) depend on the length of the measuring cable (SMA-SMA 1 m) and on whether the ***P1602*** field probe and the spectrum analyser are matched or not.

The ***P1602*** field probe has no 50 Ohm terminating resistor in the measuring branch. The 50 Ohm line coming from the spectrum analyser is terminated with a short circuit to GND in the ***P1602*** field probe. Standing waves are also produced in the branch in which the flux portion Φ (ω) is generated due to mismatching. This mismatch is caused by the connection of the tracking generator to the respective excitation field source (***BPM 02***). The field generation and measurement shares overlap and cannot be separated in the measurement result without additional measurements.

Smoothing the curve (mathematical operation "Smooth…" in ***ChipScan-ESA***, BW 100 MHz) eliminates the standing waves from the measurement result. The remaining deviations are due to parasitic effects in the ***P1602*** field probe. The deviations can be eliminated with a correction curve.

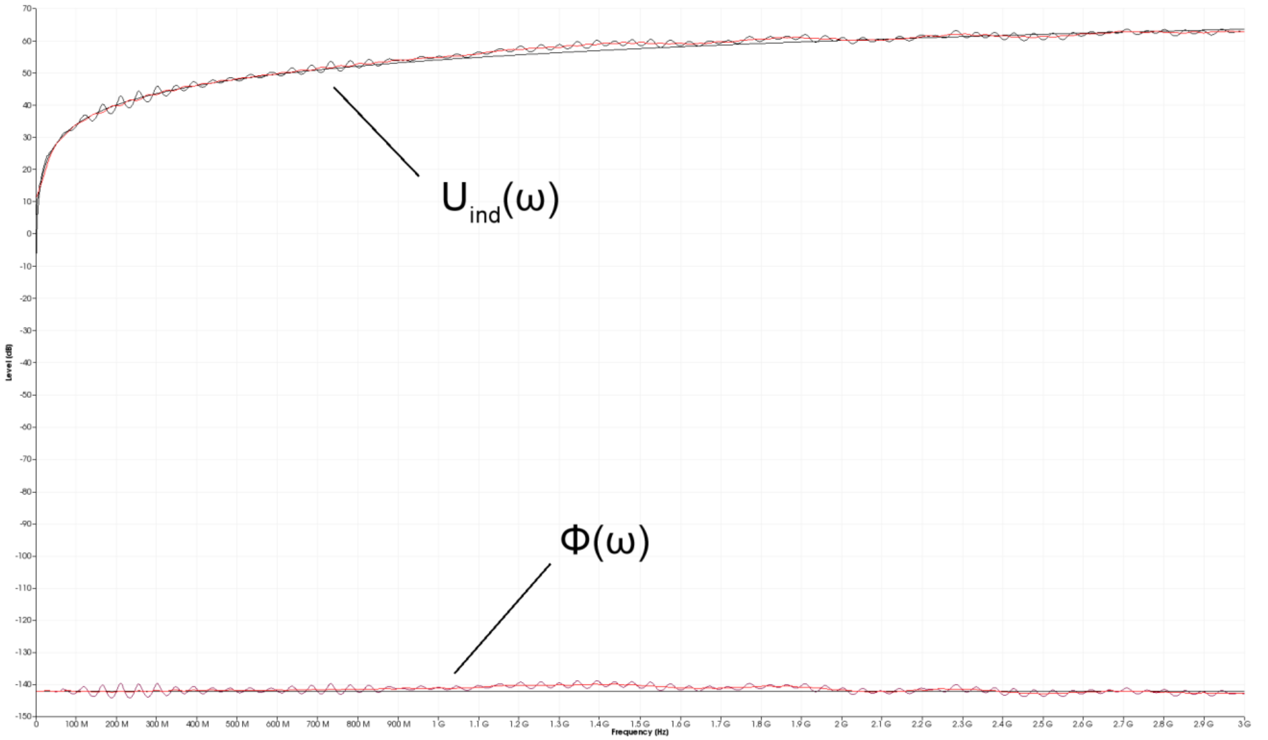


Figure 16 ***P1602***, comparison of the measured and calculated $U_{ind}(\omega)$ and $\Phi(\omega)$ values. The second variant shows the smoothed curves (performed in ***ChipScan-ESA***, BW 100 MHz).

The correction curve K1602 **Figure 17** of the ***P1602*** probe is created on the basis of these deviations. The deviations are corrected by adding the correction curve to the measurement result (performed in the ***ChipScan-ESA*** Software) **Eqn 14**. The correction curve can be created on the basis of the measured and the smoothed curve. The correction curve K1602W includes the standing waves. The correction curve K1602 is created from the smoothed measurement curve and does not include the standing waves. The correction curve is loaded to the ***ChipScan-ESA*** software to perform the correction and applied automatically to the measurement result (example **Figure 25**).

$$\Phi_{Korr}(\omega) = \Phi(\omega) + K1602 \qquad \text{Eqn 14}$$

The correction curve K1602W (with standing waves) is tailored to the measurement set-up **Figure 35** and also takes the dependency on the tracking generator and excitation field source (***BPM 02***) into account. It should only be used for this measurement set-up. The correction curve K1602 has to be used for general purposes.

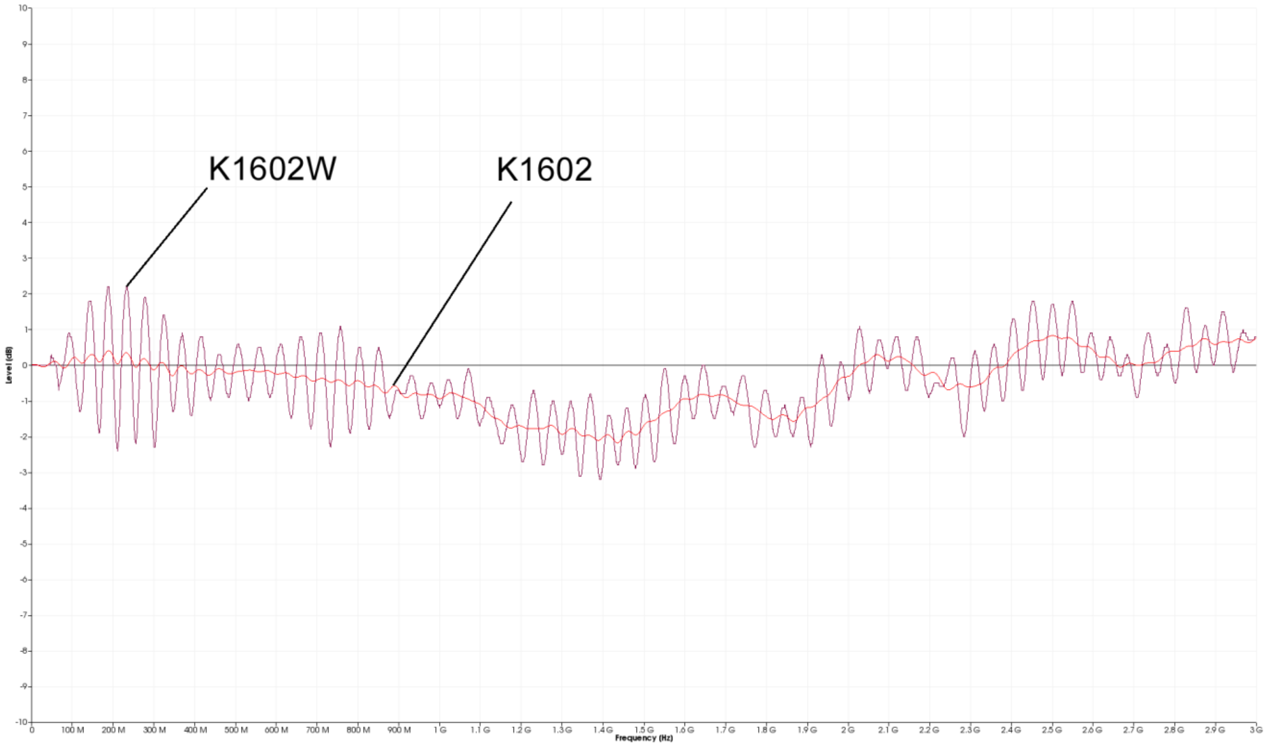


Figure 17 Correction curve K1602 of the ***P1602*** probe for general use. K1602W for special use with the measurement set-up **Figure 34.**

The curve K1602 was measured and smoothed with the ***ChipScan-ESA*** software (BW 100 MHz).

Figure 18 shows the measured and calculated $U_{ind}(\omega)$ and Φ (ω) curves for the ***P1601*** probe. **Figure 19** shows the correction curves. The correction has to be performed according to **Eqn 15**.

Φ_{Korr} (ω) = $\Phi(\omega)$ + K1601 Eqn 15

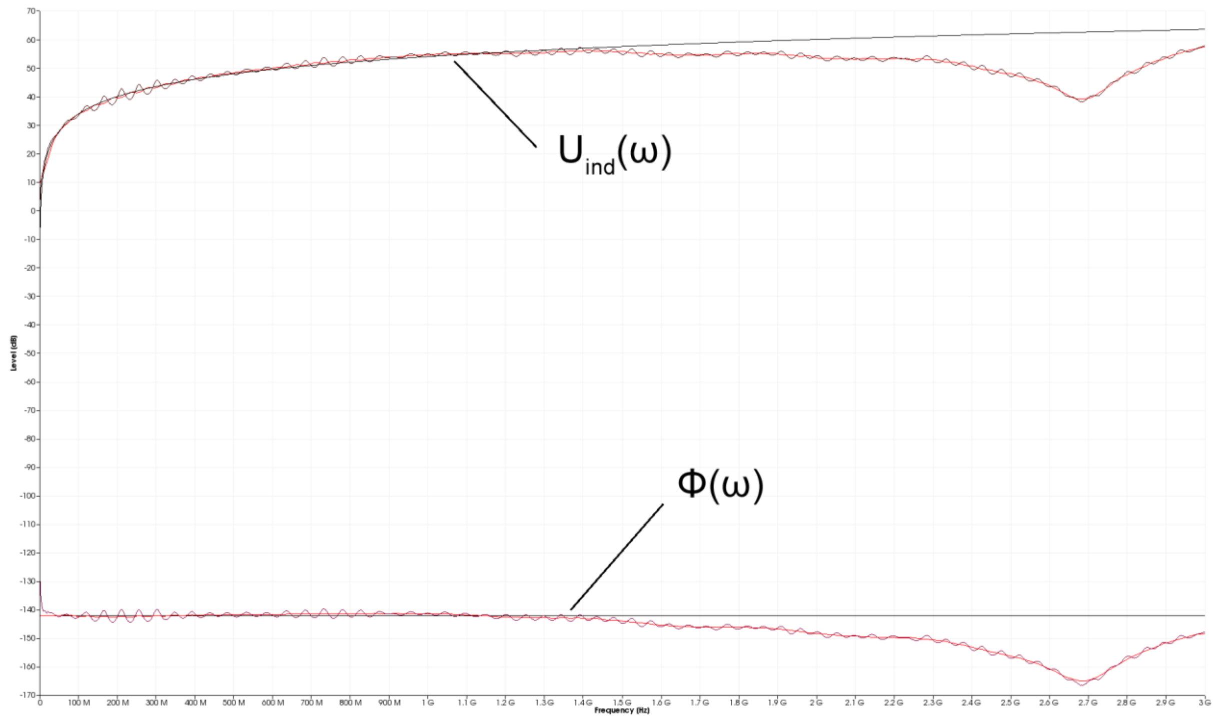


Figure 18 ***P1601***, comparison of the measured and calculated $U_{ind}(\omega)$ and Φ (ω) values. The curves are also shown in a smoothed form (BW 100 MHz). The ***P1601*** field probe is used in the frequency range 0… 1 GHz. The frequency range from 1… to 3 GHz is shown for a better orientation.

The ***P1601*** probe is provided for measurements up to 1 GHz but it can also be used up to 1.5 GHz with the correction curves.

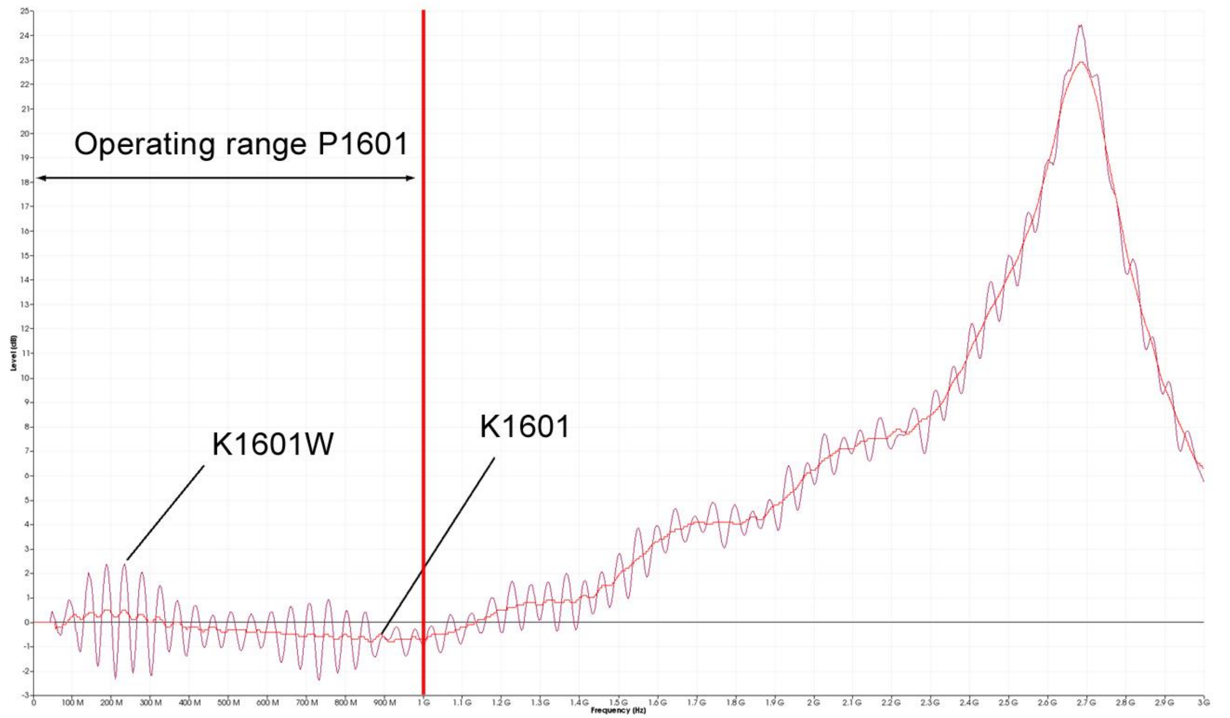


Figure 19 Correction curve K1601 of the ***P1601*** probe for general use. K1601W for special use with the measurement set-up **Figure 34.** The ***P1601*** field probe is used in the frequency range 0… 1 GHz. The frequency range from 1 to 3 GHz is shown for a better orientation.

3.2.4 Parameters to describe the magnetic field excitation by ICs

3.2.4.1 Φ(ω) flux linked between the IC and a defined neighbouring metal part

The flux portion Φ(ω) is the physical quantity which describes the excitation of emissions proportional to the current $I_{IC}(\omega)$. There is no additional dependency on ω as is the case with the induced voltage $U_{ind}(\omega)$. According to the equivalent circuit diagram **Figure 13,** the IC generates the flux portion Φ(ω) from the current $I_{IC}(\omega)$ and the coupling inductance L_h between the IC current loop and the electric conductor of the ***P1601*** or ***P1602*** field probe, **Eqn 1**: $\Phi(\omega) = L_h * I_{IC}(\omega)$. $I_{IC}(\omega)$ hereby describes the source inside the IC, L_h the coupling to the environment and Φ(ω) the excitation of the emission.
The flux Φ(ω) is practically calculated from the measured, induced voltage $U_{AV}(\omega) = U_{ind}(\omega)$ according to **Eqn** 13. The calculation can be performed with the "Correction" function of the ***ChipScan-ESA*** software during the measurement or separately thereafter. **Figure 20** shows the measured flux curve $\Phi(\omega)_{measured}$. The correction factor K1601 was added to $\Phi(\omega)_{measured}$ in the ***ChipScan-ESA*** software. This provides the actual flux curve $\Phi(\omega)_{corrected}$.

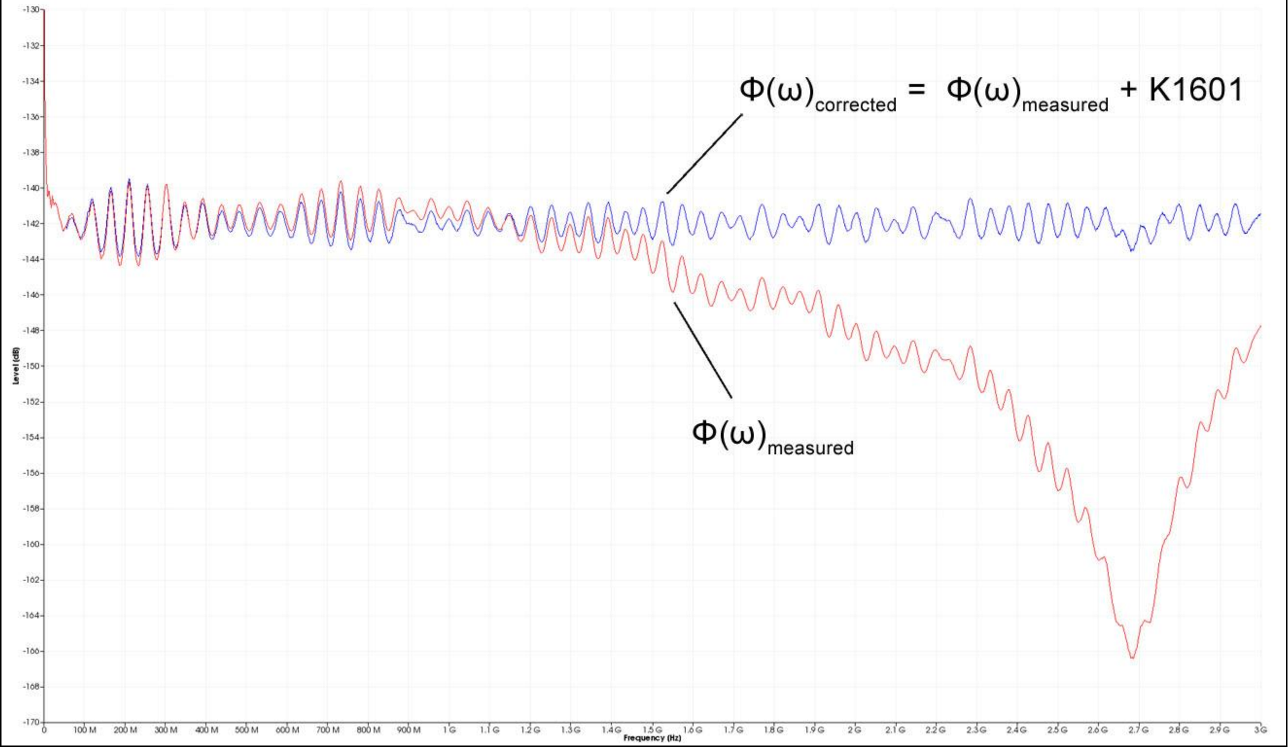


Figure 20 ***P1601***, measured $\Phi(\omega)_{measured}$ and actual flux variation. Φ(ω) was corrected with K1601 ($\Phi(\omega)_{corrected} = \Phi(\omega)_{measured}$ + K1601.

3.2.4.2 $U_{ind}(\omega)$ voltage coupled inductively to a defined neighbouring metal part

According to the equivalent circuit diagram **Figure 13,** the IC generates the flux portion from the current $I_{IC}(\omega)$ and the coupling inductance L_h between the IC current loop and the electric conductor of the ***P1600*** field probes, **Eqn 1**: $\Phi(\omega) = L_h * I_{IC}(\omega)$. The flux portion Φ(ω) encircles the electric conductor of the ***P1600*** field probe and induces the voltage $U_{ind}(\omega)$ in this electric conductor (equivalent circuit diagram **Figure 13** and **Eqn 1** to **Eqn 9**). The voltage which is induced in the electric conductor is a measure of the potential excitation of emissions by the IC.
In practice, the voltage $U_{ind}(\omega)$ which is induced in P1600 is measured with a spectrum analyser.
$U_{ind}(\omega)$ depends on ω. $U_{ind}(\omega)$ rises linearly with ω. The higher the frequency ω, the more emissions are excited and coupled out.

The measured curve is corrected with the correction curve K1600 **Figure 21**.

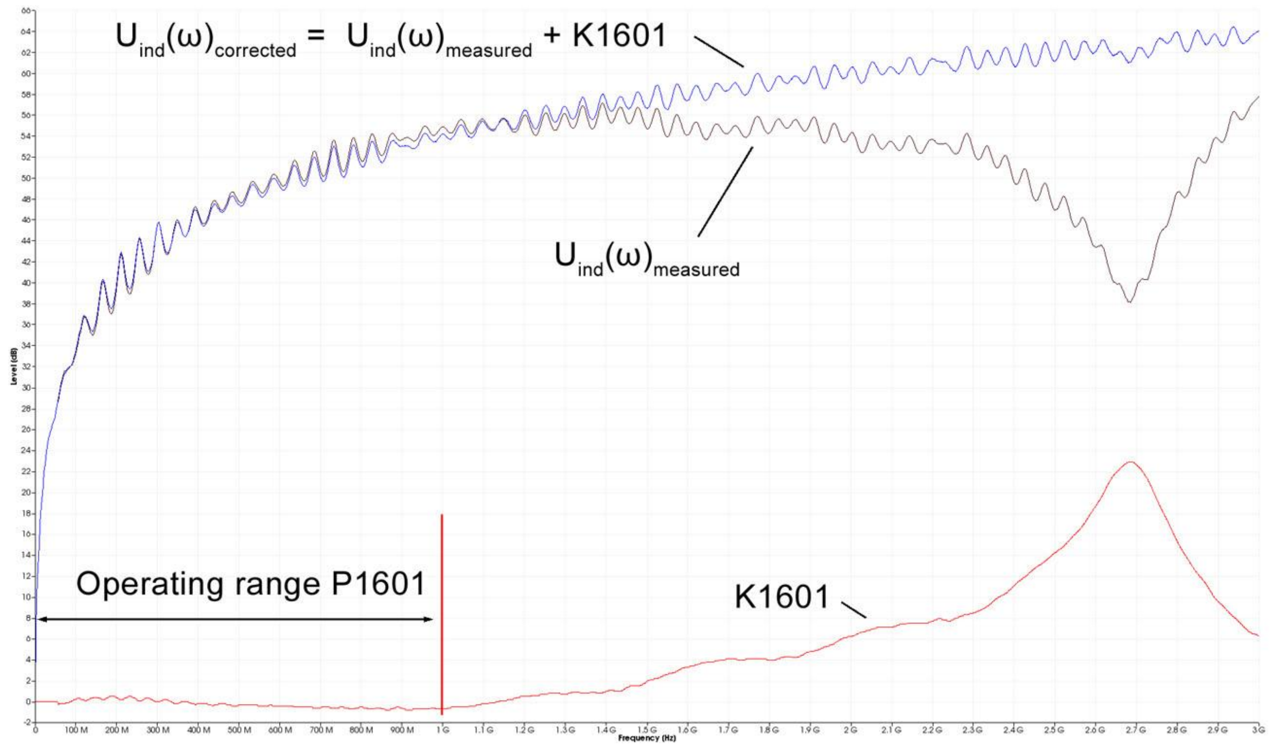


Figure 21 ***P1601***, measured $U_{ind}(\omega)$ (with $I_{IC}(\omega)$ = 57 dBµA constant) and the voltage that is actually induced. $U_{ind}(\omega)_{measured}$ was corrected with K1601 ($U_{ind}(\omega)_{corrected} = U_{ind}(\omega) + K1601$).

3.3 Measurement with a spectrum analyser

3.3.1 Measurement set-up and measurement with the ChipScan-ESA software

Figure 22 shows the measurement set-up to measure magnetic field coupling from the test IC. The test IC is mounted on the test board. The test board is inserted into the corresponding ground adapter such as ***GNDA 02***. The signal and supply connections to the test IC are established through a plug connector on the test board.
The field probe from the P1600 series has to be arranged above the centre of the test IC with a spacer ring. The orientation of the field probe relative to the test IC has to be defined for the measurement. The point current mark (**Figure 10**) can be turned towards the pin 1 side of the test IC until it coincides with the 0° mark of the spacer ring (reference angle 0°), for example. The measurement can be performed at different orientation angles. The automated ***ICT1*** IC tester can be used to move the probe through a sequence of orientation angles.
The AV input of the spectrum analyser is connected to the N-connector output of the probes from the P1600 series via the **N-SMA** adapter and the SMA-SMA 1m RF cable.

The ***ChipScan-ESA*** software allows an easy performance and documentation of the measurements (see also: ***ChipScan-ESA*** operating instructions).

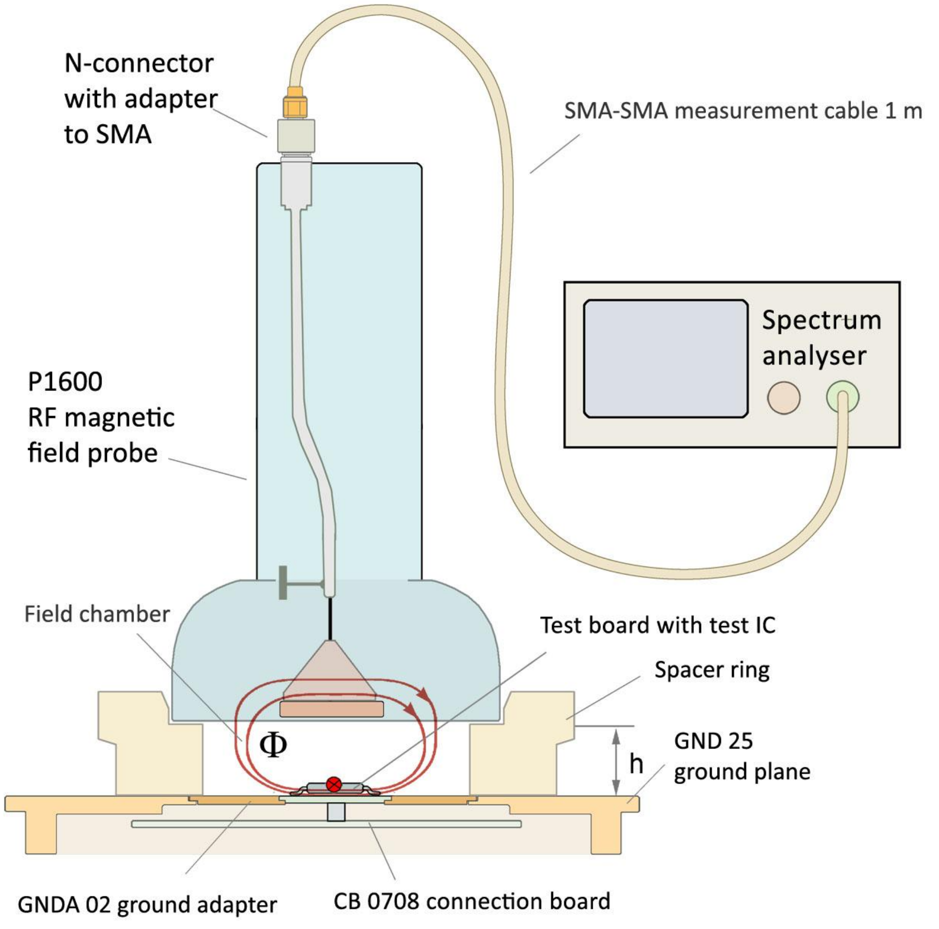
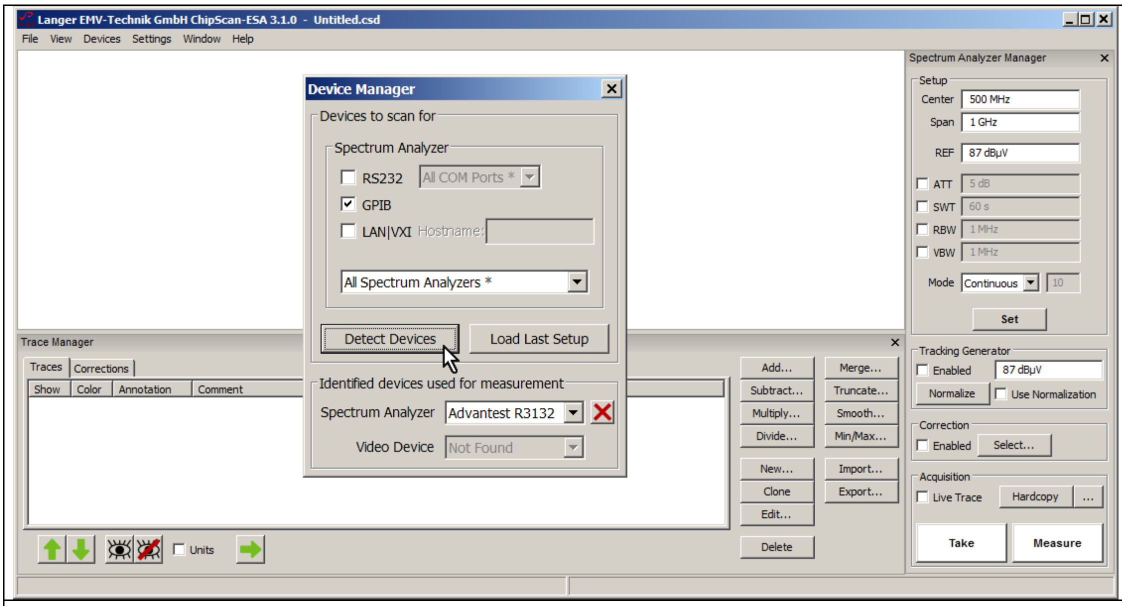


Figure 22 Measuring the induced voltage of the IC's magnetic flux with a field probe from the P1600 series and a spectrum analyser.

The spectrum analyser is sought automatically with "Devices/ Devices Manager/ Detected Devices" via the respective interface and connected to the PC (**Figure 23**).



Device Manager

Devices to scan for

Spectrum Analyzer

☐ RS232 All COM Ports *

☑ GPIB

☐ LAN|VXI Hostname:

All Spectrum Analyzers *

Identified devices used for measurement

Spectrum Analyzer Advantest R3132

Video Device Not Found

Spectrum Analyzer Manager

Setup

Center 500 MHz

Span 1 GHz

REF 87 dBµV

☐ ATT 5 dB

☐ SWT 60 s

☐ RBW 1 MHz

☐ VBW 1 MHz

Mode Continuous 10

Tracking Generator

☐ Enabled 87 dBµV

☐ Use Normalization

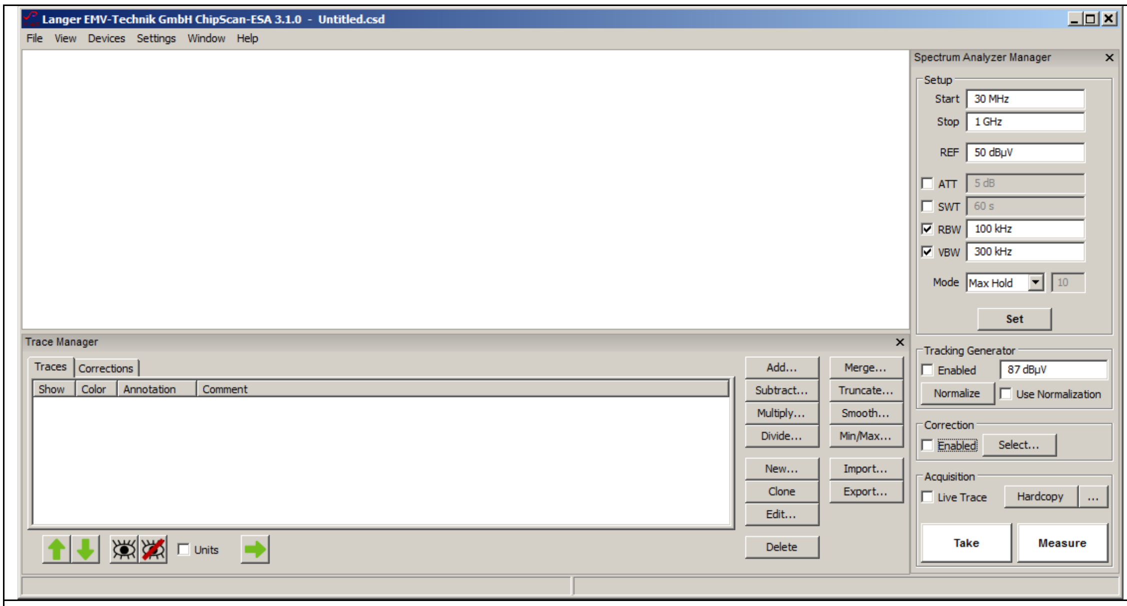
Correction

☐ Enabled

Acquisition

☐ Live Trace

Figure 23 Connecting the spectrum analyser to the PC.



Spectrum Analyzer Manager

Setup

Start 30 MHz

Stop 1 GHz

REF 50 dBµV

☐ ATT 5 dB

☐ SWT 60 s

☑ RBW 100 kHz

☑ VBW 300 kHz

Mode Max Hold 10

Tracking Generator

☐ Enabled 87 dBµV

☐ Use Normalization

Correction

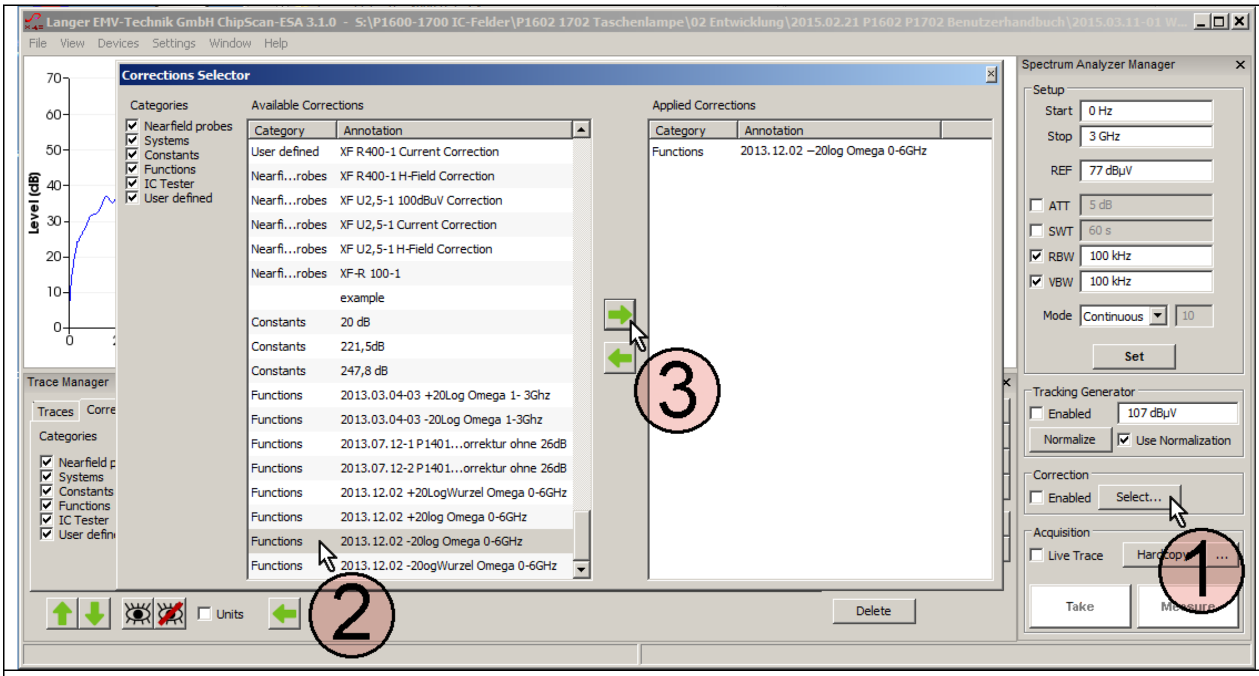
☐ Enabled

Acquisition

☐ Live Trace

Figure 24 Main settings of the spectrum analyser in the "Spectrum Analyser Manager".

The main settings of the spectrum analyser have to be defined in the "Spectrum Analyser Manager" (**Figure 24**). The correction curve K1601 or K1602 is used to correct the frequency response of the measurement result $U_{AV}(\omega)$ of the ***P1601*** or ***P1602*** field probe. $U_{AV}(\omega)$ can be converted to $\Phi(\omega)$ (**Eqn 11** to **Eqn 13**) automatically under "Correction" in the "Spectrum Analyser Manager". The correction curve (- 20 Log ω) is used for this purpose.
You can find the correction curve (- 20 Log ω) in the "Corrections" list of the "Trace Manager".
Click the "Select" button (mouse cursor ① **Figure 25**) under "Correction" in the "Spectrum Analyser Manager" to select the respective correction curve.



Categories:
- ☑ Nearfield probes
- ☑ Systems
- ☑ Constants
- ☑ Functions
- ☑ IC Tester
- ☑ User defined

Available Corrections:

Category	Annotation
User defined	XF R400-1 Current Correction
Nearfi...robes	XF R400-1 H-Field Correction
Nearfi...robes	XF U2,5-1 100dBuV Correction
Nearfi...robes	XF U2,5-1 Current Correction
Nearfi...robes	XF U2,5-1 H-Field Correction
Nearfi...robes	XF-R 100-1
	example
Constants	20 dB
Constants	221,5dB
Constants	247,8 dB
Functions	2013.03.04-03 +20Log Omega 1- 3Ghz
Functions	2013.03.04-03 -20Log Omega 1-3Ghz
Functions	2013.07.12-1 P1401...orrektur ohne 26dB
Functions	2013.07.12-2 P1401...orrektur ohne 26dB
Functions	2013.12.02 +20LogWurzel Omega 0-6GHz
Functions	2013.12.02 +20log Omega 0-6GHz
Functions	2013.12.02 -20log Omega 0-6GHz
Functions	2013.12.02 -20ogWurzel Omega 0-6GHz

Applied Corrections:

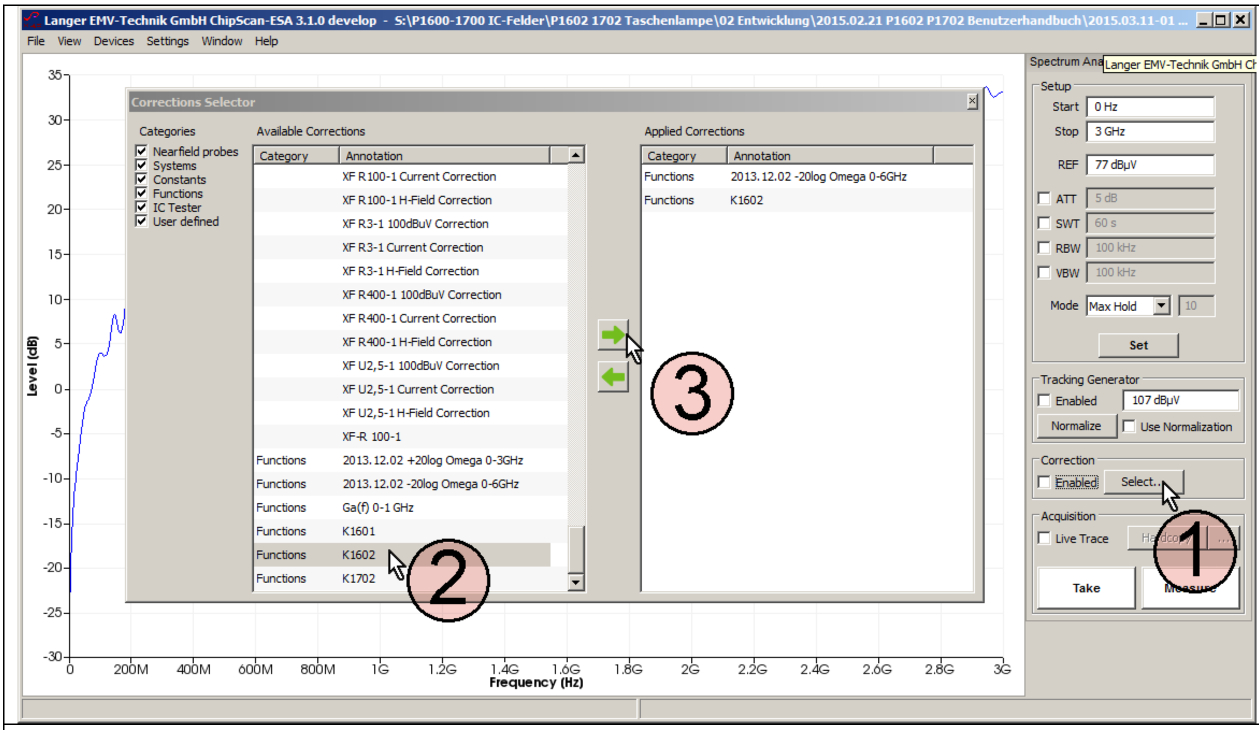
Category	Annotation
Functions	2013.12.02 –20log Omega 0-6GHz

Trace Manager categories: ☑ Nearfield p, ☑ Systems, ☑ Constants, ☑ Functions, ☑ IC Tester, ☑ User defin

Spectrum Analyzer Manager – Setup:
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10
Tracking Generator: ☐ Enabled 107 dBµV; ☑ Use Normalization
Correction: ☐ Enabled
Acquisition: ☐ Live Trace

Figure 25 Activating correction curves with the "Corrections Selector".

The "Corrections Selector" window opens **Figure 25**. Click and activate the correction curve -20 Log ω with the mouse cursor ②. Click the "Arrow right" ③ button to move the correction curve to the "Applied Corrections" list. You can load further correction factors and correction curves (**Figure 26**) such as K1601 or K1602 by repeating this procedure.



Categories:
- ☑ Nearfield probes
- ☑ Systems
- ☑ Constants
- ☑ Functions
- ☑ IC Tester
- ☑ User defined

Available Corrections:

Category	Annotation
	XF R100-1 Current Correction
	XF R100-1 H-Field Correction
	XF R3-1 100dBuV Correction
	XF R3-1 Current Correction
	XF R3-1 H-Field Correction
	XF R400-1 100dBuV Correction
	XF R400-1 Current Correction
	XF R400-1 H-Field Correction
	XF U2,5-1 100dBuV Correction
	XF U2,5-1 Current Correction
	XF U2,5-1 H-Field Correction
	XF-R 100-1
Functions	2013.12.02 +20log Omega 0-3GHz
Functions	2013.12.02 -20log Omega 0-6GHz
Functions	Ga(f) 0-1 GHz
Functions	K1601
Functions	K1602
Functions	K1702

Applied Corrections:

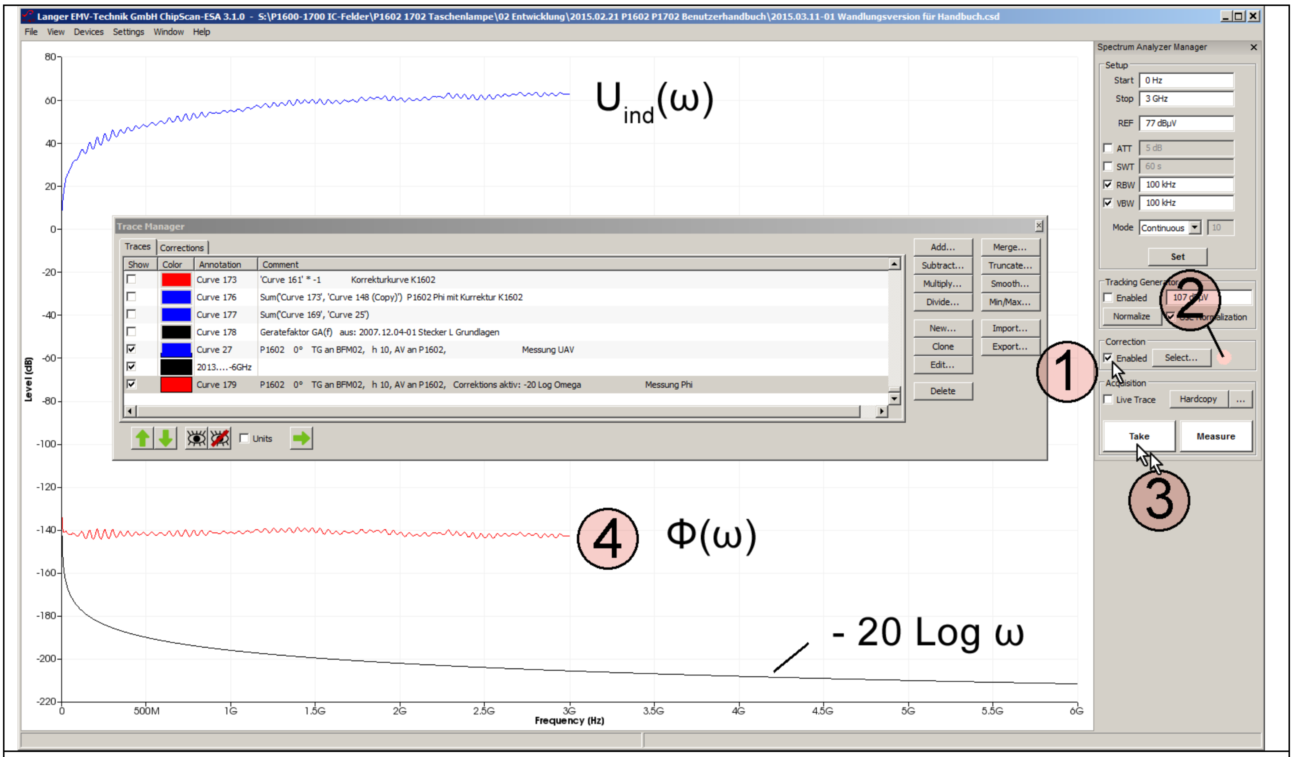
Category	Annotation
Functions	2013.12.02 -20log Omega 0-6GHz
Functions	K1602

Spectrum Analyzer Manager – Setup:
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Max Hold 10
Tracking Generator: ☐ Enabled 107 dBµV; ☐ Use Normalization
Correction: ☐ Enabled
Acquisition: ☐ Live Trace

Figure 26 Loading further correction curves such as K1602 in the "Corrections Selector".

Activate the "Enabled" box in the "Correction" field in the "Spectrum Analyser Manager" with the mouse cursor ① (**Figure 27**). The field ② flashes if the correction is active **Figure 27**. Click "Take" or "Measure" (mouse cursor ③ **Figure 27** to transfer the current measurement curve ④ Φ(ω) from the spectrum analyser to the PC.

The calculation **Eqn 13**: $\Phi(\omega) = U_{AV}(\omega) - 20 \text{ Log } \omega$ is performed automatically at the same time. The curve $\Phi(\omega)$ is added to the bottom of the "Traces" list in the "Trace Manager". A measurement log can be kept in the free text field under "Comment".
Delete the check mark from the "Enabled" box if you only want to measure $U_{AV}(\omega)$; the field ② then stops flashing.



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Trace Manager

Show	Color	Annotation	Comment
☐	🟥	Curve 173	'Curve 161' * -1 Korrekturkurve K1602
☐	🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602
☐	🟦	Curve 177	Sum('Curve 169', 'Curve 25')
☐	⬛	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☑	🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
☑	⬛	2013.....-6GHz	
☑	🟥	Curve 179	P1602 0° TG an BFM02, h 10, AV an P1602, Correktions aktiv: -20 Log Omega Messung Phi

☐ Units

Spectrum Analyzer Manager

Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10

Tracking Generator
☐ Enabled 107 dBµV
☑ Use Normalization

Correction
☑ Enabled

Acquisition
☐ Live Trace

Figure 27 Measuring the magnetic flux $\Phi(\omega)$ by means of the correction curve - 20 Log ω and K1602. Curve 179 $\Phi(\omega)$ is the result of this measurement.

The "Curve" number is counted automatically (Curve 179) under "Annotation". The measurement log can be kept in the respective free text field under "Comment".

Follow the instructions in chapter **3.2.3** if you want to create a new correction curve.

3.3.2 Magnetic field measurement on the IC

Figure 22 shows the measurement set-up. **3.3** describes how to operate the ***ChipScan-ESA*** software (to set the correction curves).
Figure 28 shows the results of the measurement which was performed on a test IC. The voltage $U_{AV}(\omega)$ is measured and converted to the flux $\Phi(\omega)$ during the measurement. The flux is corrected with the correction curve K1600 of the respective probe.

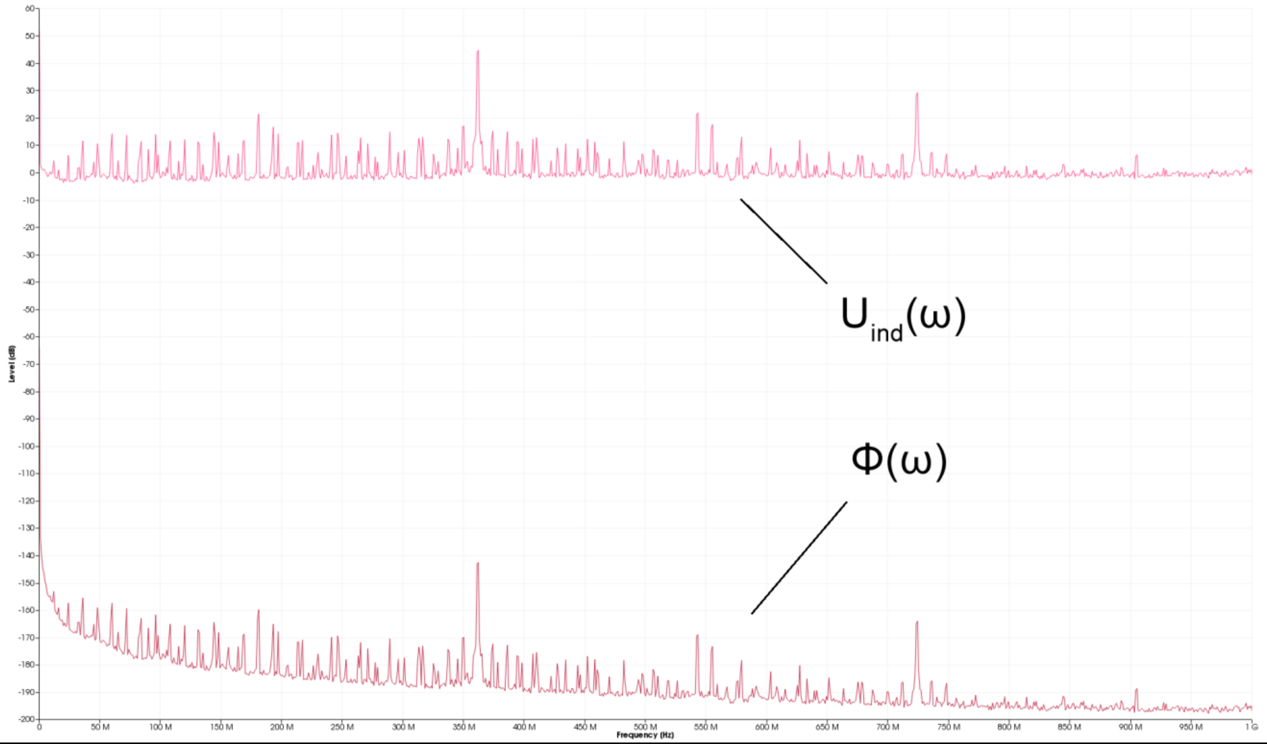


Figure 28 Measuring an IC's radiated emissions which are excited in the form of a magnetic field with the ***P1601*** field probe, orientation angle 0°. Results: induced interference voltage $U_{ind}(\omega)$ and flux $\Phi(\omega)$ (corrected with K1601).

3.3.3 Determining the IC emissions radiated in the worst case

The highest radiated emissions from the IC occur if the IC couples to a neighbouring rod-like metal part **Figure 4**. The metal part can be a cable which runs above the IC.
On account of its flux $\Phi(\omega)$, the IC induces the voltage $U_{ind}(\omega)$ in the metal part. If the metal part is arranged above the IC at the same height h = 10 mm as the ***P1601*** or ***P1602*** field probe, the voltage induced in the metal part corresponds to the voltage measured with the ***P1601*** or ***P1602*** field probe. The induced voltage $U_{ind}(\omega)$ can be roughly converted for other geometric arrangements.
Eqn 16 can be used to calculate the worst case value of the electric field strength E_{Ant} [dBµV/m] of the radiated electromagnetic wave from the induced voltage $U_{ind}(\omega)$ for a distance of 10 meters. GA(f)[4] is hereby the worst case device factor for the excitation of radiated emissions through inductive coupling. The conditions of the metal part are ideal for radiated emissions at all frequencies. Its length always corresponds notionally to a quarter wavelength of the induced voltage's frequency.

$$E_{Ant}(\omega)\,[\mathrm{dB\mu V/m}] = GA(f)[\mathrm{dB/m}] + U_{ind}(\omega)\,[\mathrm{dB\mu V}] \qquad \text{Eqn 16}$$

Figure 29 shows the frequency response which was measured for GA(f).

---

[4] "Connector coupling inductance", Gunter Langer, company publication, Dec. 2007

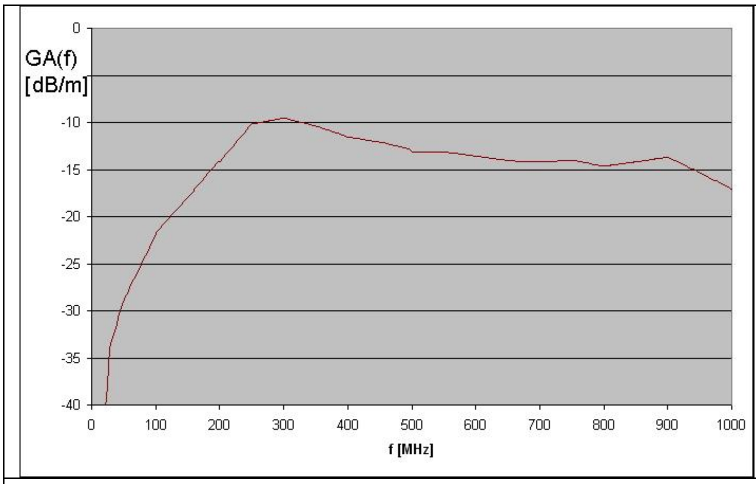
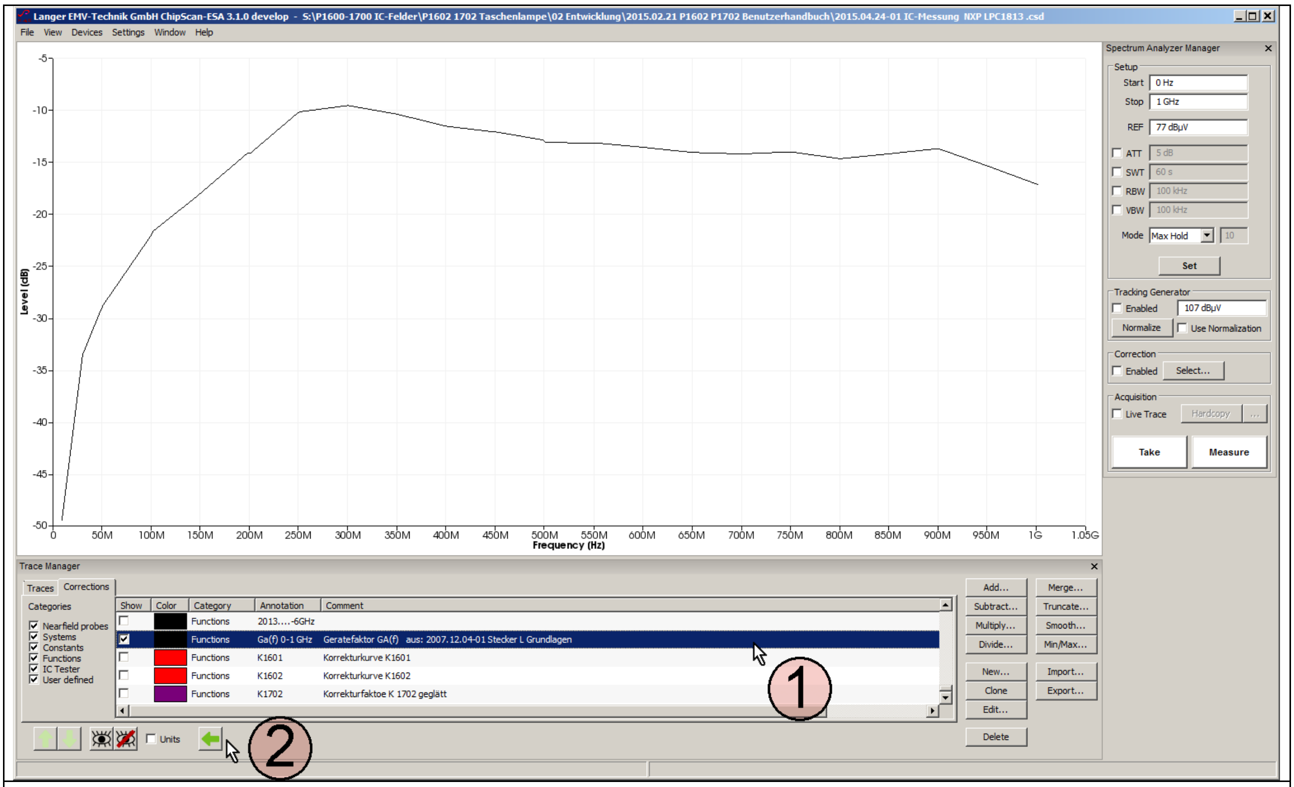


Figure 29 Worst case device factor GA(f)[dB/m] of the radiated emissions at a distance of 10 m.

E_{Ant} (ω) [dBµV/m] can be calculated with the ***ChipScan-ESA*** software. Mark the function GA(f) in the "Corrections" list with the mouse cursor ①. Copy the function GA(f) to the "Traces" list with the "Arrow left" button (**Figure 30**).

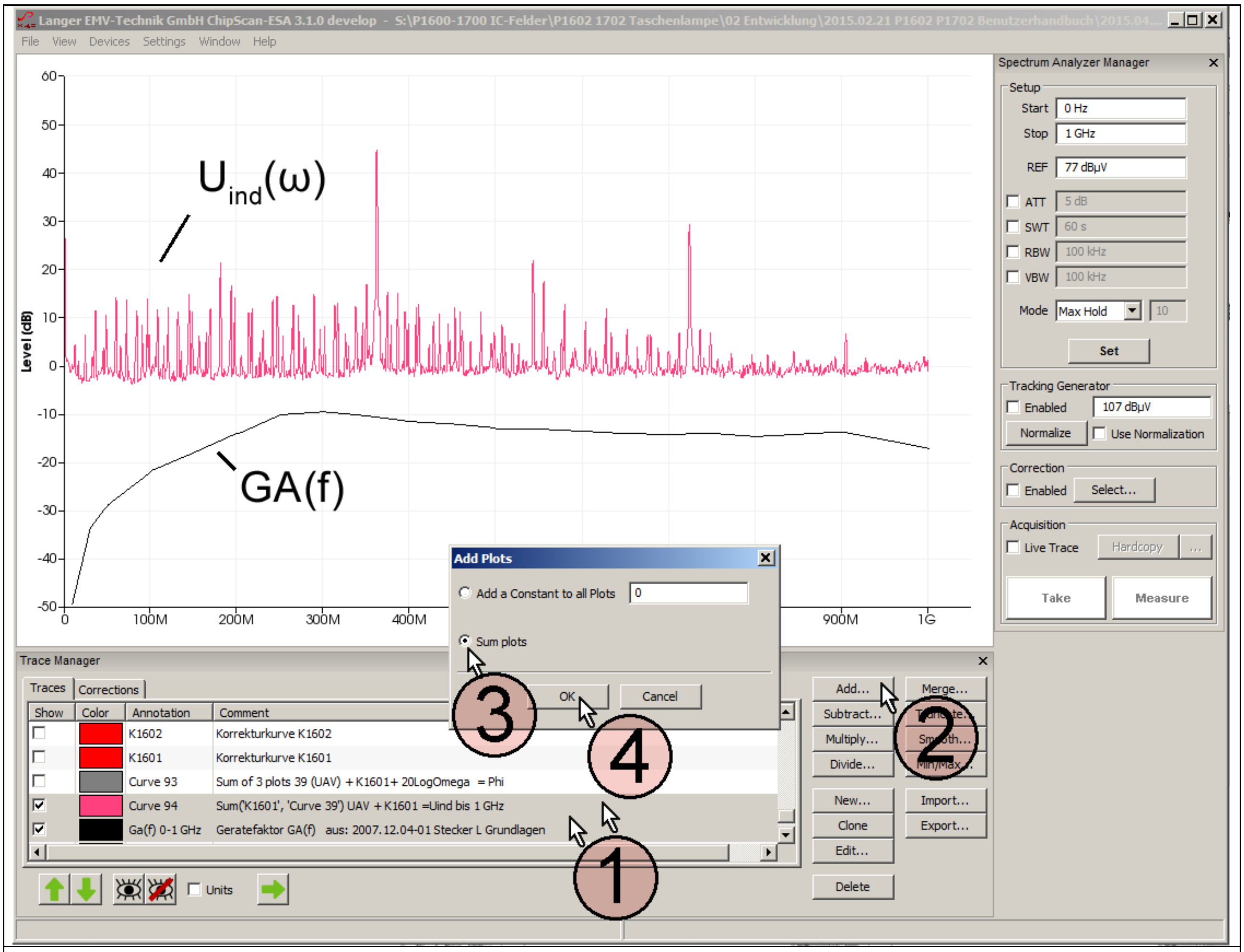

Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.04.24-01 IC-Messung NXP LPC1813 .csd

Start 0 Hz
Stop 1 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Max Hold 10
Tracking Generator ☐ Enabled 107 dBµV

Show	Color	Category	Annotation	Comment
☐	■	Functions	2013….-6GHz	
☑	■	Functions	Ga(f) 0-1 GHz	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☐	🟥	Functions	K1601	Korrekturkurve K1601
☐	🟥	Functions	K1602	Korrekturkurve K1602
☐	🟪	Functions	K1702	Korrekturfaktoe K 1702 geglätt

Figure 30 Selecting the correction curve GA(f) in the "Corrections" list and moving it to the "Traces" list of ***ChipScan-ESA***.

E_{Ant} (ω) can be calculated in the "Traces" list. Mark the curve U_{ind} (Curve 94, **Figure 31**) and the function GA(f) with the mouse cursor ①. Call up the mathematical operation "Add…" (mouse cursor ②).



Spectrum Analyzer Manager – Setup: Start 0 Hz; Stop 1 GHz; REF 77 dBµV; ☐ ATT 5 dB; ☐ SWT 60 s; ☐ RBW 100 kHz; ☐ VBW 100 kHz; Mode Max Hold, 10; Set

Tracking Generator: ☐ Enabled 107 dBµV; Normalize; ☐ Use Normalization

Correction: ☐ Enabled; Select...

Acquisition: ☐ Live Trace; Hardcopy

Add Plots

○ Add a Constant to all Plots 0

● Sum plots

OK Cancel

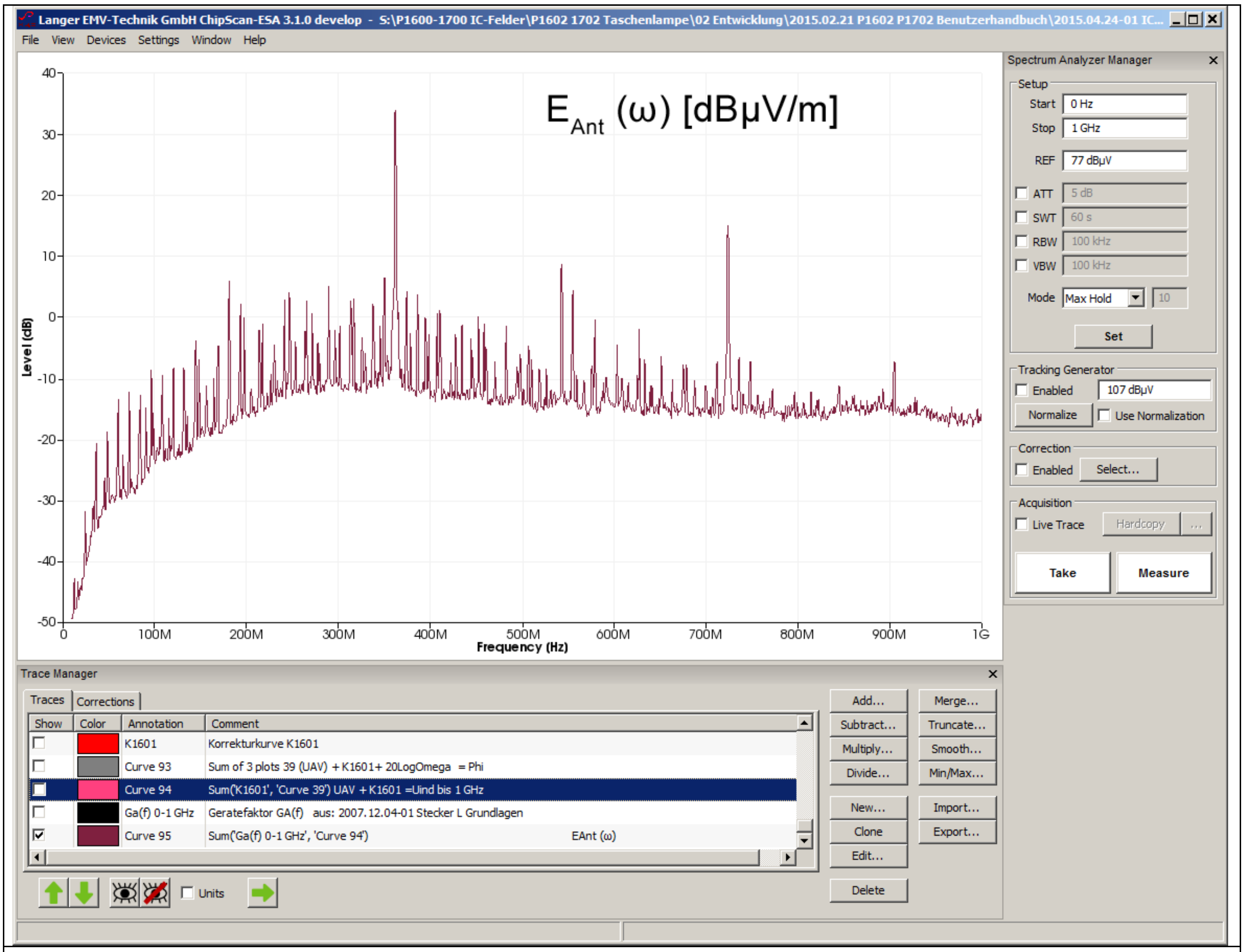
Trace Manager

Show	Color	Annotation	Comment
☐	🟥	K1602	Korrekturkurve K1602
☐	🟥	K1601	Korrekturkurve K1601
☐	▨	Curve 93	Sum of 3 plots 39 (UAV) + K1601+ 20LogOmega = Phi
☑	🟥	Curve 94	Sum('K1601', 'Curve 39') UAV + K1601 =Uind bis 1 GHz
☑	■	Ga(f) 0-1 GHz	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen

☐ Units

Figure 31 Calculating the worst case radiated emissions from the voltage induced by the IC. E_{Ant} (ω) = GA(f) + U_{ind}(ω) is calculated with the mathematical function "Addition" in ***ChipScan-ESA***.

Activate "Sum plots" ③. Click OK to start the calculation ④. Curve 95 E_{Ant} (ω) is the result of this calculation (**Figure 32**).



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.04.24-01 IC...

Start 0 Hz
Stop 1 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Max Hold 10

☐ Enabled 107 dBµV
☐ Use Normalization

☐ Enabled

☐ Live Trace

Show	Color	Annotation	Comment
☐	🟥	K1601	Korrekturkurve K1601
☐	⬛	Curve 93	Sum of 3 plots 39 (UAV) + K1601+ 20LogOmega = Phi
☐	🟥	Curve 94	Sum('K1601', 'Curve 39') UAV + K1601 =Uind bis 1 GHz
☐	⬛	Ga(f) 0-1 GHz	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☑	🟥	Curve 95	Sum('Ga(f) 0-1 GHz', 'Curve 94') EAnt (ω)

☐ Units

Figure 32 Calculating the worst case radiated emissions E_{Ant} (ω) [dBµV/m] from the voltage induced by the IC. The calculation is performed with the "Add..." mathematical function in ***ChipScan-ESA***.

In the worst case the IC generates an electromagnetic wave with an electric field strength E_{Ant} (ω) of 35.5 dBµV/mst at a distance of 10 m with a coupling distance to the metal part as little as 10 mm. Smaller coupling distances are possible in reality so that radiated emissions may even be higher. The IC can produce emissions in practice. There are ICs with considerably lower excitation fields, though also ICs whose excitation fields are much stronger.

3.3.4 Generating the excitation flux $\Phi(\omega)$ with the BPM 02 Ḃ field meter as a test source

The ***BPM 02*** Ḃ-field meter (**Figure 33**) can be used as a field source to generate the excitation flux $\Phi(\omega)$. It is operated in the opposite direction to generate a B-field, i.e. it is supplied with the voltage U_{TG} of a tracking generator via its SMB signal output. It thus generates the excitation flux $\Phi(\omega)$ and/or the magnetic field B on the measurement loop in the same way as an IC. The ***BPM 02***'s measurement loop acts as an induction loop which is formed by the IC's conductor. The dimensions of the ***BPM 02***'s measurement loop are (7.8 x 1.5) mm.

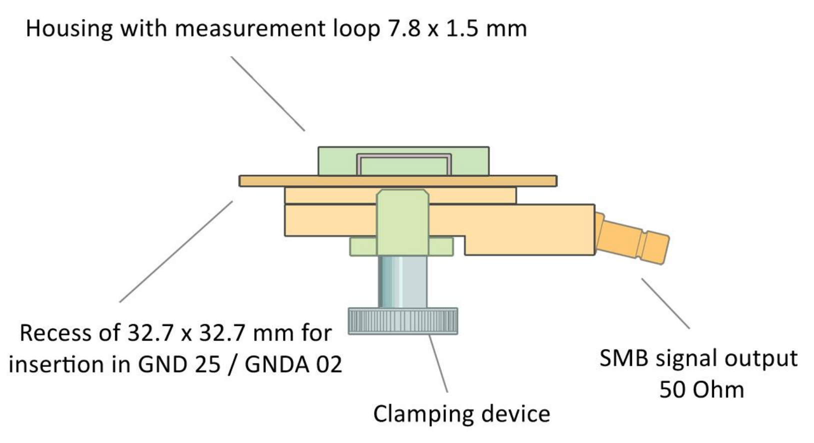


Figure 33 ***BPM 02*** Ḃ-field meter to generate the magnetic fields B, H and the excitation flux $\Phi(\omega)$.

Figure 34 shows the measurement set-up. The ***BPM 02*** Ḃ-field meter is inserted into the ground adapter instead of the test IC. The ***BPM 02*** Ḃ-field meter fits into the ***GNDA 02*** ground adapter and has to be inserted into the ***GND 25*** ground plane for the measurement[5].

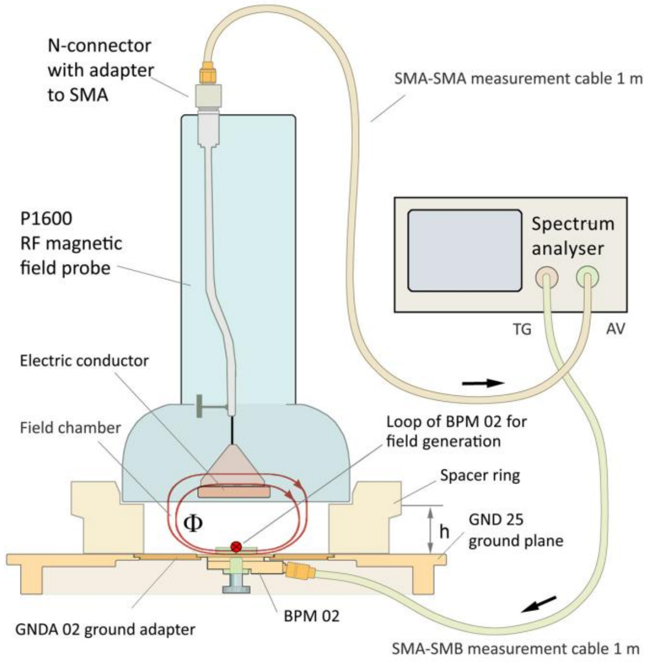


Figure 34 Measuring the transfer function of the field probe in the P1600 series.

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[5] ***GNDA 02*** ground adapter and ***GND 25*** ground plane are included in the ***ICE1 IC test environment set*** www.langer-emv.de. The test board is described in the ***IC test instructions manual***, mail@langer-emv.de.

The SMB port of the ***BPM 02*** $\dot{B}$-field meter is connected to the tracking generator output of the spectrum analyser with the 50 Ohm SMA-SMB measuring cable. The measurement output is matched to 50 Ohm. The tracking generator voltage U_{TG} of the spectrum analyser (**Figure 35**) drives the current I_{IC} through the loop of the ***BPM 02***. The ***BPM 02*** contains a voltage divider (shown in a simplified form in the equivalent circuit diagram) which adjusts the current in the loop according to **Eqn 17**.

$I_{IC} = U_{TG} - 49.55\text{ dB}$ Eqn 17

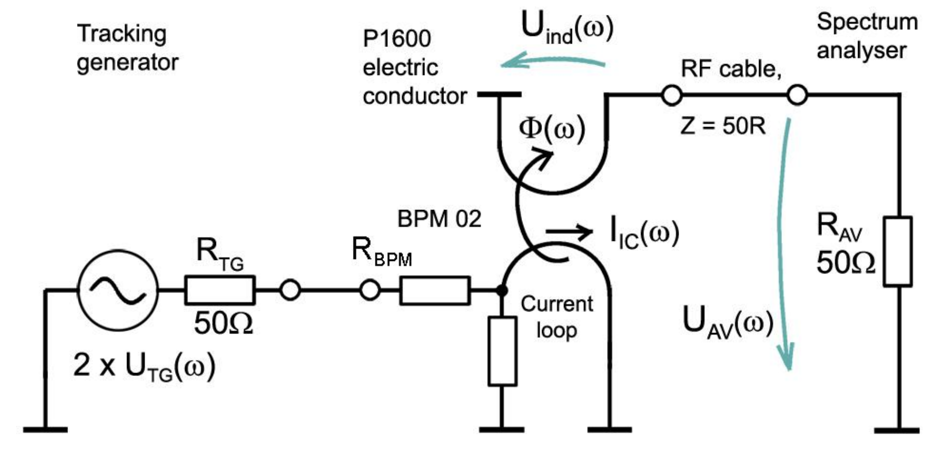


Figure 35 Equivalent circuit diagram of the measurement set-up in **Figure 34** including the tracking generator, ***BPM 02*** field source, P1600 field probe and the spectrum analyser.

The P1600 has a coupling inductance per unit length of 12.4 pH / mm² (**Table 2**) at a spacer ring height of 10 mm. The ***BPM 02*** has a loop surface area of 7.8 mm x 1.5 mm = 11.7 mm². Hence it follows from **Eqn 5** that the coupling inductance L_h is roughly 0.145 nH. The actual inductance is around 0.108 nH (**Figure 46**). For the time being, the calculated inductance of L_h = 0.145 nH is used in the further process to determine the difference (**Figure 46)** to the actual inductivity.

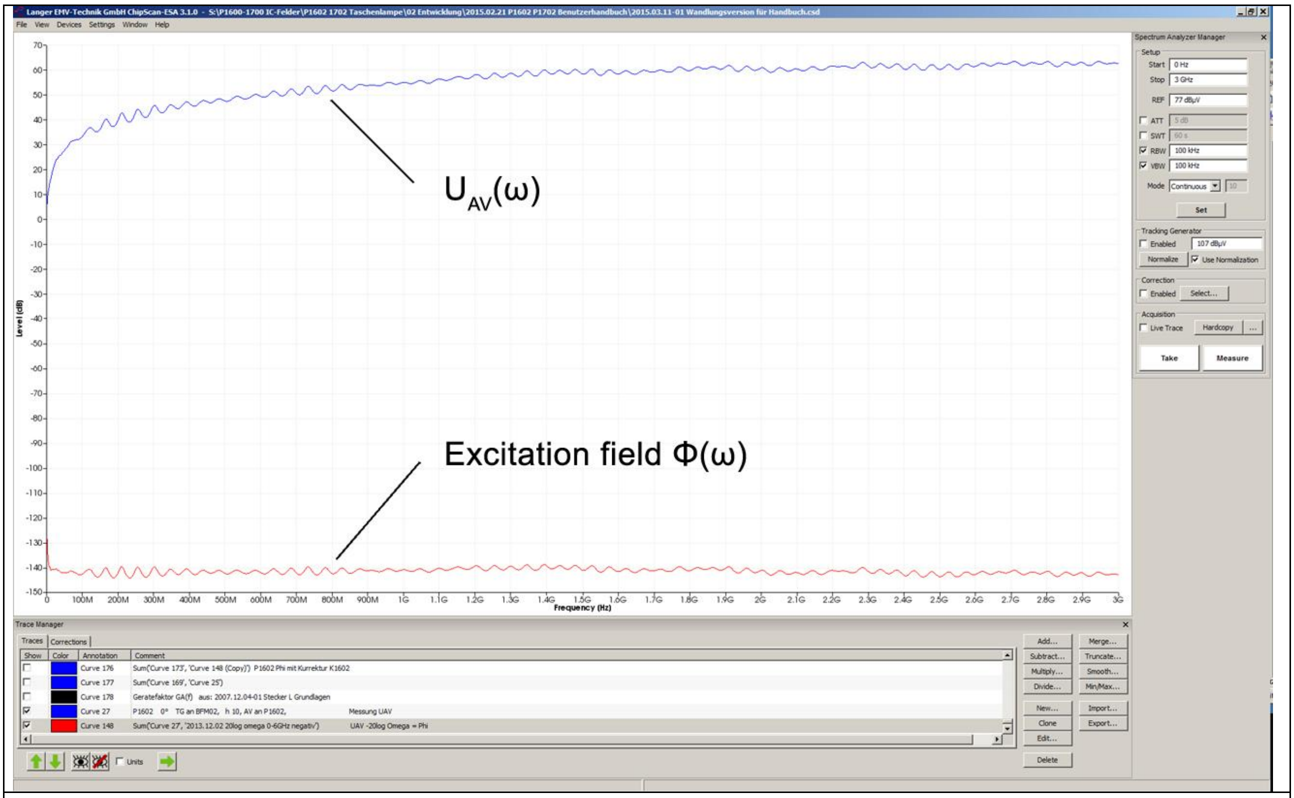
Eqn 18 results from **Eqn 3** and **Eqn 17**:

$\Phi(\omega) = 20 \text{ Log } L_h + U_{TG} - 49.55\text{ dB}$ Eqn 18

The ***P1601*** or ***P1602*** field probe is located above the ***GND 25*** ground plane (**Figure 34**). The distance to the ground plane is set with the spacer ring. The spacer ring h = 10 mm is preferred for the measurements. The electric conductor of the ***P1601*** or ***P1602*** field probe thus has a defined distance to the ***BPM 02*** field source. The spectrum analyser which is used for measurement is wired as shown in **Figure 34**.

The spectrum analyser has to be normalized prior to the measurement (U_{TG} 107 dBµV, external attenuator 30 dB).
BPM 02 is supplied with 107 dBµV by the tracking generator of the spectrum analyser. The voltage $U_{AV}(\omega)$ **Figure 14** which is produced on the input resistor R_{AV} of the spectrum analyser (set-up **Figure 34**, equivalent circuit diagram **Figure 35**) is obtained as the result of this measurement. The frequency response of the ***BPM 02*** excitation field source can be taken into account in the form of the correction curve KBPM 02R.

The ***ChipScan-ESA*** software is used to control the spectrum analyser, perform the calculations and document the measurements **Figure 36**.



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Spectrum Analyzer Manager – Setup:
Start: 0 Hz
Stop: 3 GHz
REF: 77 dBµV
☐ ATT: 5 dB
☐ SWT: 60 s
☑ RBW: 100 kHz
☑ VBW: 100 kHz
Mode: Continuous

Tracking Generator: ☐ Enabled 107 dBµV, ☑ Use Normalization

Correction: ☐ Enabled

Acquisition: ☐ Live Trace

Trace Manager – Traces:

Show	Color	Annotation	Comment	
☐	🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602	
☐	🟦	Curve 177	Sum('Curve 169', 'Curve 25')	
☐	⬛	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen	
☑	🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602,	Messung UAV
☑	🟥	Curve 148	Sum('Curve 27', '2013.12.02 20log omega 0-6GHz negativ')	UAV -20log Omega = Phi

Figure 36 User interface of the ***ChipScan-ESA*** software. Measuring the voltage U_{AV} which the excitation field Φ(ω) (constant) of the ***BPM 02*** induces in the electric conductor of the ***P1602*** field probe. The constant excitation current $I_{IC}(\omega)$ = 57 dBµA was generated by a tracking generator.

$U_{AV}(\omega)$ can be converted to the excitation field Φ(ω) with **Eqn 13**: $\Phi(\omega) = U_{AV}(\omega) - 20 \text{ Log } \omega$; result: **Figure 36**.

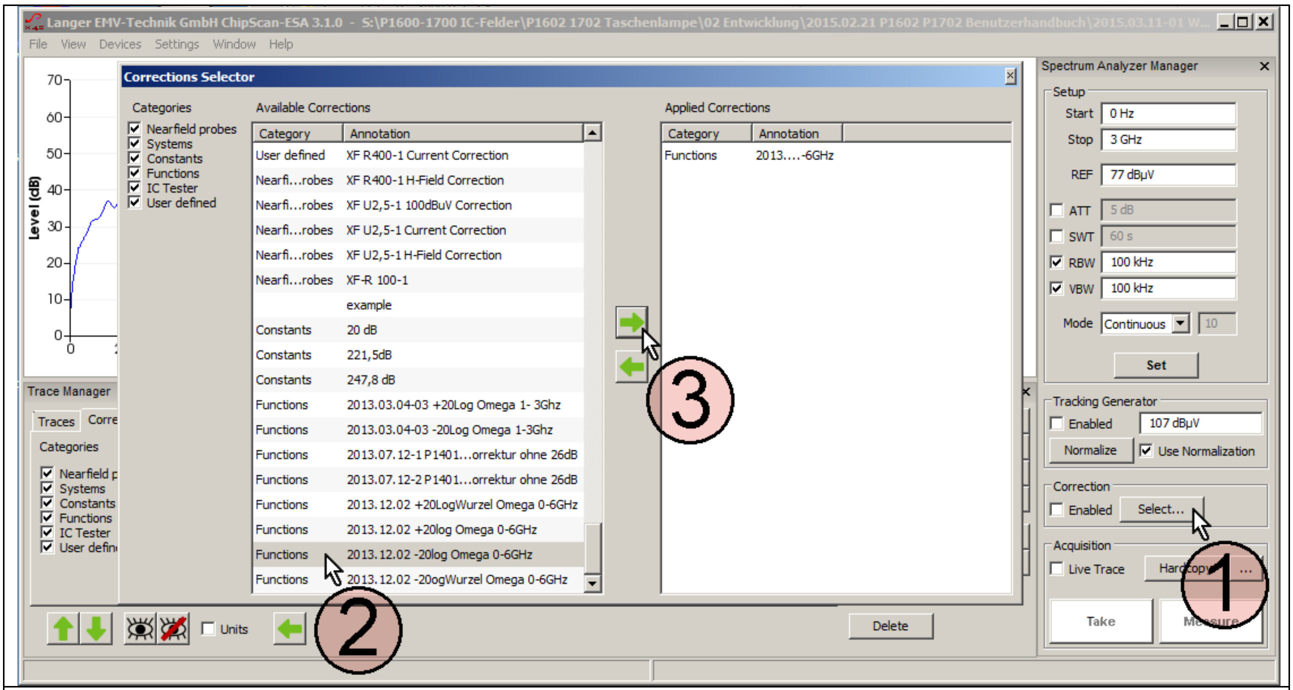
There are two ways to do this:

1. By using the correction curve - 20 Log ω during the measurement
2. By using the mathematical operation "Add…" - 20 Log ω after the measurement

The ***ChipScan-ESA*** software is used to perform the conversion. You can find the correction curve - 20 Log ω in the "Corrections" list of its "Trace Manager".

3.3.4.1 Using the correction curve (- 20 Log ω) during the measurement

You can find the correction curve (- 20 Log ω) in the "Corrections" list of the "Trace Manager". Click the "Select" button (mouse cursor ① **Figure 37**) under "Correction" in the "Spectrum Analyser Manager" to select the respective correction curve.



Categories
☑ Nearfield probes
☑ Systems
☑ Constants
☑ Functions
☑ IC Tester
☑ User defined

Available Corrections

Category	Annotation
User defined	XF R400-1 Current Correction
Nearfi...robes	XF R400-1 H-Field Correction
Nearfi...robes	XF U2,5-1 100dBuV Correction
Nearfi...robes	XF U2,5-1 Current Correction
Nearfi...robes	XF U2,5-1 H-Field Correction
Nearfi...robes	XF-R 100-1
	example
Constants	20 dB
Constants	221,5dB
Constants	247,8 dB
Functions	2013.03.04-03 +20Log Omega 1- 3Ghz
Functions	2013.03.04-03 -20Log Omega 1-3Ghz
Functions	2013.07.12-1 P1401...orrektur ohne 26dB
Functions	2013.07.12-2 P1401...orrektur ohne 26dB
Functions	2013.12.02 +20LogWurzel Omega 0-6GHz
Functions	2013.12.02 +20log Omega 0-6GHz
Functions	2013.12.02 -20log Omega 0-6GHz
Functions	2013.12.02 -20ogWurzel Omega 0-6GHz

Applied Corrections

Category	Annotation
Functions	2013....-6GHz

Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10

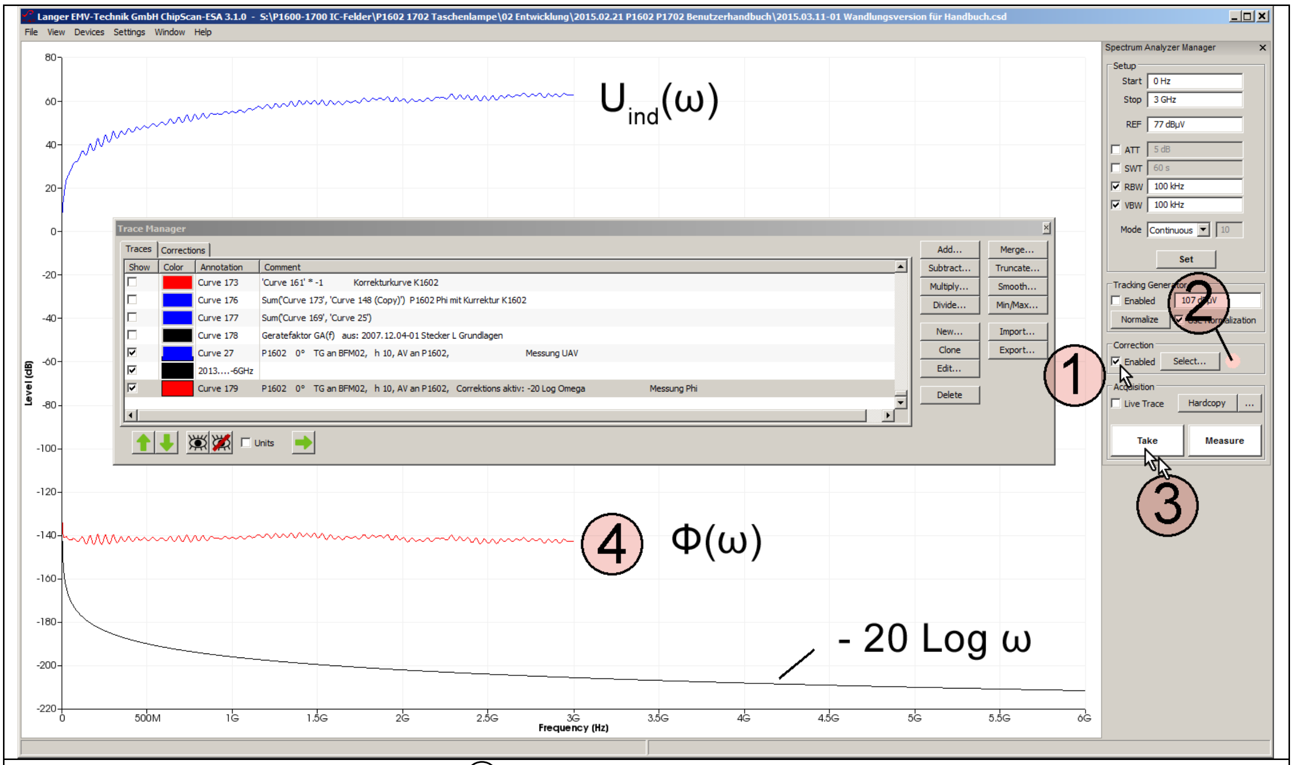
Tracking Generator
☐ Enabled 107 dBµV
Normalize ☑ Use Normalization

Correction
☐ Enabled Select...

Acquisition
☐ Live Trace

Figure 37 Activating correction curves and correction factors with the "Corrections Selector".

The "Corrections Selector" window opens **Figure 37**. Click and activate the correction curve -20 Log ω with the mouse cursor ②. Click the "Arrow right" button ③ to move the correction curve to the "Applied Corrections" list.
Activate the "Enabled" box in the "Correction" field in the "Spectrum Analyser Manager" with the mouse coursor ① **Figure 38**. The field ② flashes if the correction is active (**Figure 38)**. Click "Take" or "Measure" (mouse cursor ③) **Figure 38** to transfer the current measurement curve ④ $\Phi(\omega)$ from the spectrum analyser to the PC. The calculation **Eqn 13**: $\Phi(\omega) = U_{AV}(\omega) - 20 \log \omega$ is performed automatically at the same time. The curve $\Phi(\omega)$ is added to the bottom of the "Traces" list in the "Trace Manager". A measurement log can be kept in the respective free text field under "Comment".
Delete the check mark from the "Enabled" box if you only want to measure $U_{AV}(\omega)$; the field ② then stops flashing.



Traces | Corrections

Show	Color	Annotation	Comment
☐	🟥	Curve 173	'Curve 161' * -1 Korrekturkurve K1602
☐	🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602
☐	🟦	Curve 177	Sum('Curve 169', 'Curve 25')
☐	⬛	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☑	🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
☑	⬛	2013....-6GHz	
☑	🟥	Curve 179	P1602 0° TG an BFM02, h 10, AV an P1602, Correktions aktiv: -20 Log Omega Messung Phi

Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10

Tracking Generator
☐ Enabled 107 dBµV
☑ Use Normalization

Correction
☑ Enabled

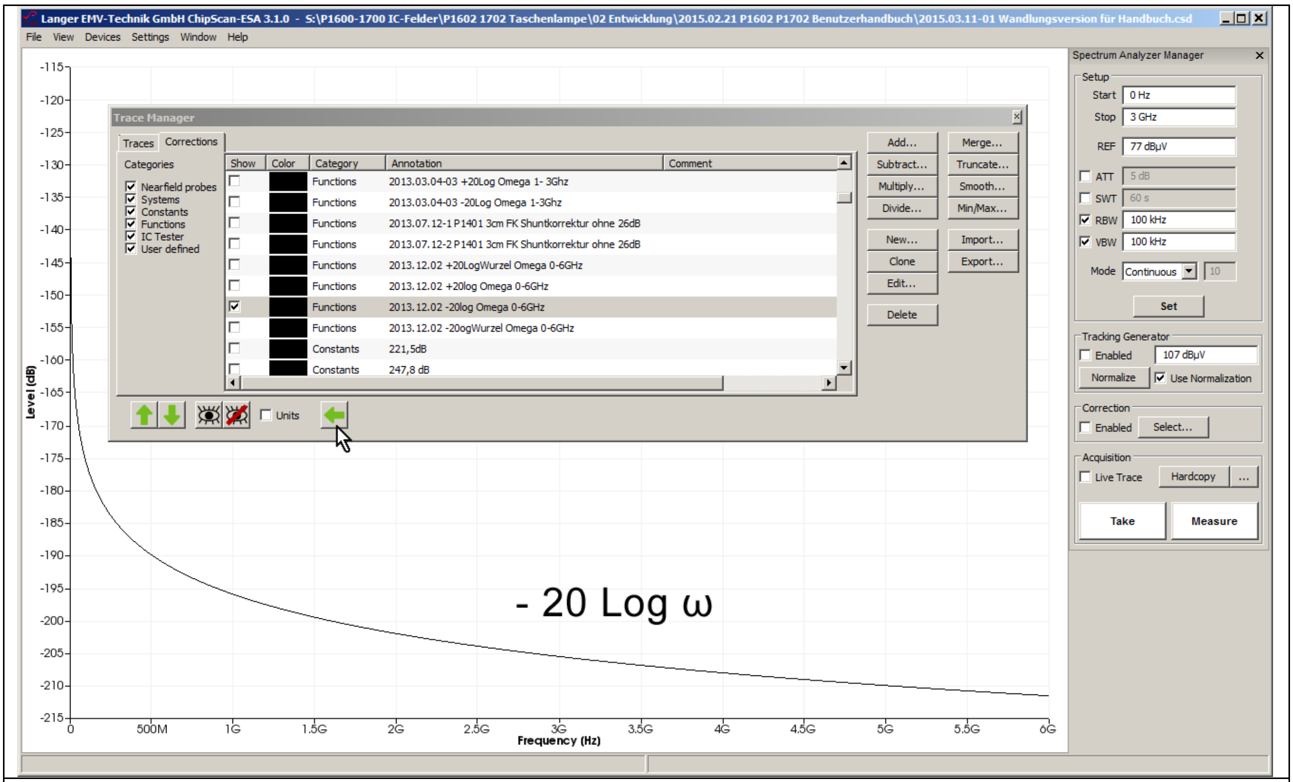
Acquisition
☐ Live Trace

Figure 38 Measuring the curve Φ(ω) ④. It is added as Curve 179 to the bottom of the "Traces" list.

The curve number is counted automatically (Curve 179) under "Annotation".

3.3.4.2 Using the mathematical operation (- 20 Log ω) after the measurement

The mathematical operation "Add…" is used for the calculation according to **Eqn 13**: $\Phi(\omega) = U_{AV}(\omega) - 20 \text{ Log } \omega$. However, the function - 20 Log ω first has to be copied from the "Correction" list to the "Traces" list in the Trace Manager.



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Trace Manager – Corrections

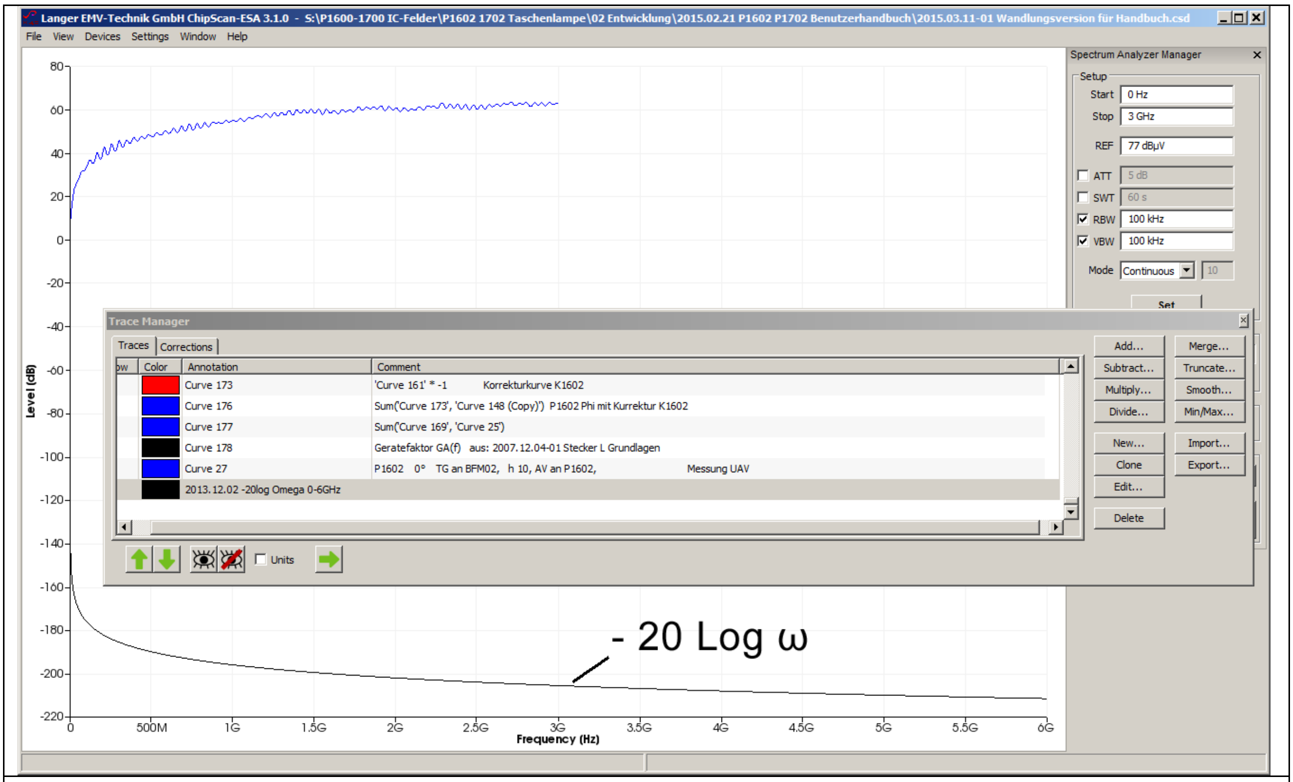
Categories:
☑ Nearfield probes
☑ Systems
☑ Constants
☑ Functions
☑ IC Tester
☑ User defined

Show	Color	Category	Annotation	Comment
☐	■	Functions	2013.03.04-03 +20Log Omega 1- 3Ghz	
☐	■	Functions	2013.03.04-03 -20Log Omega 1-3Ghz	
☐	■	Functions	2013.07.12-1 P1401 3cm FK Shuntkorrektur ohne 26dB	
☐	■	Functions	2013.07.12-2 P1401 3cm FK Shuntkorrektur ohne 26dB	
☐	■	Functions	2013.12.02 +20LogWurzel Omega 0-6GHz	
☐	■	Functions	2013.12.02 +20log Omega 0-6GHz	
☑	■	Functions	2013.12.02 -20log Omega 0-6GHz	
☐	■	Functions	2013.12.02 -20ogWurzel Omega 0-6GHz	
☐	■	Constants	221,5dB	
☐	■	Constants	247,8 dB	

☐ Units

Spectrum Analyzer Manager
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10
Tracking Generator: ☐ Enabled 107 dBµV
☑ Use Normalization
Correction: ☐ Enabled
Acquisition: ☐ Live Trace

Figure 39 Marking the correction curve (- 20 Log ω) in the "Corrections" list and copying it to the "Traces" list with the "Arrow left" key (mouse cursor).



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Trace Manager – Traces

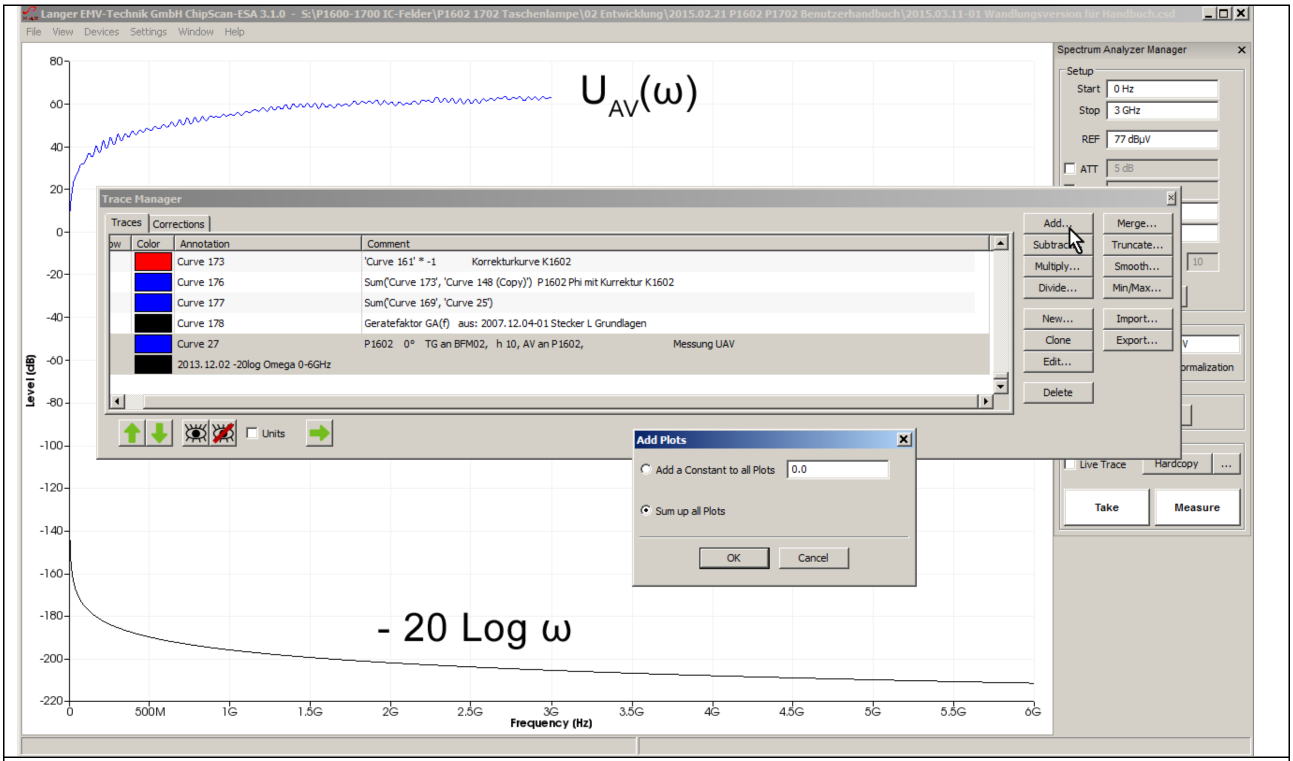
Color	Annotation	Comment
🟥	Curve 173	'Curve 161' * -1 Korrekturkurve K1602
🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602
🟦	Curve 177	Sum('Curve 169', 'Curve 25')
■	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
■	2013.12.02 -20log Omega 0-6GHz	

☐ Units

Spectrum Analyzer Manager
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 100 kHz
Mode Continuous 10

Figure 40 The correction curve (- 20 Log ω) has been added to the "Traces" list.

Activate the function (- 20 Log ω) in the "Corrections" list with the mouse cursor. Copy the function to the "Traces" list with the "Arrow left" button (**Figure 39** mouse cursor) **Figure 40**.



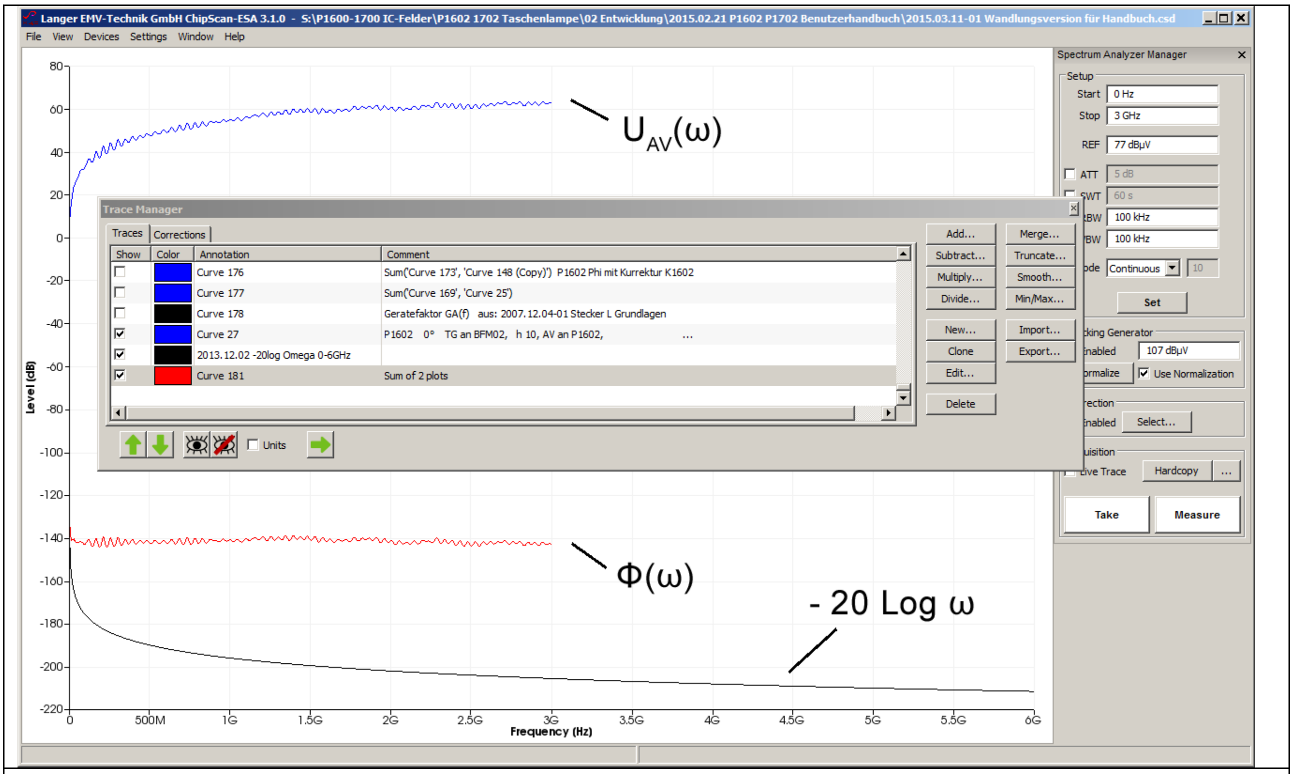
Color	Annotation	Comment
🟥	Curve 173	'Curve 161' * -1 Korrekturkurve K1602
🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602
🟦	Curve 177	Sum('Curve 169', 'Curve 25')
■	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
■	2013.12.02 -20log Omega 0-6GHz	

○ Add a Constant to all Plots 0.0

● Sum up all Plots

Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB

Figure 41 "Curve 27" (U_{AV}) and the curve "… - 20 Log Omega" are marked. The mathematical operation "Add…" (addition) is opened and "Sum up all Plots" activated.



Show	Color	Annotation	Comment
☐	🟦	Curve 176	Sum('Curve 173', 'Curve 148 (Copy)') P1602 Phi mit Kurrektur K1602
☐	🟦	Curve 177	Sum('Curve 169', 'Curve 25')
☐	■	Curve 178	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☑	🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, ...
☑	■	2013.12.02 -20log Omega 0-6GHz	
☑	🟥	Curve 181	Sum of 2 plots

Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
BW 100 kHz
BW 100 kHz
ode Continuous 10
king Generator
nabled 107 dBµV
ormalize ☑ Use Normalization

Figure 42 The addition U_{AV} + (- 20 Log ω) = Φ(ω) is performed by clicking OK.

Mark the "Curve 27" (U_{AV}) curve and the "… - 20 Log Omega" curve in the "Traces" list in the "Trace Manager" with the mouse cursor **Figure 41.** Open the mathematical operation "Add…" (addition) and activate "Sum up all Plots" (**Figure 41** mouse cursor). Click OK to perform the addition U_{AV} + (- 20 Log ω) = Φ(ω). The result of the calculation, "Curve 181", is added to the bottom of the "Traces" list.

3.3.5 Creating the correction factor K1600

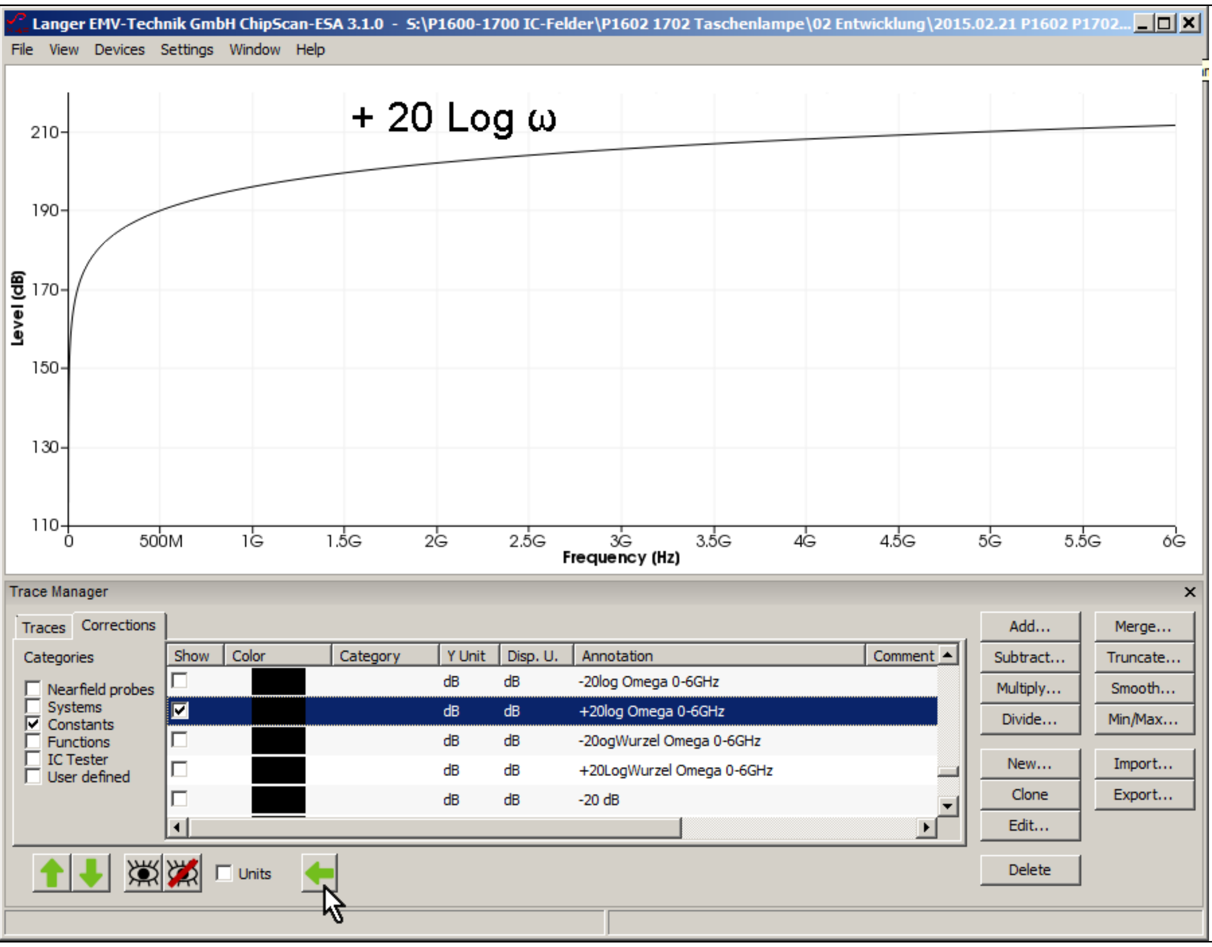
The ideal curve of the induced voltage $U_{ind}(\omega)$ is the basis for creating the correction curve to correct the frequency response deviation of probes in the P1600 series. The correction curve is created from the difference between the calculated induced voltage $(U_{ind}(\omega))_{berechnet}$ and the measured induced voltage $(U_{ind}(\omega))_{gemessen} = U_{AV}$.

$K1600 = U_{ind}(\omega)_{berechnet} - U_{AV}$ Eqn 19

Calculation of $U_{ind}(\omega)$:
If **Eqn 3** ($\Phi(\omega) = 20 \text{ Log } L_h + I_{IC}(\omega)$) is inserted in **Eqn 9** ($U_{ind}(\omega) = 20 \text{ Log } \omega + \Phi(\omega)$), it follows that:

$U_{ind}(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } L_h + I_{IC}(\omega)$ Eqn 20

Firstly, the values for 20 Log ω and 20 Log L_h are needed. The inductance L_h is 12.4 pH with a spacer ring height h = 10 mm, see **Eqn 5**.
The function 20 Log ω is provided in the "Corrections" list of the Trace Manager.



☐ Nearfield probes
☐ Systems
☑ Constants
☐ Functions
☐ IC Tester
☐ User defined

Show	Color	Category	Y Unit	Disp. U.	Annotation	Comment
☐	■		dB	dB	-20log Omega 0-6GHz	
☑	■		dB	dB	+20log Omega 0-6GHz	
☐	■		dB	dB	-20ogWurzel Omega 0-6GHz	
☐	■		dB	dB	+20LogWurzel Omega 0-6GHz	
☐	■		dB	dB	-20 dB	

Figure 43 The function 20 Log ω is activated in the "Corrections" list of the Trace Manager.

Activate the function 20 Log ω with a mouse click and copy the function from the "Corrections" list to the "Traces" list by clicking the "Arrow left" button (mouse cursor **Figure 43)**. Activate the mathematical function "Add..." to perform the calculation 20 Log ω + 20 Log L_h in the "Traces" list.
The logarithm is initially taken of the inductance L_h of 0.145 nH which has been determined above (**Eqn 5**).

Calculate 20 Log 0.145 EXP-9 with a pocket calculator:

$20 \text{ Log } L_h = 20 \text{ Log } 0.145 \text{ EXP-9} = -196.8 \text{ dBH}$ Eqn 21

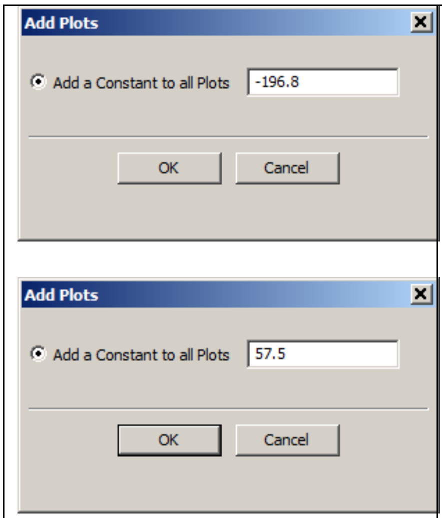
The current I_{IC} is determined with the ***ChipScan-ESA*** in the next step according to **Eqn 17**. The tracking generator voltage of the spectrum analyser is hereby U_{TG} 107 dBµV:

$I_{IC} = U_{TG} -49.55 \text{ dB}\Omega = 107 \text{ dB}\mu\text{V} -49.55 \text{ dB}\Omega = 57.5 \text{ dB}\mu\text{A}$ Eqn 22

All values can now be inserted in **Eqn 20** and added with the mathematical function "Add…" of the ***ChipScan-ESA*** software:

$U_{ind}(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } L_h + I_{IC}(\omega) = 20 \text{ Log } \omega -196.8 \text{ dBH} +57.5 \text{ dB}\mu\text{A}$ Eqn 23

Activate the curve "20 Log Omega" with a mouse click. First enter "-196.8" as the constant to be added under "Add…" **Figure 44**. Click OK to perform the addition. Then add +57.5 dB in the same way. The result $U_{ind}(\omega)$ appears at the bottom of the "Traces" list and as a curve on the display **Figure 45**.



● Add a Constant to all Plots: -196.8

● Add a Constant to all Plots: 57.5

Figure 44 Addition of -196.8 dB and 57.5 dB to the curve +20 Log Omega.

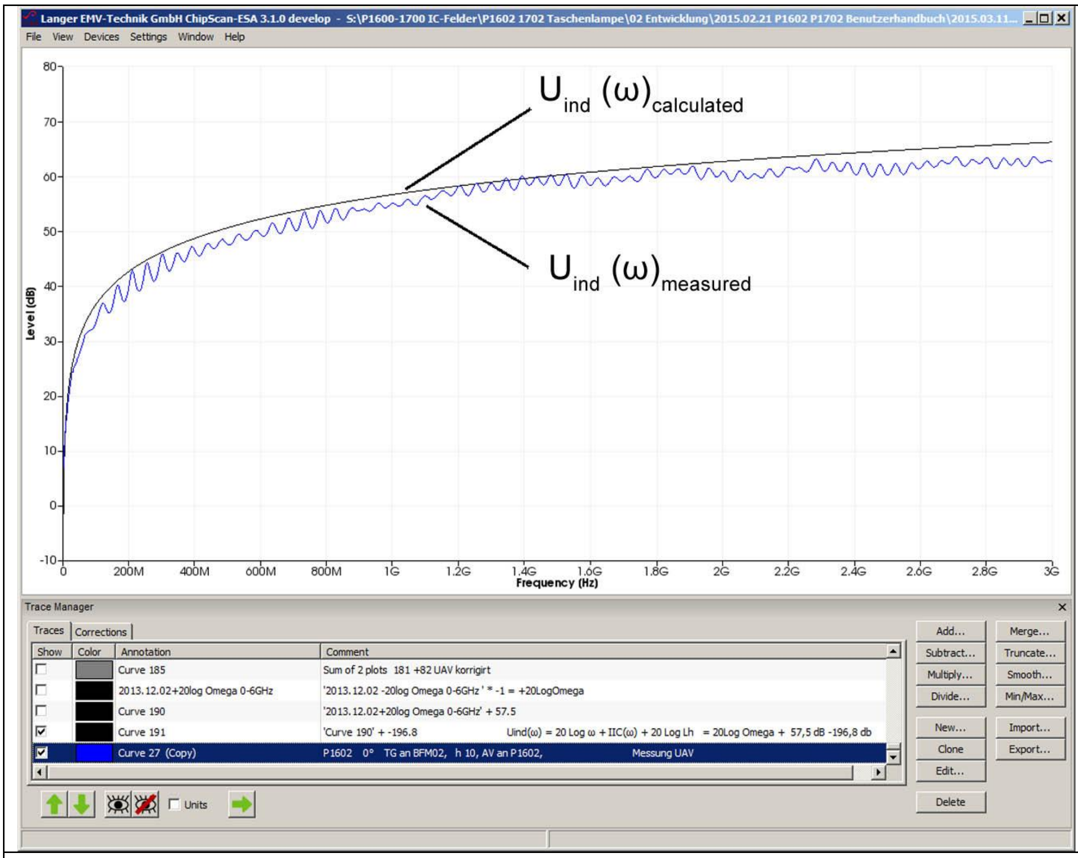
Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P160...

Show	Color	Annotation	Comment
☐	▨	Curve 184	Sum of 2 plots 182 +(-20Log omega) Ladungsmenge Q
☐	▨	Curve 185	Sum of 2 plots 181 +82 UAV korrigirt
☑	■	2013.12.02+20log Omega 0-6GHz	'2013.12.02 -20log Omega 0-6GHz ' * -1 = +20LogOmega
☐	■	Curve 187	'2013.12.02+20log Omega 0-6GHz' + -196.... P1600 Korrekturfakt
☑	■	Curve 189	'Curve 187 + 57.5

Figure 45 The result of the addition 20 Log ω -196.8 dBH +57.5 dBµA is the Curve 189 = U_{ind} (ω) (lower curve).

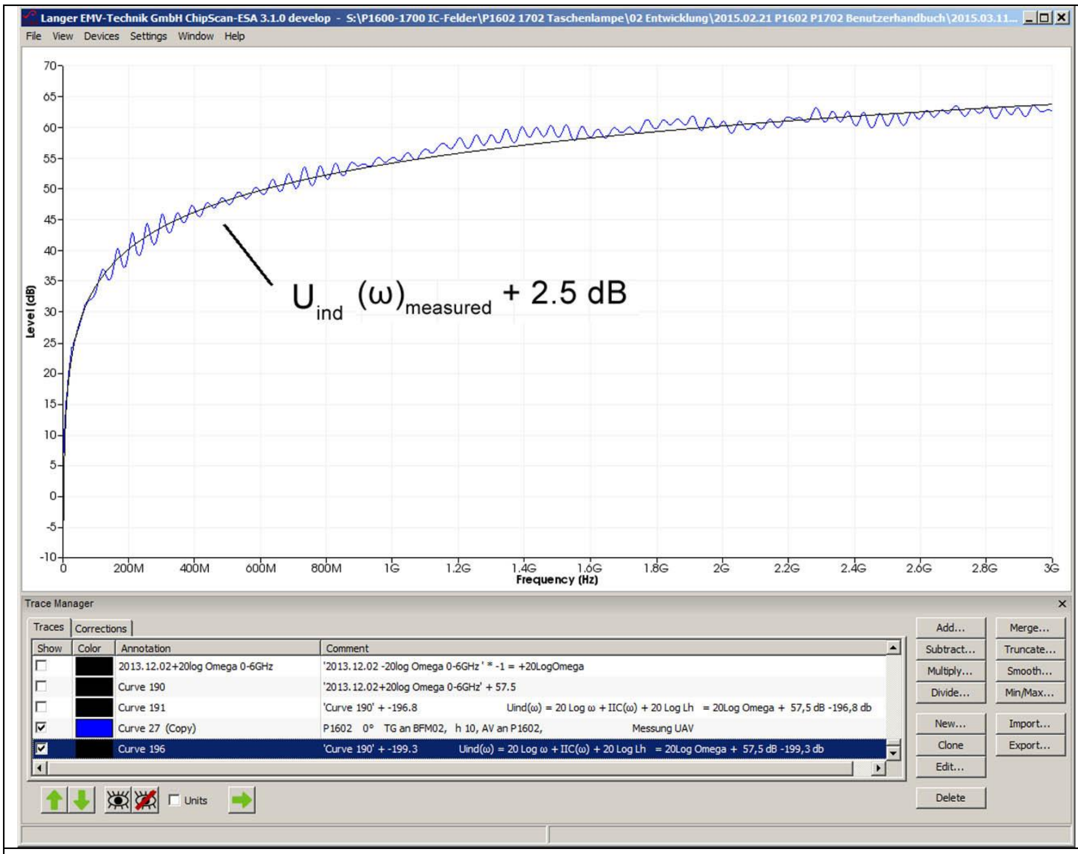
$U_{ind}(\omega)$ measured with ***P1602*** is provided as $U_{AV}(\omega)$ "Curve 27" (**Figure 46**). A comparison with the calculated curve U_{ind} $(\omega)_{\text{measured}}$ reveals a constant deviation of 2.5 dB. The inductance L_h on which the calculation is based can only be roughly determined with (**Eqn 5**) $L_h = L_h' * A_{IC} = 12.4 \text{ pH} / \text{mm}^2 * 11.7 \text{ mm}^2 = 0.145 \text{ nH}$ and thus leads to the deviation. The result is corrected with -2.5 dB. Consequently, the actual inductance is $20 \text{ Log } L_h = 20 \text{ Log } L_h = -196.8 -2.5 \text{ dB}$. By taking the antilogarithm, you get:

$L_h = 0.108 \text{ nH}$ Eqn 24



Show	Color	Annotation	Comment
☐	▨	Curve 185	Sum of 2 plots 181 +82 UAV korrigirt
☐	■	2013.12.02+20log Omega 0-6GHz	'2013.12.02 -20log Omega 0-6GHz ' * -1 = +20LogOmega
☐	■	Curve 190	'2013.12.02+20log Omega 0-6GHz' + 57.5
☑	■	Curve 191	'Curve 190' + -196.8 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -196,8 db
☑	🟦	Curve 27 (Copy)	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV

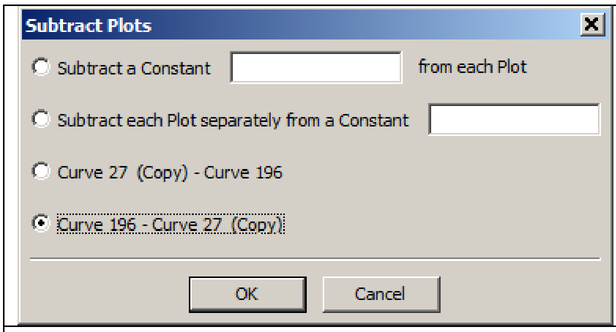
Figure 46 Calculated and measured induced voltage.



Show	Color	Annotation	Comment
☐	■	2013.12.02+20log Omega 0-6GHz	'2013.12.02 -20log Omega 0-6GHz ' * -1 = +20LogOmega
☐	■	Curve 190	'2013.12.02+20log Omega 0-6GHz' + 57.5
☐	■	Curve 191	'Curve 190' + -196.8 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -196,8 db
☑	🟦	Curve 27 (Copy)	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
☑	■	Curve 196	'Curve 190' + -199.3 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -199,3 db

Figure 47 Calculated curve corrected with -2.5 dB results in congruence in the lower frequency range.

The correction factor K1602 can now be calculated from the curves in **Figure 47** according to **Eqn 19**. $U_{ind}(\omega)$ measured with ***P1602*** is provided as $U_{AV}(\omega)$ "Curve 27". Activate $U_{ind}(\omega)_{measured}$ "Curve 196" and $U_{AV}(\omega)$ "Curve 27" in the "Traces" list of the "Trace Manager" with the mouse cursor.
Activate "Curve 196 - Curve 27" under "Subtract…". Click OK to perform the subtraction. The correction curve K1602 appears as "Curve 197" at the bottom of the list (**Figure 51**).


Subtract Plots

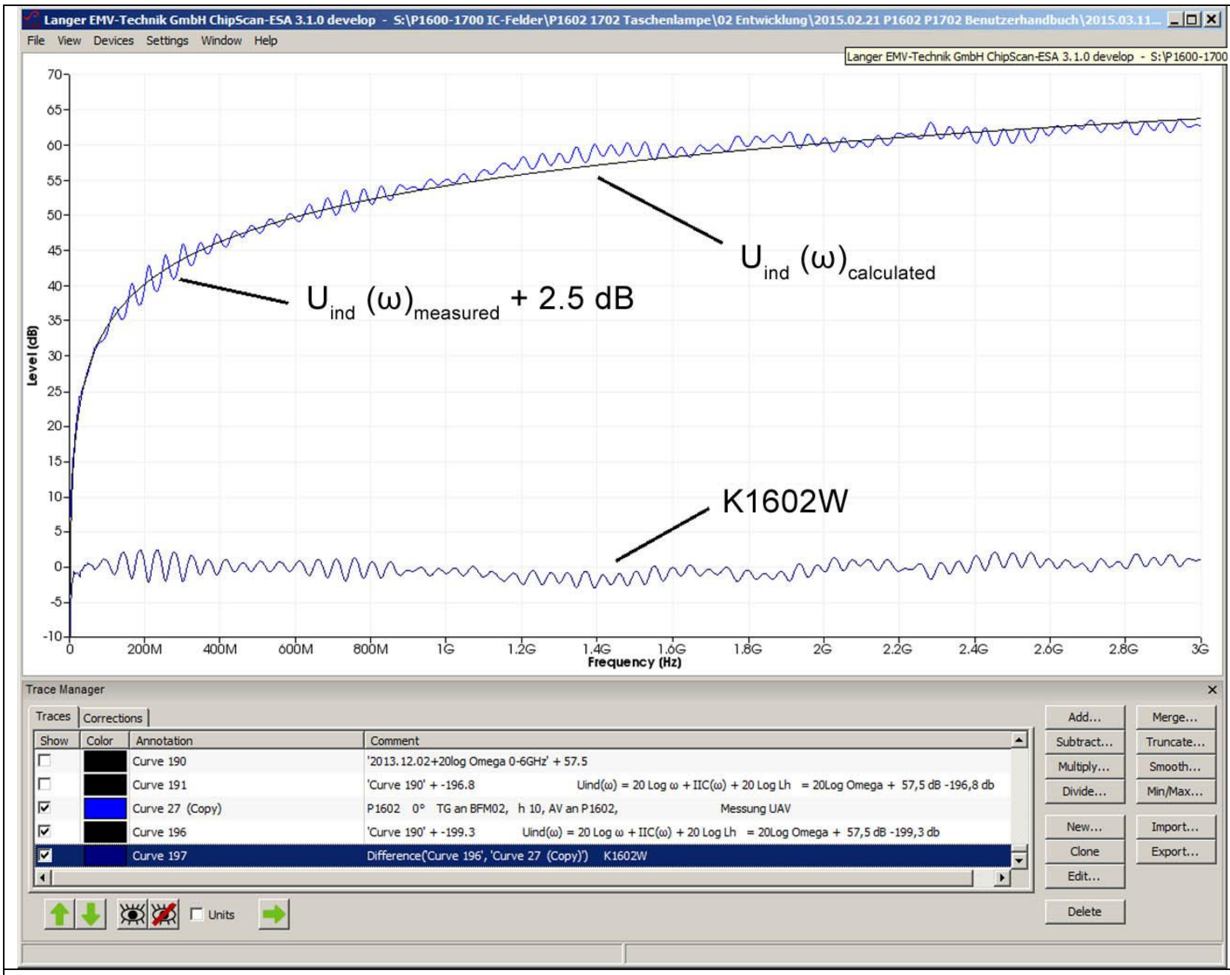
○ Subtract a Constant ☐ from each Plot

○ Subtract each Plot separately from a Constant ☐

○ Curve 27 (Copy) - Curve 196

● Curve 196 - Curve 27 (Copy)

Figure 48 Calculating the correction factor K1602 from $U_{ind}(\omega)_{measured}$ (Curve 196) and U_{AV} (Curve 27) with the mathematical operation "Subtract Plots".

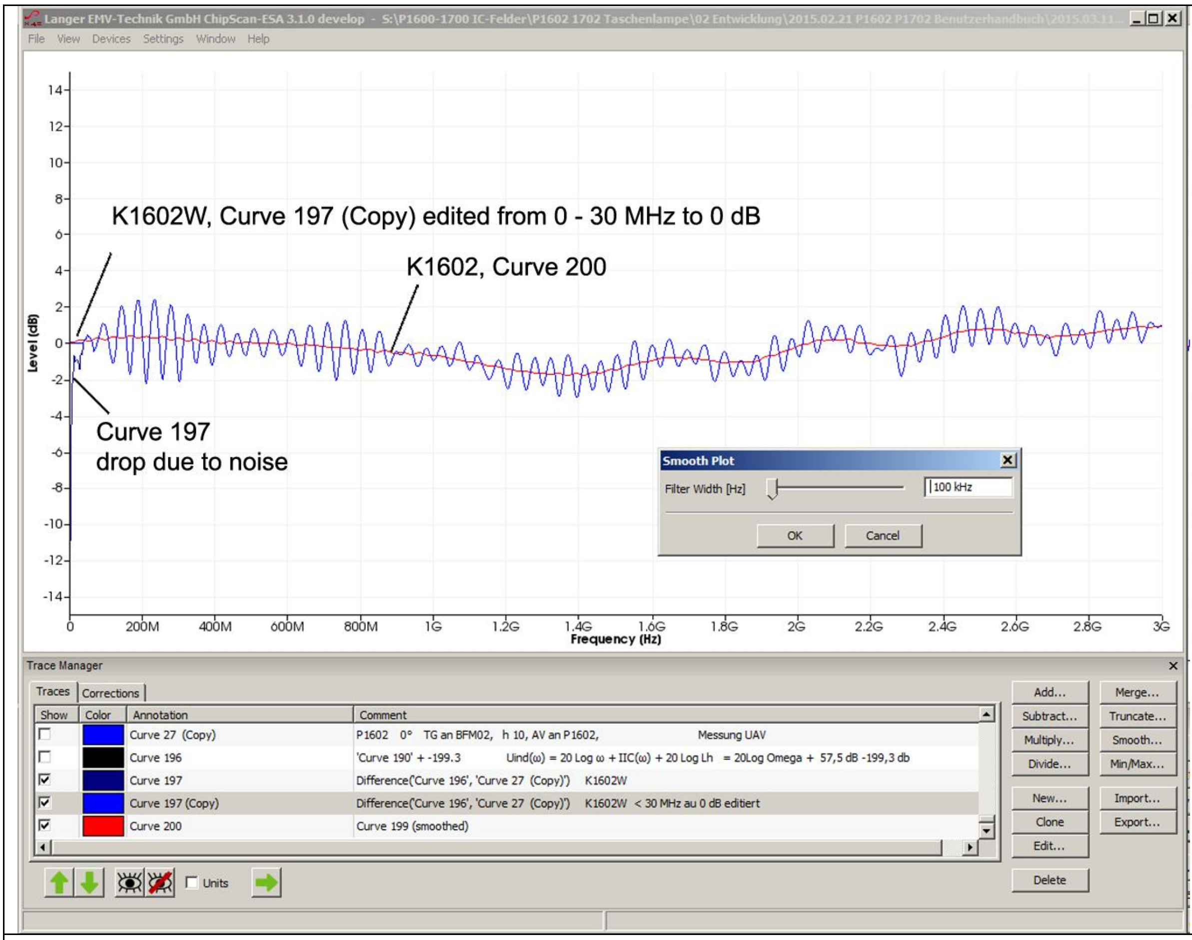


Show	Color	Annotation	Comment
☐	■	Curve 190	'2013.12.02+20log Omega 0-6GHz' + 57.5
☐	■	Curve 191	'Curve 190' + -196.8 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -196,8 db
☑	■	Curve 27 (Copy)	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
☑	■	Curve 196	'Curve 190' + -199.3 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -199,3 db
☑	■	Curve 197	Difference('Curve 196', 'Curve 27 (Copy)') K1602W

☐ Units

Figure 49 The result of the subtraction is the correction factor K1602W with ripples.

The ripples (standing waves) on the correction curve have to be eliminated before this can be applied in general use. The mathematical function "Smooth…" **Figure 50** is used for this operation. The resulting correction curve K1602 is available for general use(**Figure 51)**.



Smooth Plot

Filter Width [Hz] 100 kHz

Show	Color	Annotation	Comment
☐	🟦	Curve 27 (Copy)	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
☐	⬛	Curve 196	'Curve 190' + -199.3 Uind(ω) = 20 Log ω + IIC(ω) + 20 Log Lh = 20Log Omega + 57,5 dB -199,3 db
☑	🟦	Curve 197	Difference('Curve 196', 'Curve 27 (Copy)') K1602W
☑	🟦	Curve 197 (Copy)	Difference('Curve 196', 'Curve 27 (Copy)') K1602W < 30 MHz au 0 dB editiert
☑	🟥	Curve 200	Curve 199 (smoothed)

Figure 50 Smoothing the measured curve K1602 with the "Smooth..." function.

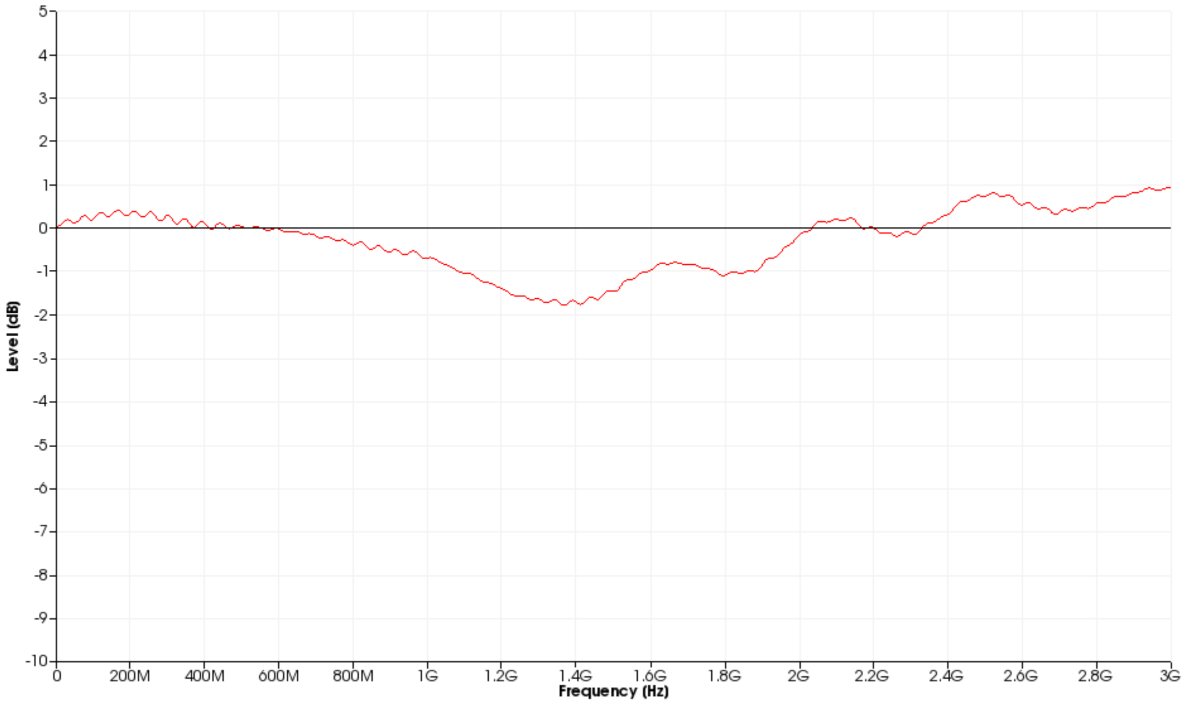


Figure 51 The correction factor K1602 is the result of smoothing with a bandwidth of 100 MHz.

The accuracy of the correction curve K1602 does not exceed the measurement accuracy of the spectrum analyser used for this purpose.

The correction curve is created analogously for the ***P1601*** field probe. The frequency response of the ***P1601*** field probe **Figure 54** reveals that the field probe can be used up to 1.5 GHz. **Figure 52** shows the correction curve up to 1 GHz.

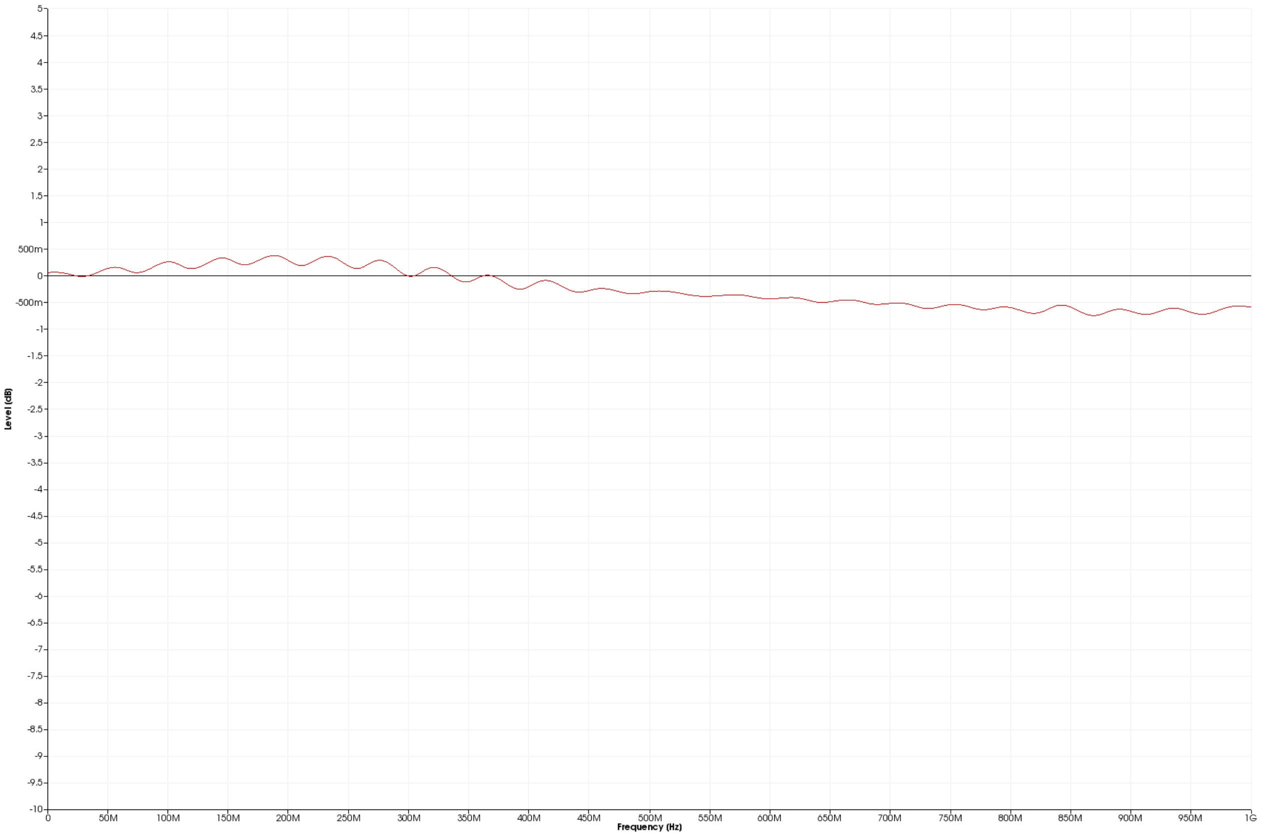


Figure 52 ***P1601*** correction curve up to 1 GHz.

3.3.6 Frequency response of the RF magnetic field probe

Figure 53 shows the frequency response of the ***P1602*** field probe. This was determined by inverting the correction curve (multiplication by -1, mathematical operation "Multiply…").

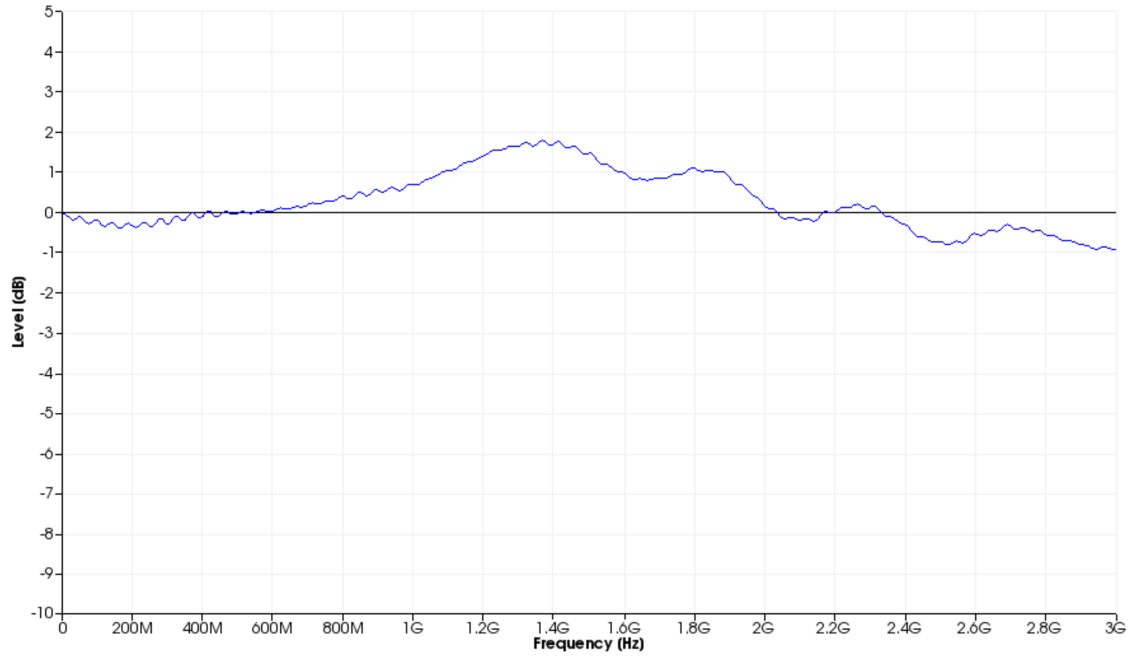


Figure 53 ***P1602*** frequency response up to 3 GHz.

Figure 54 shows the frequency response of the ***P1601*** field probe. It reveals that the probe can be used up to 1.5 GHz.

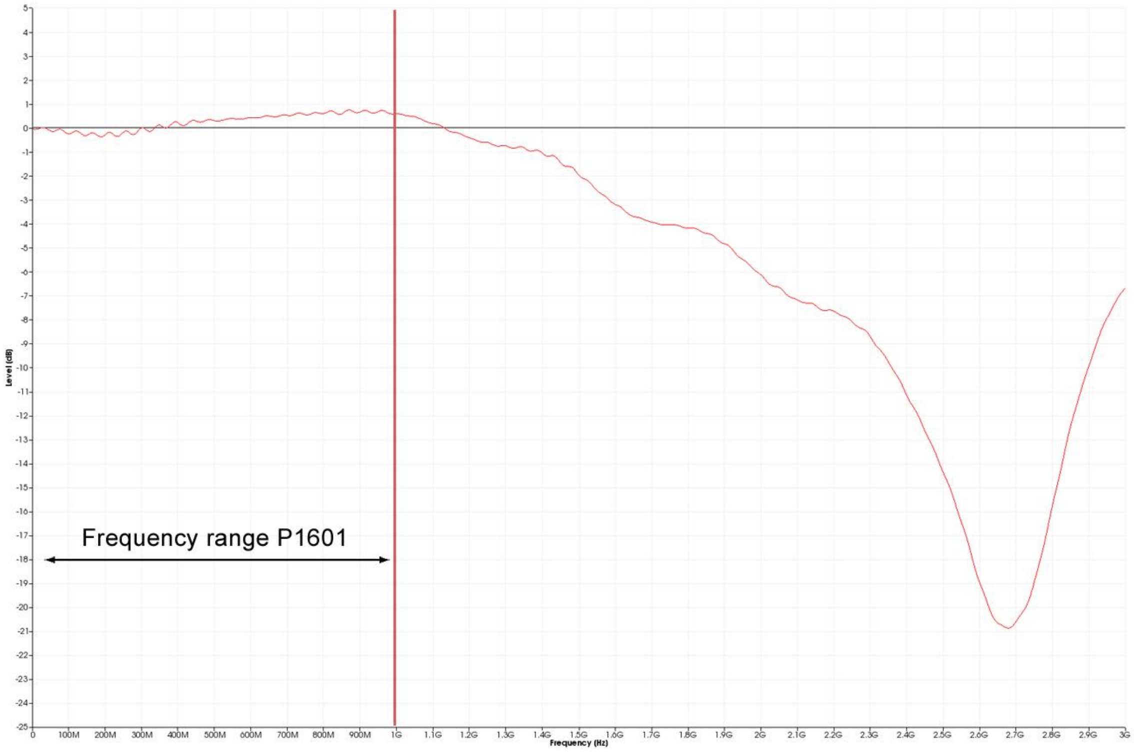


Figure 54 ***P1601*** frequency response up to 3 GHz.

3.3.7 E-field suppression of the P1600 RF magnetic field probe

ICs can emit electric interference fields E(ω). The fields generate a **capacitive interference current I_C(ω)** which enters the electric conductor of the P1600 field probe. The current I_C(ω) generates the fault voltage U_{AV}(ω) on the electric conductor. **Figure 55** shows the U_{AV}(ω) / I_C(ω) relationship used as a basis to determine how much current I_C(ω) [dBµA] the fault voltage U_{AV}(ω) [dBµV] generates.
$Q_{IC}(\omega) = + I_C(\omega) - 20 \text{ Log } \omega$, Eqn 25 can be used to convert the capacitive current into the charge Q(ω). This allows the representation of the E-field suppression with U_{AV}(ω) / Q_C(ω) (**Figure 56)**.

Figure 55 E-field suppression U_{AV}(ω) / I_C(ω). Voltage U_{AV}(ω) generated on the electric conductor by the capacitively coupled current I_C(ω).

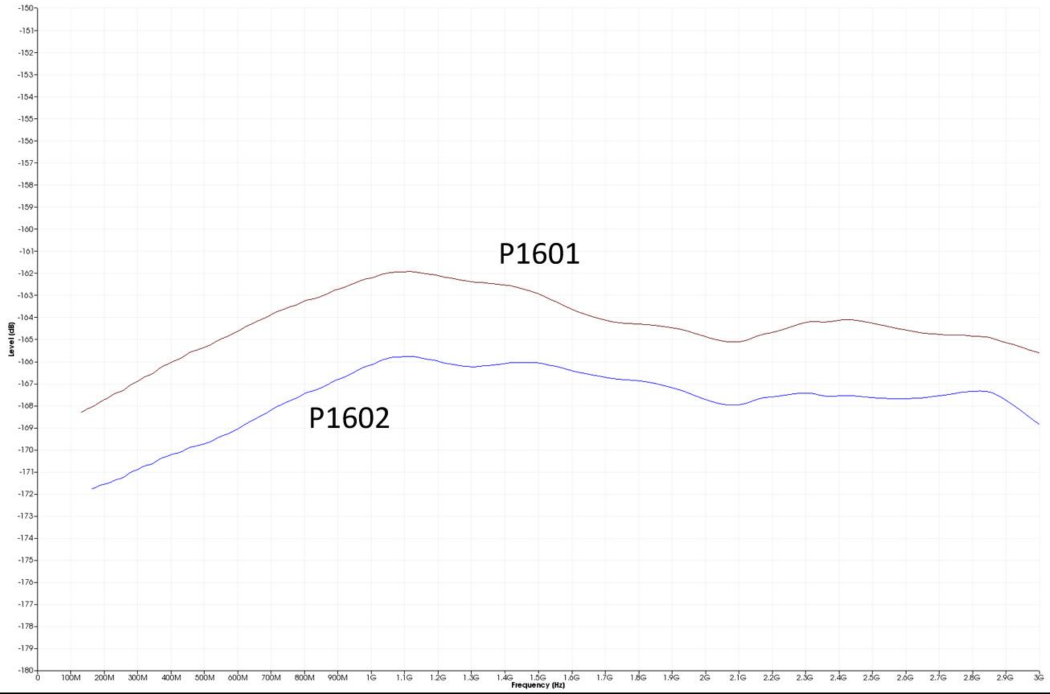


Figure 56 E-field suppression U_{AV}(ω) / Q_C(ω). Voltage U_{AV}(ω) generated on the electric conductor by the

capacitively coupled charge $Q_C(\omega)$.

4 E-field measurement with P1702

4.1 Design of the P1702 E-field probe

Figure 57 Design of the ***P1702*** E-field probe.

The field probe has an electrode (**Figure 57**) at its bottom to pick up the test IC's electric field.
The electric field enters the electrode at the bottom of the field probe **Figure 58** and couples the current $I_P(\omega)$ capacitively to the electrode. The current $I_P(\omega)$ is led to the N connector at the top of the field probe via a 50 Ohm RF line inside the field probe. The SMA-SMA 1m RF cable is connected there via an N/SMA adapter (**N-SMA**) and leads to the AV input of the spectrum analyser.

The electric field which is generated by the test IC is enclosed by the field chamber. The field chamber comprises the bottom of the field probe, the spacer ring, the ground adapter, the test board and the ***GND 25*** ground plane. The test IC is located in the field chamber. It is mounted on the test board (**Figure 9**). The test board is inserted into the ground adapter. The ground adapter fits into the respective recess of the ***GND 25*** groundplane.[6] A (100 x 100) mm TEM-cell print can be inserted instead of the ground adapter.[7]
The ***P1702*** field probe has no terminating resistor and operates under open-circuit conditions.

---

[6] ***GNDA 02*** ground adapter and ***GND 25*** ground plane are included in the ***ICE1 IC test environment set*** www.langer-emv.com. The test board is described in the ***IC test instructions manual***, mail@langer-emv.de.

[7] see Chapter **3**

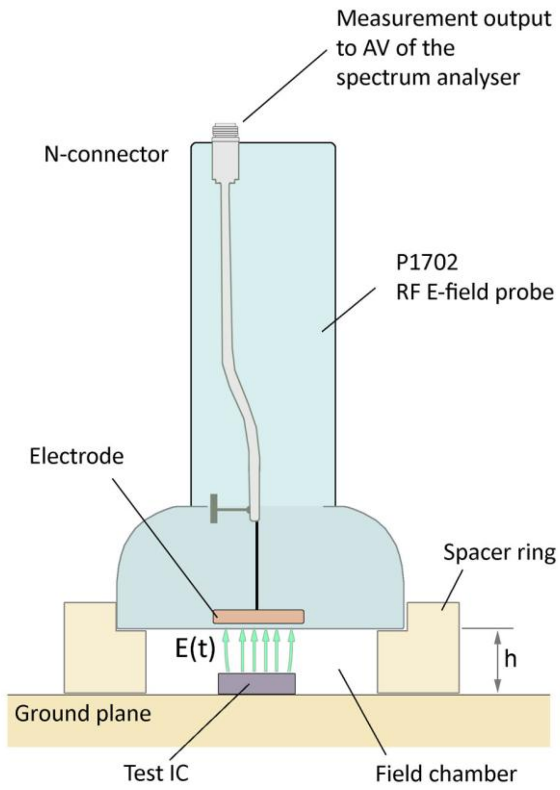


Figure 58 Sectional view of the ***P1702*** E-field probe.

The ***P1702*** field probe has a connection (**Figure 58**):

- 1 x N-connector (RF output) to connect a spectrum analyser

4.2 Function of the P1702 E-field probe

Periodic high-frequency switching operations occur within an IC depending on its functions. These switching operation generate RF voltages to ground in the IC's line networks. The conductors of the line network act like electrodes where the RF voltage generates electric fields (**Figure 59**). These line networks can also be connected to other metallic surfaces such as bonding pads, bonding wires and pins. The larger the surface, the greater the electric fields generated by the RF voltage. The majority of the electric field lines return to the IC's GND and have no excitation effect. The excitation field lines (**Figure 59**) leave the vicinity of the IC's and may generate interference emissions if they couple to neighbouring structural metal parts. The capacitively coupled current $I_P(\omega)$ excites these structural parts and stimulates them to send out emissions. The ***P1702*** field probe's task is to measure the strength of the excitation ($I_P(\omega)$) caused by the IC. The electrode of the ***P1702*** field probe (**Figure 58**) simulates a structural metal part at a distance h = 10 mm or 3 mm. The excitation current which is picked up by the electrode is led to a spectrum analyser via the measurement output (N-connector) of the field probe. The spectrum analyser measures the voltage $U_{AV}(\omega)$ that the excitation current $I_P(\omega)$ generates on the input resistor of the spectrum analyser (equivalent circuit diagram **Figure 60**).

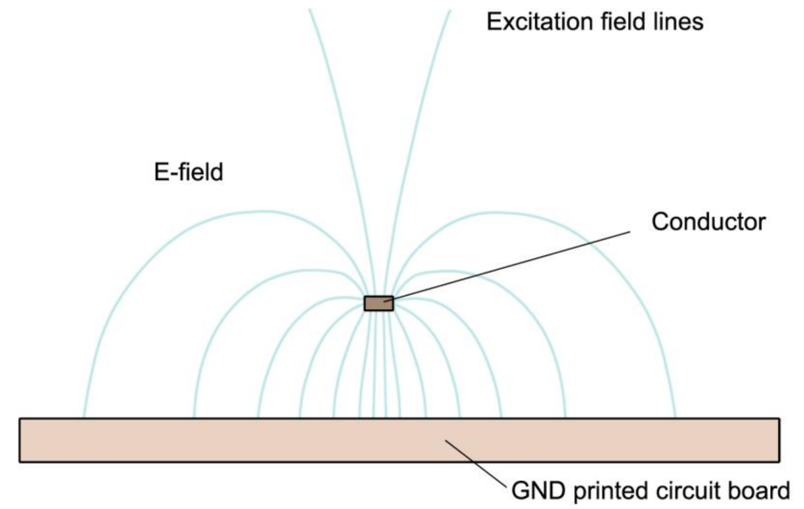


Figure 59 Principal field pattern of the electric field of a conductor in the test IC.

4.2.1 Equivalent circuit diagram and interactions of the electric field coupled out

Figure 60 shows the equivalent circuit diagram of the test set-up. The IC contains an RF voltage source $U_{IC}(\omega)$. This drives a pad via the impedance Z_{IC}. The pad represents the total area of all relevant continuous metal surfaces of the test IC. The pad has the capacitance C_3 to the IC's GND.

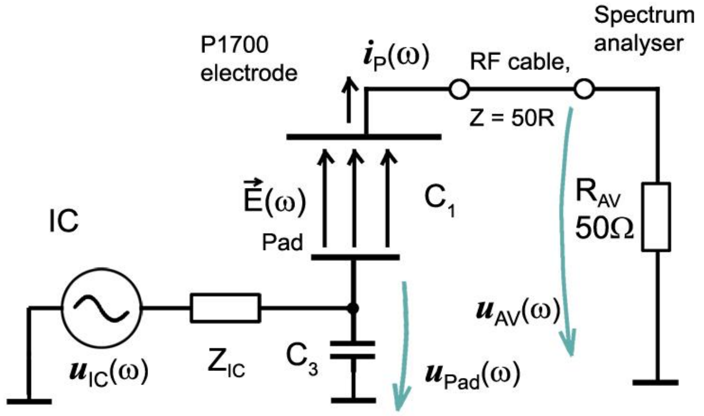


Figure 60 Equivalent circuit diagram with IC, excitation field lines, electrode of the ***P1702*** field probe, RF cable and spectrum analyser.

The capacitance C_1 is the capacitance between the pad (relevant continuous metal surface) of the IC and the electrode of the ***P1702*** field probe. The capacitance C_1 is a plate capacitor (**Figure 61**). The plate capacitor comprises the pad surface A_{Pad} (lower plate) and the electrode of the field probe (upper plate). The capacitance C_1 is in the fF (Femtofarad) range and usually does not stress the IC circuit. $U_{Pad}(\omega)$ drives the current $I_P(\omega)$ to GND via C_1, the RF cable and the resistor R_{AV} of the spectrum analyser (**Figure 60**). The current $I_P(\omega)$ essentially only depends on the capacitance C_1 since Z_{ic} and R_{AV} are significantly smaller than $1/(\omega\ C_1)$.

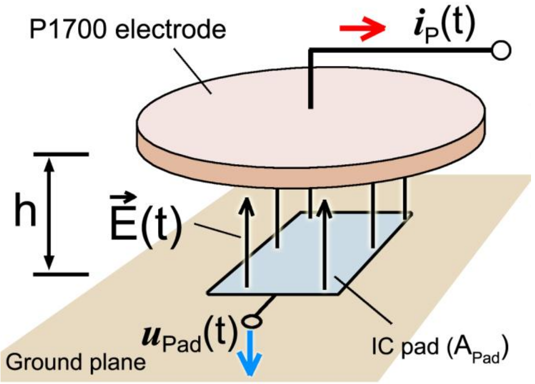


Figure 61 Operational principle behind E-field coupling from the test IC via excitation field lines.

The voltage $U_{Pad}(\omega)$ is then:

$U_{Pad}(\omega) = U_{IC}(\omega)$ Eqn 26

As a function of time, the current I_P follows the equation:

$i_P(t) = C_1\, du_{Pad}(t) / dt$ Eqn 27

If $i_P(t)$ is divided into harmonics, the following equation results for the frequency domain:

$I_P(\omega) = \omega\, C_1\, U_{IC}(\omega)$ Eqn 28

In a logarithmic form:

$20 \text{ Log } I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + 20 \text{ Log } U_{IC}(\omega)$ Eqn 29

In a reduced logarithmic form where 20 log is omitted in front of electric quantities:

$I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + U_{IC}(\omega)$ Eqn 30

C_1 is the coupling capacitance between the pad and the electrode of the ***P1702*** field probe. The coupling capacitance C_1 can be calculated from:

$C_1 = C_1' * A_{Pad}$ Eqn 31

Where C_1' is the coupling capacitance per unit length of the IC pad to the electrode of the field probe (**Figure 5**). A_{Pad} is the surface area of the pad. The capacitance per unit length C_1' is shown in **Table 4** for h 10 mm and 3 mm.

Example: a pad with a diameter of 2.1 mm has a surface area A_{pad} of 3.14 (2.1 mm²/2) = 3.5 mm². C_1' from **Table 4** is 0.88 fF/mm² (without the capacitance portion caused by the edge effect) at a spacer ring height of 10 mm. It follows from **Eqn 31**: C_1 = 0.88 fF / mm² * 3.5 mm² = 3.1 fF. The capacitance portion which develops at the edge of the plate capacitor is not taken into account in **Eqn 31.** Consequently, the actual capacitance may be twice as high. The actual capacitance, including a measurement error, is approximately:

C_1 = 10.6 fF Eqn 32

If the voltage $U_{IC}(\omega)$ is constant over frequency, $U_{IC}(\omega)$ = 107 dBµV, it follows according to **Eqn 26**:
20 Log C_1 = 20 Log 10.6 fF = -279.5 dBF, that the current $I_P(\omega)$ to the electrode of the ***P1702*** field probe according to **Eqn 30 is**:

$I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + U_{IC}(\omega)$ Eqn 33

$= 20 \text{ Log } \omega - 279.5 \text{ dBF} + 107 \text{ dB}\mu\text{V}$

$= 20 \text{ Log } \omega - 172.5 \text{ dB}\mu\text{A}$

The current $I_P(\omega)$ rises proportional to the frequency ω. If $U_{IC}(\omega)$ is constant over frequency in special cases, $I_P(\omega)$ rises linearly as a function of the frequency or logarithmically in the logarithmic form.

The interaction chain can be pursued in the equivalent circuit diagram **Figure 60**. The current $I_P(\omega)$ generates the voltage $U_{AV}(\omega)$ on the input resistor R_{AV} of the spectrum analyser.

$U_{AV}(\omega) = R_{AV} * I_P(\omega)$ Eqn 34

The spectrum analyser records the voltage $U_{AV}(\omega)$.

4.2.2 Converting the measurement value U_{AV} of the spectrum analyser into EMC parameters

The voltage $U_{AV}(\omega)$ is generated on R_{AV} of the spectrum analyser (**Figure 60**). It is measured and displayed by the spectrum analyser.
$I_P(\omega)$ can be calculated from $U_{AV}(\omega)$ with **Eqn 35** (effective values).

$I_P(\omega) = U_{AV}(\omega) / R_{AV}$ Eqn 35

R_{AV} is the input resistor (50 Ohm) of the spectrum analyser. The logarithm can be taken of **Eqn 35** to provide a logarithmic form:

$20 \text{ Log}(I_P(\omega)) = 20 \text{ Log}(U_{AV}(\omega)) - 20 \text{ Log } R_{AV}$ Eqn 36

Where:

$20 \text{ Log } R_{AV} = 20 \text{ Log } 50 \text{ Ohm} = 34 \text{ dB}\Omega$ Eqn 37

Inserted in **Eqn 36**:

$20 \text{ Log}(I_P(\omega)) = 20 \text{ Log}(U_{AV}(\omega)) - 34 \text{ dB}\Omega$ Eqn 38

This notation will be simplified in the following by omitting 20 Log in front of the electric quantities:

$I_P(\omega) = U_{AV}(\omega) - 34 \text{ dB}\Omega$ Eqn 39

Figure 62 shows the voltage U_{AV} which was measured with the spectrum analyser and the current $I_P(\omega) = U_{AV}(\omega) - 34 \text{ dB}\Omega$ which was calculated from **Eqn 39.**

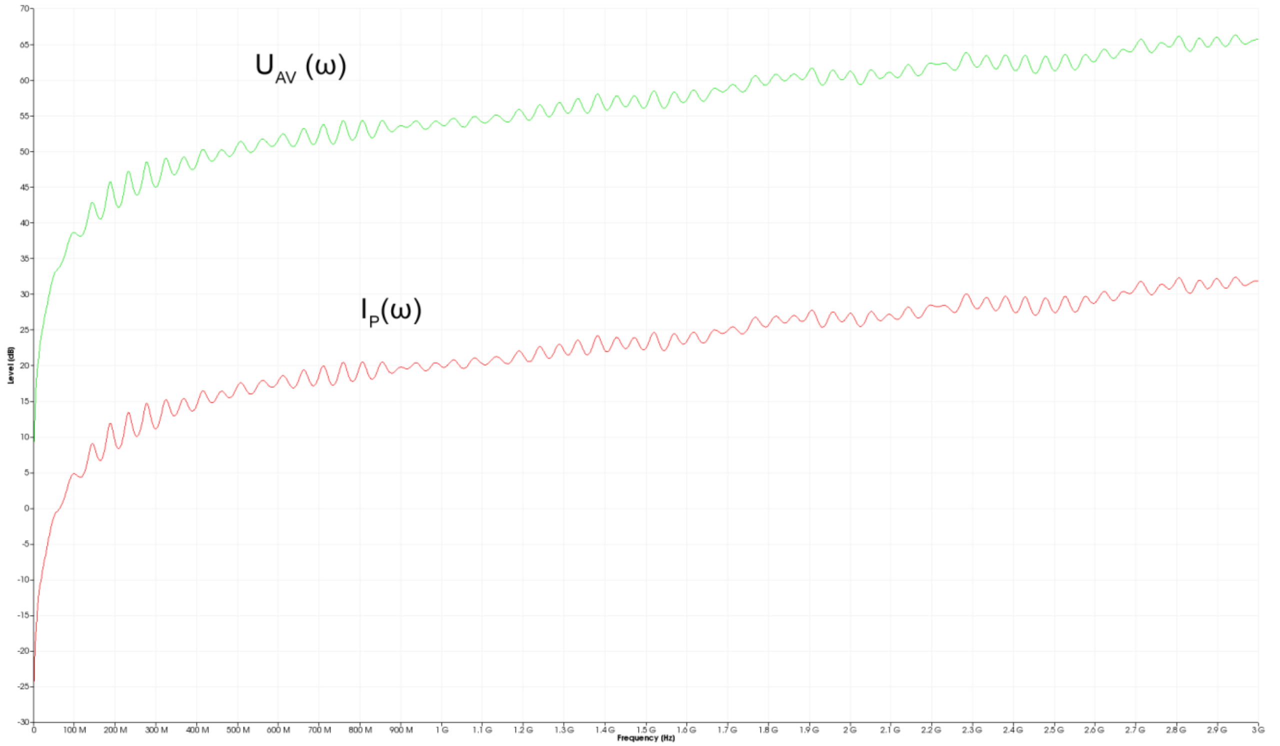


Figure 62 $U_{AV}(\omega)$ measured with the spectrum analyser at $U_{Pad}(\omega)$ 107 dBµV, C_1 10.6 fF; calculation of the current $I_P(\omega) = U_{AV}(\omega) - 34$ dBΩ with **Eqn 39.**

The equivalent circuit diagram in **Figure 60** shows that the driving voltage U_{Pad} and C_1 produce the current $I_P(t)$ or $I_P(\omega)$. It is hereby assumed that $R_{AV} << 1/(\omega\ C_1)$.
The variation of the current I_P with frequency follows **Eqn 28** $I_P(\omega) = \omega\ C_1\ U_{IC}(\omega)$.

In a logarithmic form **Eqn 30**: $I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + U_{IC}(\omega)$

$I_P(\omega)$ rises linearly as a function of the frequency ω **Eqn 28** or logarithmically in the logarithmic form **Eqn 30** (**Figure 63**).
The value of $I_P(\omega) = 20 \text{ Log } \omega - 172.5$ dBµA was calculated with **Eqn 33** above.

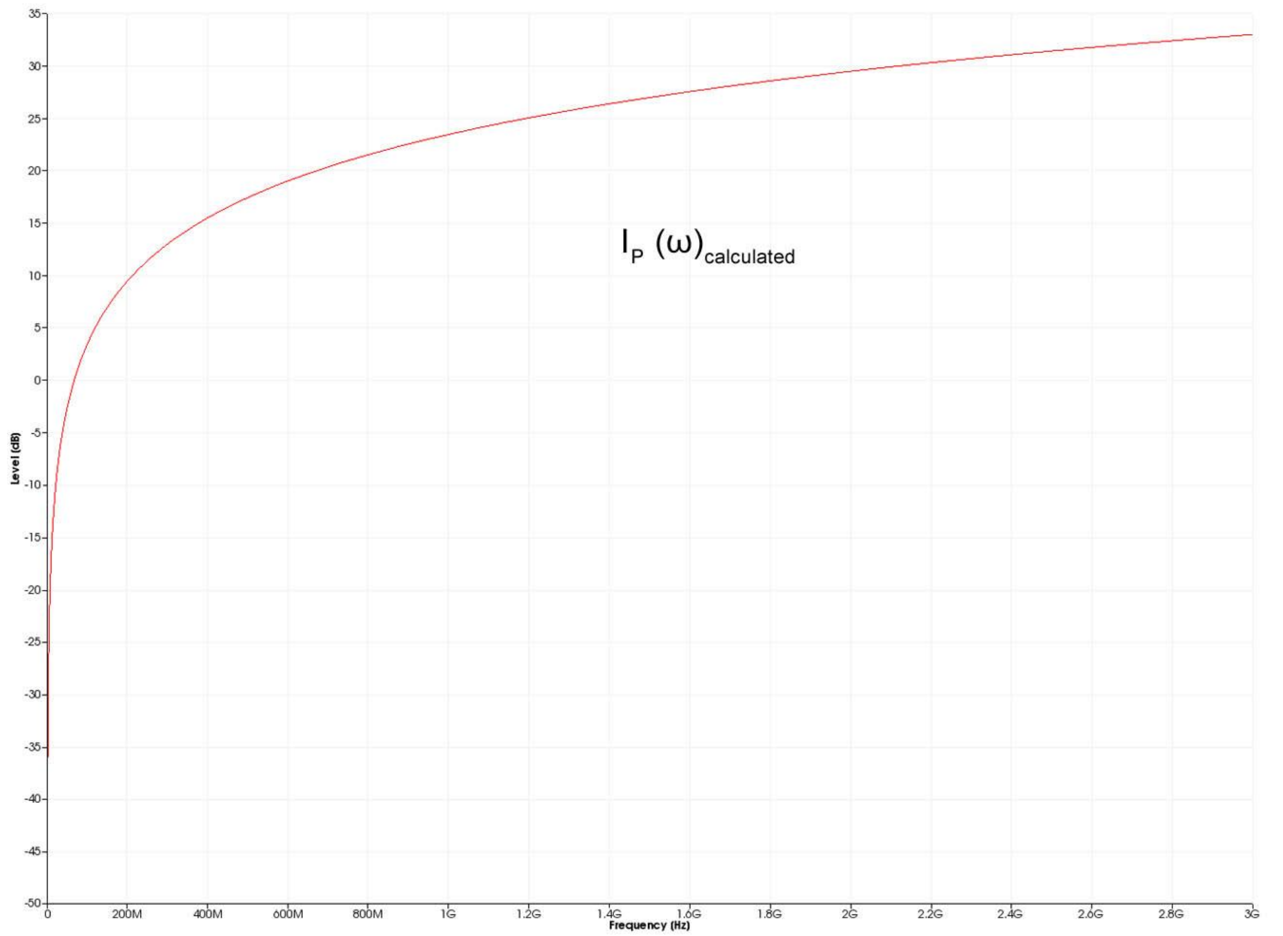


Figure 63 $I_P(\omega)$ calculated from **Eqn 33** with $U_{Pad}(\omega)$ = 107 dBµV constant and C1 = 10.6 fF.

4.2.3 Correction curves and matching of the P1702 probe

Figure 64 shows both the measured current variation **Figure 62** and the calculated current variation **Figure 63**. The measured variation is smaller than the calculated variation with a rising frequency. The measured curve shows standing waves. The standing waves (2 dB) depend on the length of the measuring cable (SMA-SMA 1 m) and on whether the ***P1702*** field probe and the spectrum analyser are matched or not.
The ***P1702*** field probe has no 50 Ohm terminating resistor in the measuring branch. The 50 Ohm line from the spectrum analyser is terminated with high impedance in the ***P1702*** field probe.
In this case the standing waves are essentially produced by the tracking generator which is part of the measurement set-up and which generates the excitation field together with the ***EPM 02*** that is used as an excitation field source.
Smoothing the curve (mathematical operation "Smooth…" in ***ChipScan-ESA***, BW 100 MHz) eliminates the standing waves from the measurement result. The remaining deviations are due to parasitic effects in the ***P1702*** field probe.

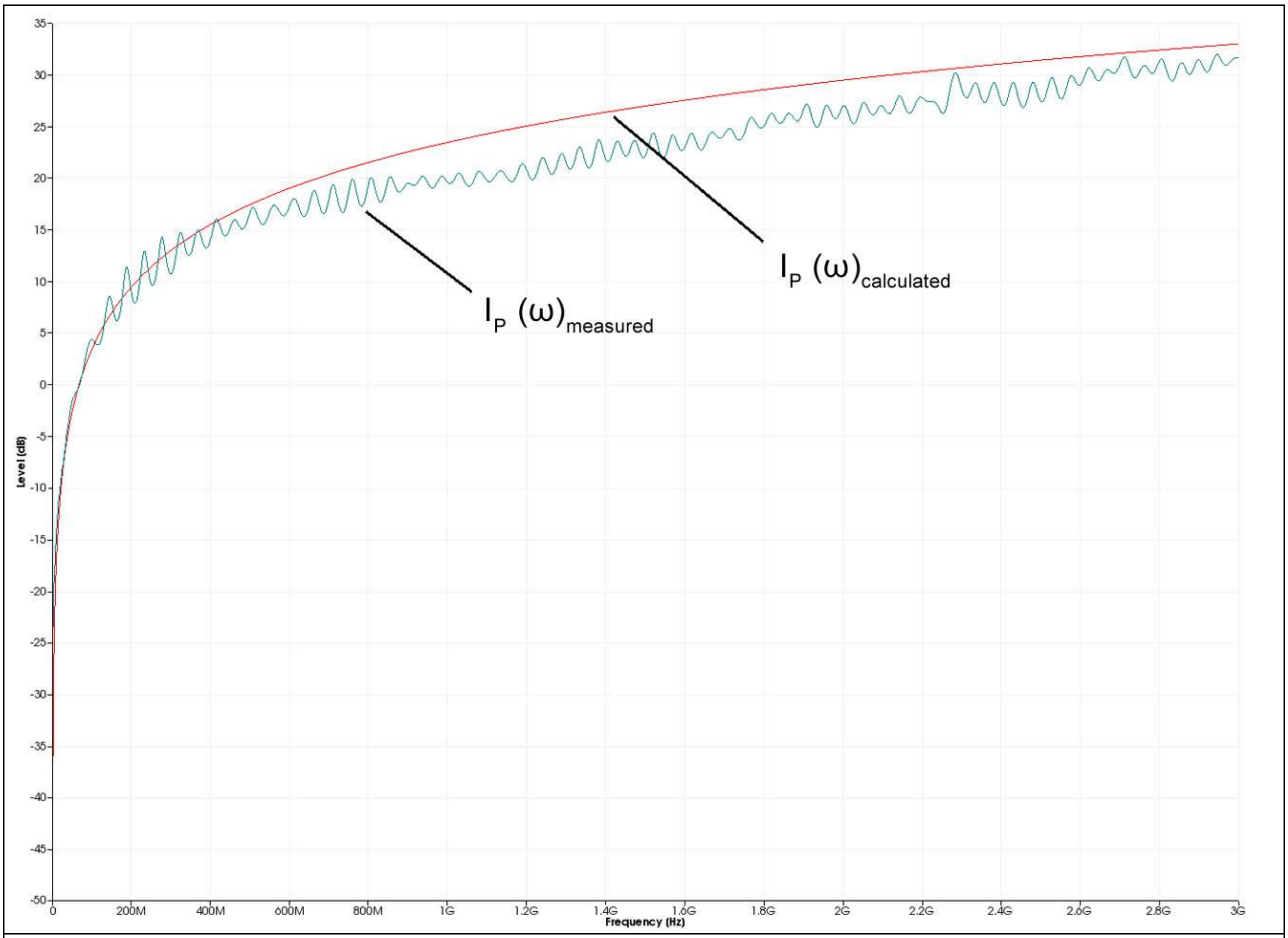


Figure 64 $I_P(\omega) = U_{AV}$ - 34 dBΩ measured with the spectrum analyser at $U_{Pad}(\omega)$ = 107 dBµV constant and C1 = 10.6 fF. The curve was measured with the ***ChipScan-ESA*** software.

The correction factor K1702 **Figure 65** of the ***P1702*** field probe is created on the basis of these deviations. The deviations are corrected by adding the correction factor (performed in the ***ChipScan-ESA*** Software). The correction factor can be created on the basis of the measured and smoothed curve. The correction factor K1702W includes standing waves. The correction factor is loaded to the ***ChipScan-ESA*** software to perform the correction and applied to the measurement result (example **Figure 66**) automatically.

The correction factor K1702W is tailored to the measurement set-up **Figure 74** and also takes the dependency on the tracking generator and excitation field source into account. It should only be used for this measurement set-up. The correction factor K1702 is used for general purposes.

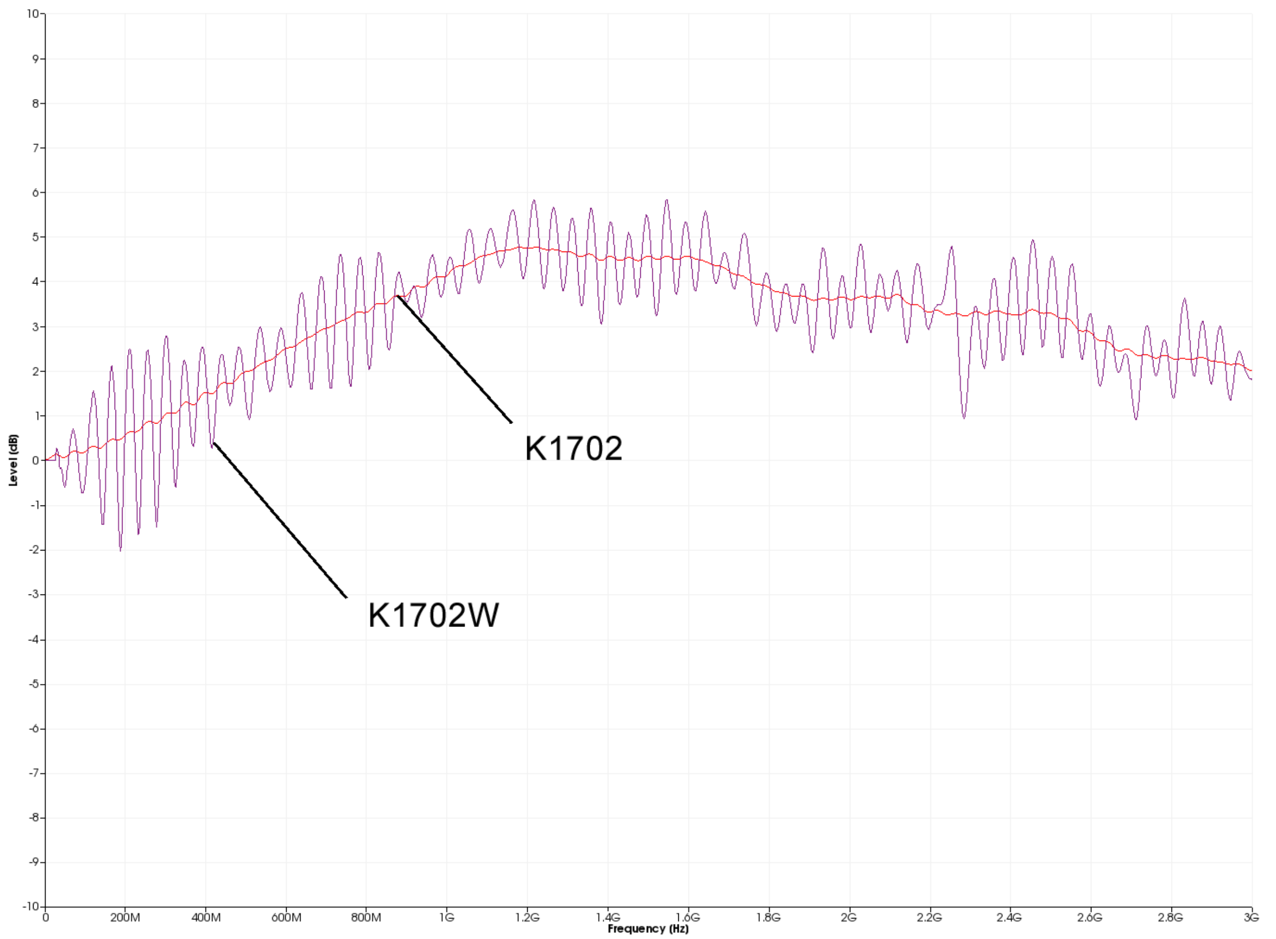


Figure 65 Correction curve K1702 of the ***P1702*** probe for general use. K1702W for special use with the measurement set-up **Figure 74.** The curve K1702 was measured and smoothed as K1702W (BW 300 MHz) with the ***ChipScan-ESA*** software.

4.2.4 Parameters to describe electric field excitation by ICs

4.2.4.1 $I_P(\omega)$ excitation current coupled out capacitively from the IC

The IC generates the excitation current $I_P(\omega)$ according to the equivalent circuit diagram **Figure 60** and **Eqn** 28 or **Eqn 30**:
$I_P(\omega) = \omega\ C_1\ U_{Pad}(\omega)$
$I_P(\omega) = 20\ \mathrm{Log}\ \omega + 20\ \mathrm{Log}\ C_1 + U_{IC}(\omega)$
The excitation current $i_P(t)$ or $I_P(\omega)$ is the physical quantity which stimulates emissions via the IC's electric field. The generation of the excitation current I_P which is capacitively coupled out is the mechanism of action behind the emissions. The capacitance C_1 in conjunction with the voltage $U_{Pad}(\omega)$ is responsible for coupling out. I_P also depends on ω. I_P rises linearly with ω. The higher the frequency ω, the greater the coupling out and the more excitation there is.

4.2.4.2 $Q_{IC}(\omega)$ charge coupled out capacitely (effective value)

$Q_{IC}(\omega)$ is the physical quantity which describes the excitation of radiated emissions proportional to the voltage $U_{Pad}(\omega)$.

$Q_{IC}(t) = C_1\, u_{Pad}(t)$ Eqn 40

$Q_{IC}(t) = \int i_P(t)\, dt$ Eqn 41

Eqn 41 leads to the frequency domain representation:

$Q_{IC}(\omega) = I_P(\omega) * 1 / \omega$ Eqn 42

In a reduced logarithmic form where 20 Log is omitted in front of the electrical quantities:

$Q_{IC}(\omega) = + I_P(\omega) - 20 \text{ Log } \omega$ Eqn 43

Figure 66 shows the measured current curve $I_P(\omega)_{measured}$. The correction factor K1701 was added to $I_P(\omega)_{measured}$ in the ***ChipScan-ESA*** software. This results in the corrected actual current curve of I_P. 20 Log ω was subtracted from the actual current curve with the ***ChipScan-ESA*** software to determine the effective value of the charge $Q_{IC}(\omega)$ (**Eqn 43**).

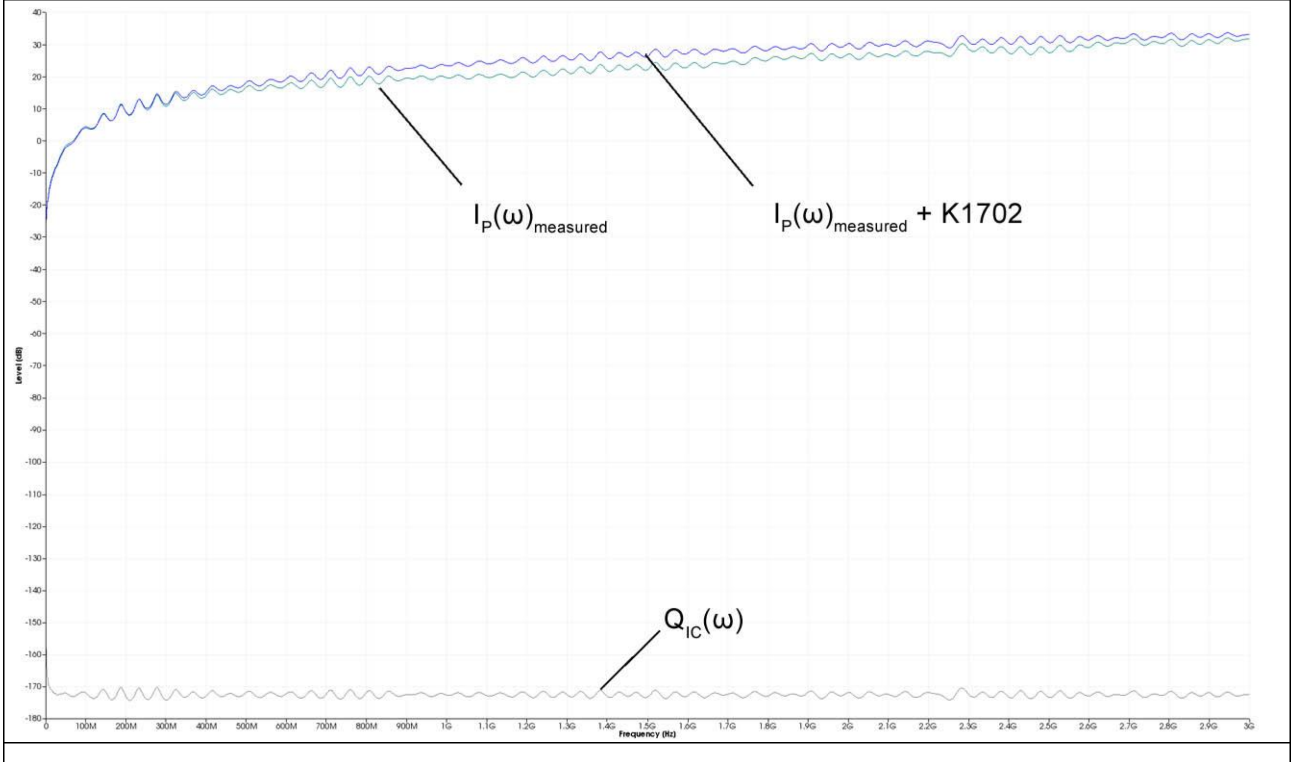


Figure 66 The measured $I_P(\omega)_{measured}$ was corrected $I_P(\omega)_{measured}$ + K1702 and converted into the charge $Q_{IC}(\omega) = + I_P(\omega)_{measured} + K1702 - 20 \text{ Log } \omega$ where $U_{Pad}(\omega) = 107$ dBµV constant and C1 = 10.6 fF.

$Q_{IC}(\omega)$ is the effective value of the charge oscillation emitted by the IC. The charge per half-wave is the mean value per half-wave. It can be established from the effective value or peak value:
mean value = 2/π * peak value = 2/ π * √2 * effective value.
The effective value of the charge $Q_{IC}(\omega)$ is constant over frequency as well as the voltage $U_{Pad}(\omega)$ (**Eqn 40**). Assuming $Q_{IC}(\omega)$, one obtains an EMC parameter for ICs which, unlike the current I_P, is independent of frequency.

4.3 Measurement with a spectrum analyser

4.3.1 Measurement set-up and measurement with the ChipScan-ESA software

Figure 67 shows the measurement set-up to measure the electric coupling of the test IC. The test IC is mounted on the test circuit board. The test board is inserted into the ground adapter such as ***GNDA 02***. The signal and supply connections to the test IC are provided via a plug connector on the test board.
The ***P1702*** field probe has to be arranged above the centre of the test IC with a spacer ring. The AV input of the spectrum analyser is connected to the N-connector output of the ***P1702*** probes via the **N-SMA** adapter and the SMA-SMA 1m RF cable.
The ***ChipScan-ESA*** software allows an easy measurement of the spectra (see also: ***ChipScan-ESA*** operating instructions).

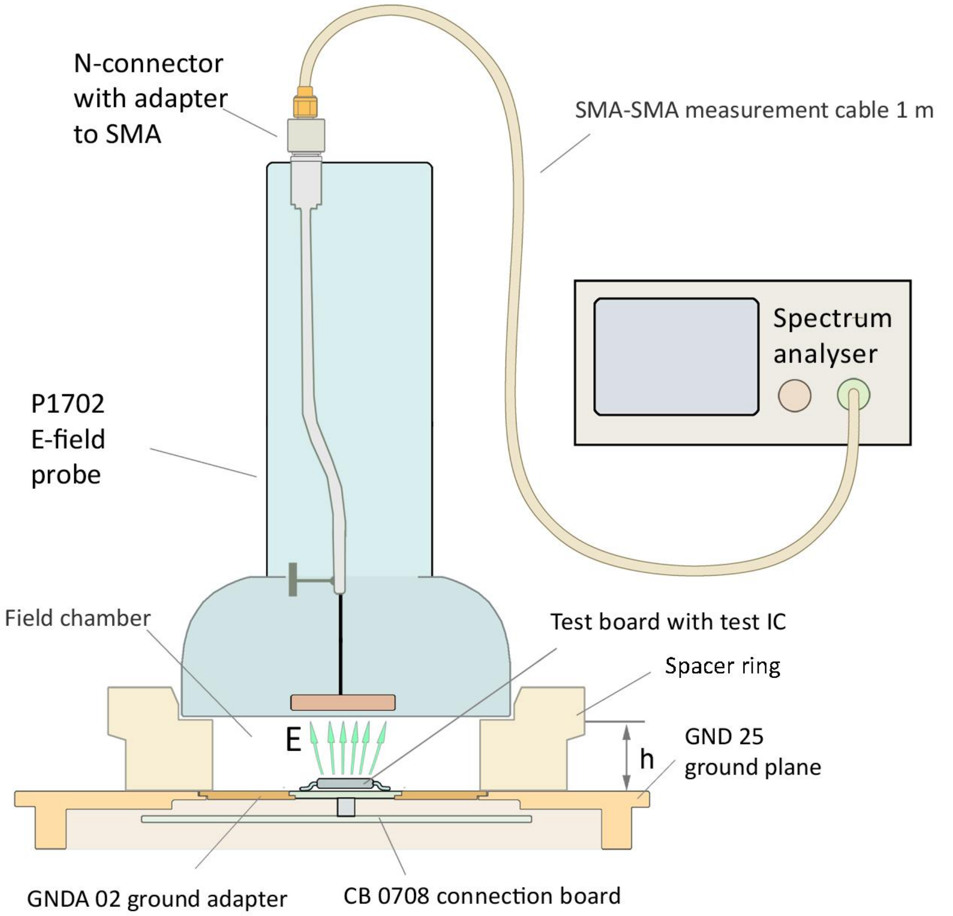
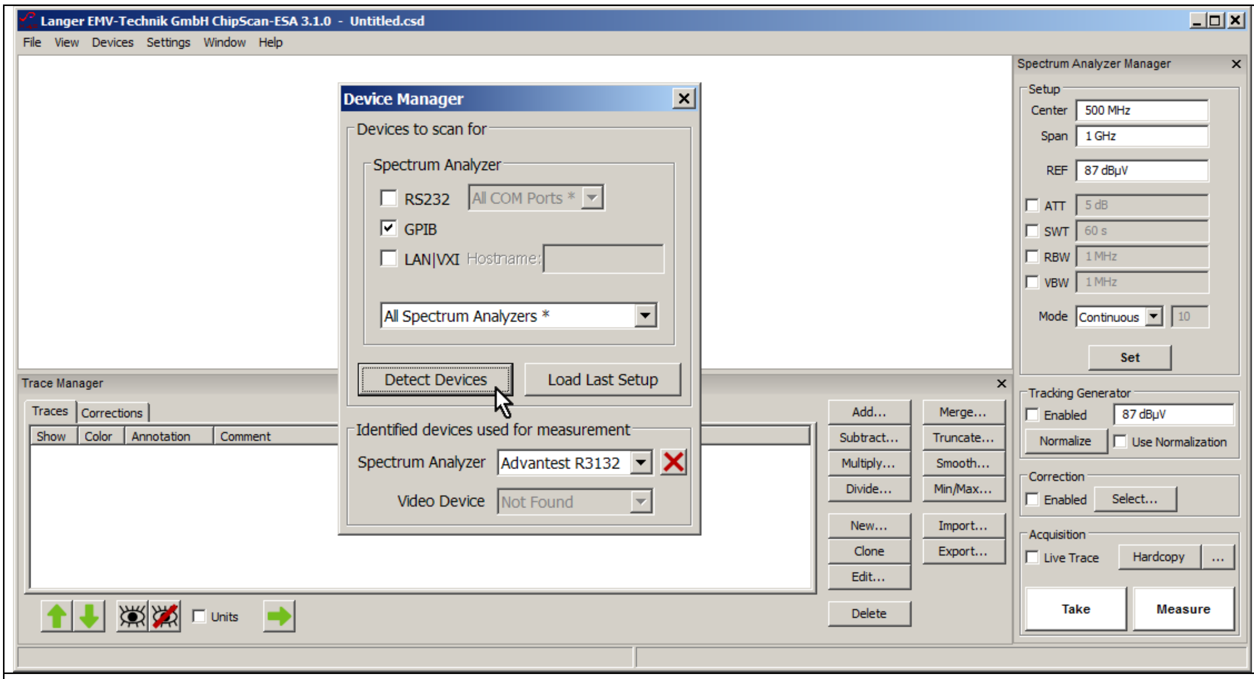


Figure 67 Measuring the excitation current I_P of the electric field E of the IC with the ***P1702*** field probe and a spectrum analyser.

The spectrum analyser is sought automatically with "Devices/ Devices Manager/ Detected Devices" via the respective interface and connected to the PC (**Figure 68**).



Devices to scan for
Spectrum Analyzer
☐ RS232 All COM Ports *
☑ GPIB
☐ LAN|VXI Hostname:
All Spectrum Analyzers *

Identified devices used for measurement
Spectrum Analyzer: Advantest R3132
Video Device: Not Found

Setup
Center: 500 MHz
Span: 1 GHz
REF: 87 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 1 MHz
☐ VBW 1 MHz
Mode: Continuous 10

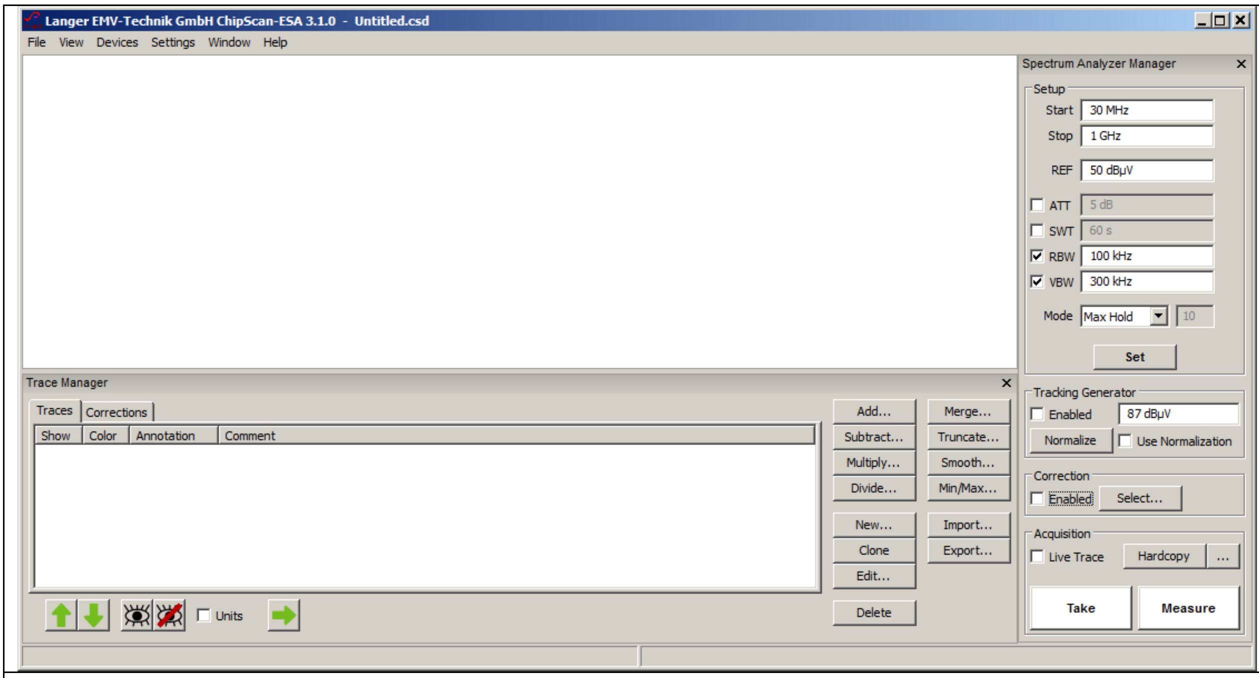
Tracking Generator
☐ Enabled 87 dBµV
☐ Use Normalization

Correction
☐ Enabled

Acquisition
☐ Live Trace

☐ Units

Figure 68 Connecting the spectrum analyser to the PC.



Setup
Start: 30 MHz
Stop: 1 GHz
REF: 50 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☑ RBW 100 kHz
☑ VBW 300 kHz
Mode: Max Hold 10

Tracking Generator
☐ Enabled 87 dBµV
☐ Use Normalization

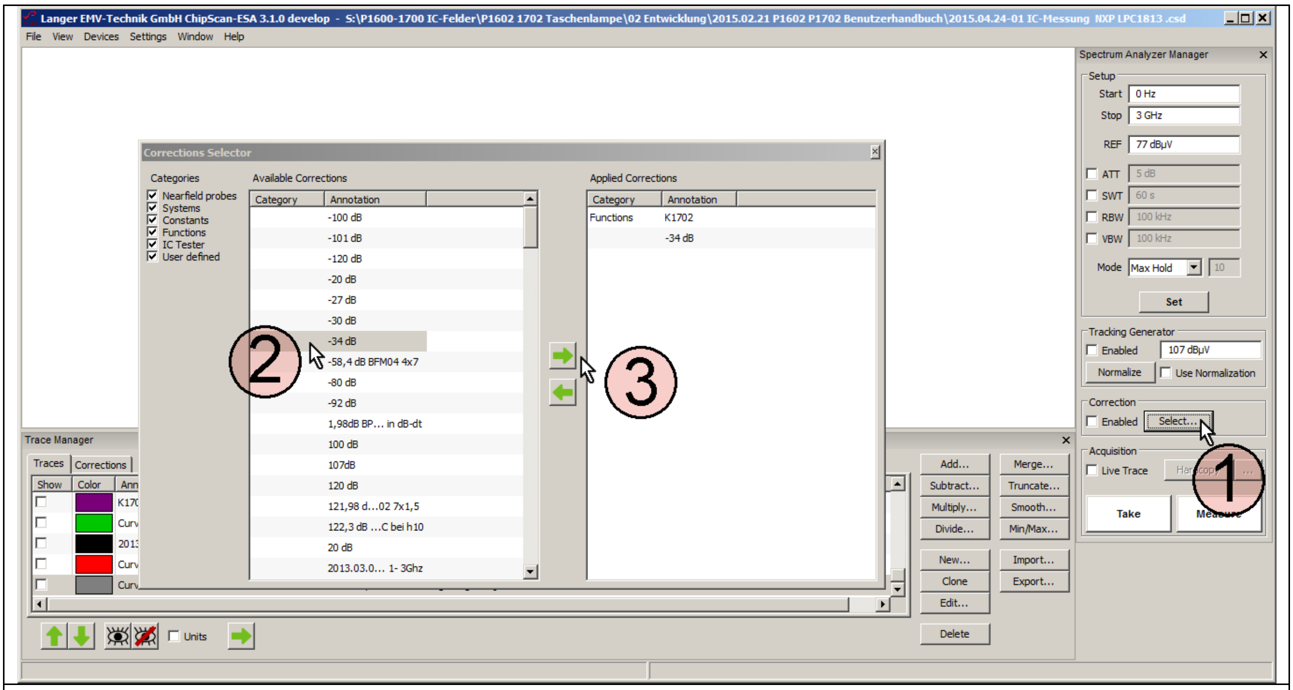
Correction
☐ Enabled

Acquisition
☐ Live Trace

☐ Units

Figure 69 Main settings of the spectrum analyser in the "Spectrum Analyser Manager".

The main settings of the spectrum analyser have to be defined in the "Spectrum Analyser Manager" (**Figure 69**). $U_{AV}(\omega)$ can be converted into $I_P(\omega)$ (**Eqn 39** $I_P(\omega) = U_{AV}(\omega) – 34\ dB\Omega$) under "Correction" in the "Spectrum Analyser Manager". The correction curve -34 dB has to be created according to **4.3.3.1** for this purpose. Select the correction curve under "Spectrum Analyser Manager", "Correction", "Select" in "Corrections Selector" (mouse cursor ① **Figure 70**).


Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.04.24-01 IC-Messung NXP LPC1813 .csd

Corrections Selector

Categories
☑ Nearfield probes
☑ Systems
☑ Constants
☑ Functions
☑ IC Tester
☑ User defined

Available Corrections

Category	Annotation
	-100 dB
	-101 dB
	-120 dB
	-20 dB
	-27 dB
	-30 dB
	-34 dB
	-58,4 dB BFM04 4x7
	-80 dB
	-92 dB
	1,98dB BP... in dB-dt
	100 dB
	107dB
	120 dB
	121,98 d...02 7x1,5
	122,3 dB ...C bei h10
	20 dB
	2013.03.0... 1- 3Ghz

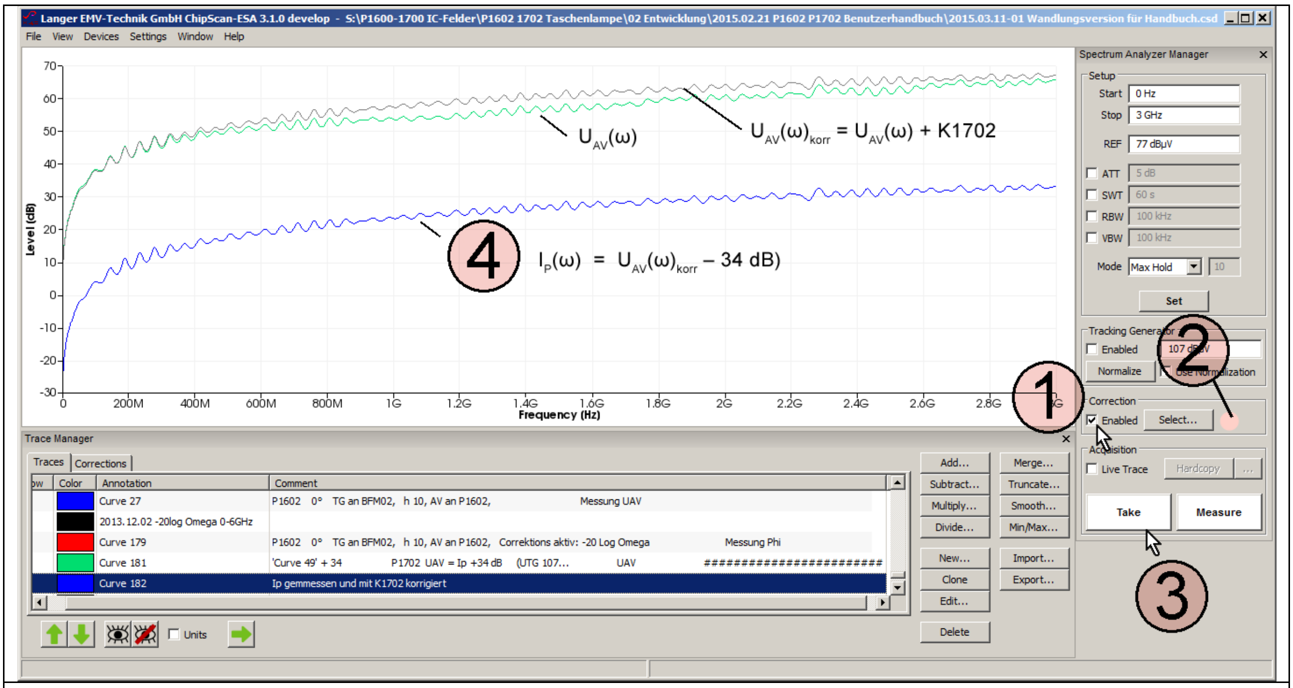
Applied Corrections

Category	Annotation
Functions	K1702
	-34 dB

Spectrum Analyzer Manager
Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Max Hold 10
Tracking Generator
☐ Enabled 107 dBµV
☐ Use Normalization
Correction
☐ Enabled
Acquisition
☐ Live Trace

Figure 70 Activating correction factors (-34 dB) and correction curves (K1702) with the "Corrections Selector".

The "Corrections Selector" window opens **Figure 70**. Activate the correction curve K1702 and the correction factor -34 dB with the mouse cursor ②. Click the "Arrow right" ③ button to move K1702 and -34 dB to the "Applied Corrections" list. Further correction curves such as cable correction curve can also be loaded and added to the list.


Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Color	Annotation	Comment
🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Messung UAV
⬛	2013.12.02 -20log Omega 0-6GHz	
🟥	Curve 179	P1602 0° TG an BFM02, h 10, AV an P1602, Correktions aktiv: -20 Log Omega Messung Phi
🟩	Curve 181	'Curve 49' + 34 P1702 UAV = Ip +34 dB (UTG 107... UAV ########################
🟦	Curve 182	Ip gemmessen und mit K1702 korrigiert

Spectrum Analyzer Manager
Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Max Hold 10
Tracking Generator
☐ Enabled 107 dBµV
☐ Use Normalization
Correction
☑ Enabled
Acquisition
☐ Live Trace

Figure 71 Measuring the excitation current $I_P(\omega)$ with the correction factor -34 dB and the correction curve K1702. Curve 182 $I_P(\omega)$ is the result of this measurement. The measurement was performed at the ***EPM 02*** excitation field source with a constant pad voltage $U_{Pad}(\omega)$ = 107 dBµV.

Activate the corrections by checking the "Enabled" box under "Correction" (mouse cursor ①). The field ② flashes when the correction is active.
Start the measurement with "Take" or "Measure" (mouse cursor ③). The measured curve appears on the display ④. Delete the check mark from the "Enabled" box if you only want to measure $U_{AV}(\omega)$. The field ② then stops flashing.
Follow the instructions in section **4.3.4** if you want to create a new correction curve.

4.3.2 Measuring the electric field on the IC

Figure 67 shows the measurement set-up. Section **4.3.1** describes how to operate the ***ChipScan-ESA*** software (setting the correction curves).

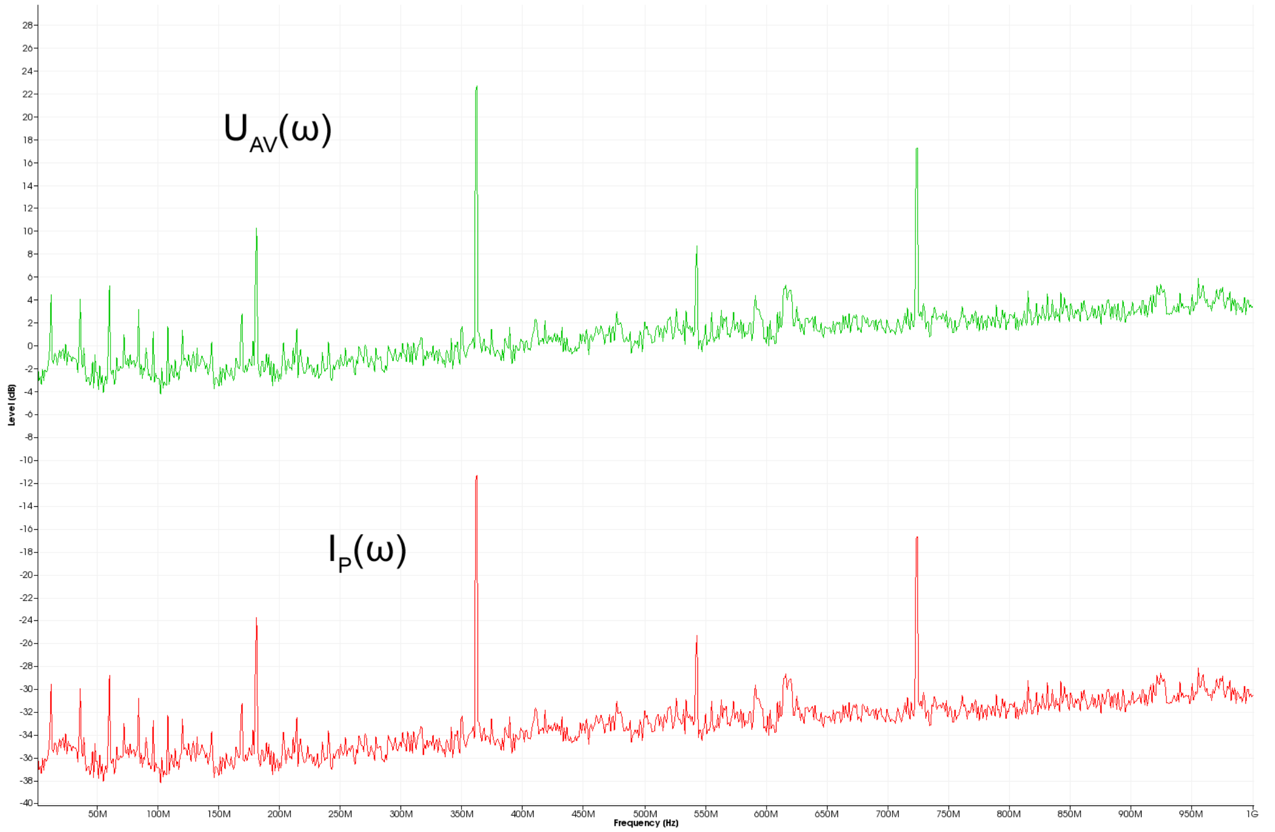


Figure 72 Measuring the voltage $U_{AV}(\omega)$ and the excitation current $I_P(\omega)$ (corrected with K1702) of the electric field E of a test IC with the ***P1702*** field probe and a spectrum analyser.

Figure 72 shows the results for the voltage $U_{AV}(\omega)$ and the excitation current $I_P(\omega)$ which was corrected with -34 dB and K1702.

4.3.3 Generating the excitation current I_P with the EPM 02 Ė-field meter as a test source

The ***EPM 02*** Ė-field meter (**Figure 73**) is used as an excitation field source to generate the excitation current I_P. It is operated in the opposite direction to generate an E-field, i.e. it is supplied with the voltage U_{TG} of a tracking generator via its SMB signal output. It thus generates the excitation current I_P or the electric field E at the measuring electrode in the same way as an IC. The measuring electrode of the ***EPM 02*** hereby replaces the pad surface area A_{Pad} of the IC. The measuring electrode of the ***EPM 02*** has a diameter of 2.1 mm.

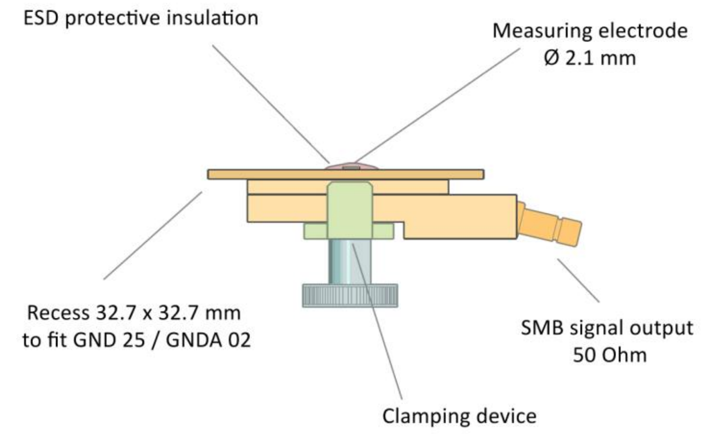


Figure 73 ***EPM 02*** Ė-field meter to generate the electric field E and the excitation current I_P.

Figure 74 shows the measurement set-up. The ***EPM 02*** Ė-field meter is inserted into the ground adapter instead of the test IC. The ***EPM 02*** Ė-field meter fits into the ***GNDA 02*** ground adapter and has to be inserted into the ***GND 25*** ground plane for the measurement.[8]

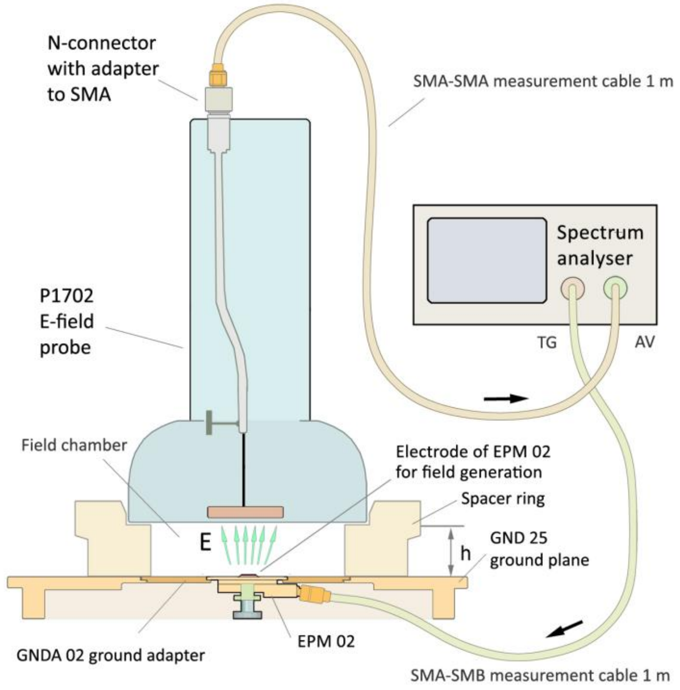


Figure 74 Measurement set-up with ***EPM 02***, ***P1702*** field probe and spectrum analyser.

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[8] ***GNDA 02*** ground adapter and ***GND 25*** ground plane are included in the ***ICE1 IC test environment set*** www.langer-emv.de. The test board is described in the ***IC test instructions manual***, mail@langer-emv.de.

The SMB port of the ***EPM 02*** Ė-field meter is connected to the tracking generator output of the spectrum analyser via the SMA-SMB measuring cable. The measurement output is matched to 50 Ohm.
The 50 Ohm resistor of the ***EPM 02*** and the output resistor of the tracking generator together form a divider where the internal generator voltage of the tracking generator 2 $U_{TG}(\omega)$ is split into two and is provided as U_{TG} at the electrode (**Figure 75**).
The tracking generator voltage U_{TG} is equal to the pad voltage $U_{Pad}(\omega)$ for ***EPM 02***:

$U_{TG}(\omega) = U_{Pad}(\omega)$ Eqn 44

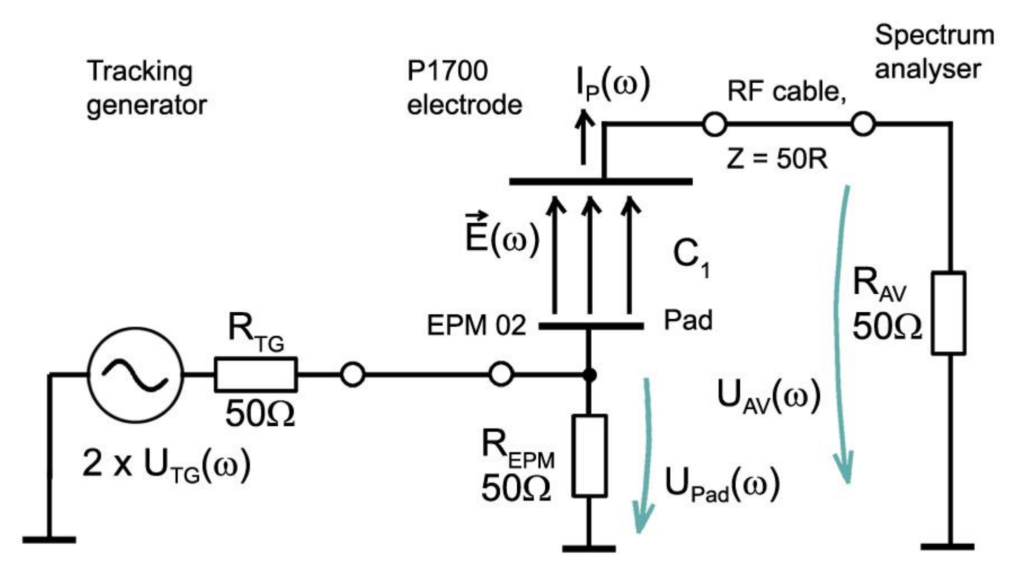
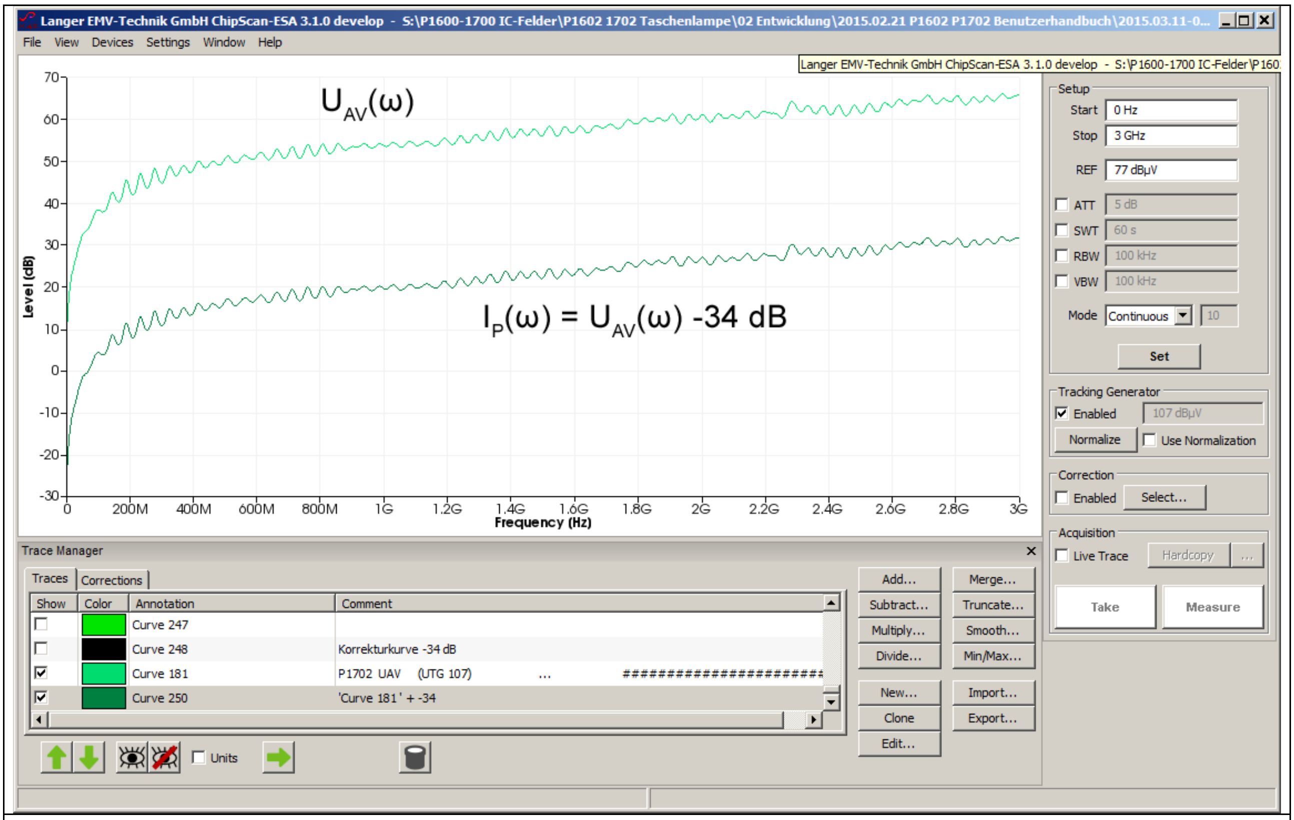


Figure 75 Equivalent circuit diagram of the electrode of the ***P1702*** field probe, tracking generator, ***EPM 02*** and spectrum analyser.

The electrode of the ***EPM 02*** generates the excitation current $I_P(\omega)$ according to the equivalent circuit diagram **Figure 75** and **Eqn 28** or **Eqn 30**:
$I_P(\omega) = \omega\ C_1\ U_{Pad}(\omega)$
$I_P(\omega) = 20\ \text{Log}\ \omega + 20\ \text{Log}\ C_1 + U_{Pad}(\omega)$

The ***P1702*** field probe is located above the ***GND 25*** ground plane. The distance to the ground plane is set with the spacer ring. The spacer ring h = 10 mm is preferred for the measurements. It provides a defined distance between the electrode of the ***P1702*** field probe and the ***EPM 02*** excitation field source.
The spectrum analyser which is used for measurement is wired as shown in **Figure 74**.
The spectrum analyser has to be normalized before the measurement (U_{TG} 107 dBµV, external attenuator 30 dB).
The ***EPM 02*** is supplied with 107 dBµV by the tracking generator of the spectrum analyser. The voltage $U_{AV}(\omega)$ **Figure 62** which is generated on the input resistor R_{AV} of the spectrum analyser (set-up **Figure 74**, equivalent circuit diagram **Figure 75**) is obtained as the result of this measurement. The frequency response of the ***EPM 02*** excitation field source can be taken into account by means of the correction curve KEPM 02R.

The ***ChipScan-ESA*** software is used to control the spektrum analyser, perform the calculations and document the measurements **Figure 76**.



Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Continuous 10
☑ Enabled 107 dBµV
☐ Use Normalization
☐ Enabled
☐ Live Trace

Show	Color	Annotation	Comment
☐	🟩	Curve 247	
☐	■	Curve 248	Korrekturkurve -34 dB
☑	🟩	Curve 181	P1702 UAV (UTG 107) ... #######################
☑	🟩	Curve 250	'Curve 181' + -34

☐ Units

Figure 76 User interface of the ***ChipScan-ESA*** software; measuring the voltage U_{AV} and the excitation current $I_P(\omega)$ which generate the excitation field of the ***EPM 02*** E-field meter in the ***P1702*** field probe. The excitation voltage $U_{Pad}(\omega)$ = 107 dBµV was generated by a tracking generator.

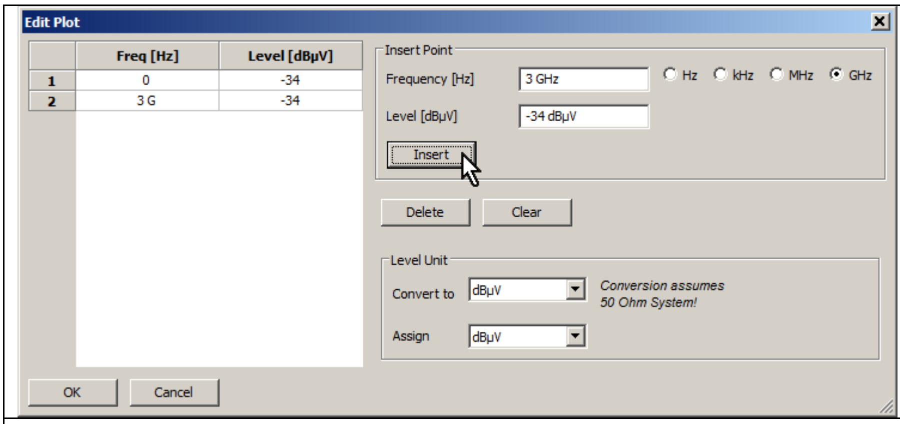
$U_{AV}(\omega)$ can be converted into the excitation current $I_P(\omega)$ with **Eqn 39** $I_P(\omega) = U_{AV}(\omega) - 34$ dBΩ **Figure 76**. There are two ways to do this:

1. By using the correction factor -34 dB during the measurement
2. By using the mathematical operation -34 dB after the measurement

The ***ChipScan-ESA*** software is used to perform the conversion. Begin by creating the correction factor -34 dB.

4.3.3.1 Creating a constant correction factor, taking -34 dB as an example

Begin by creating the correction factor -34 dB. Go to the mathematical menu on the right side of the "Trace Manager" **Figure 76**. Open the "Edit Plot" editor via the "New..." button to create the correction curve -34 dB **Figure 77**.



	Freq [Hz]	Level [dBµV]
1	0	-34
2	3 G	-34

Frequency [Hz] 3 GHz ○ Hz ○ kHz ○ MHz ● GHz

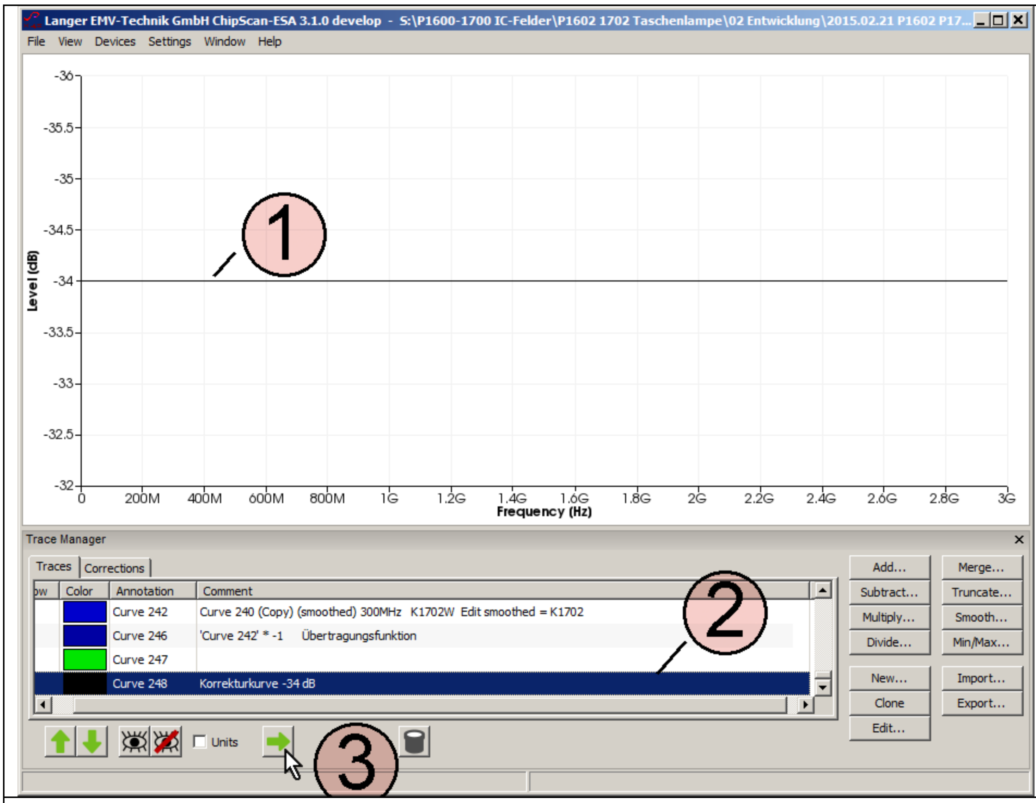
Level [dBµV] -34 dBµV

Convert to dBµV

Assign dBµV

Conversion assumes 50 Ohm System!

Figure 77 Editor to create a curve (plot).



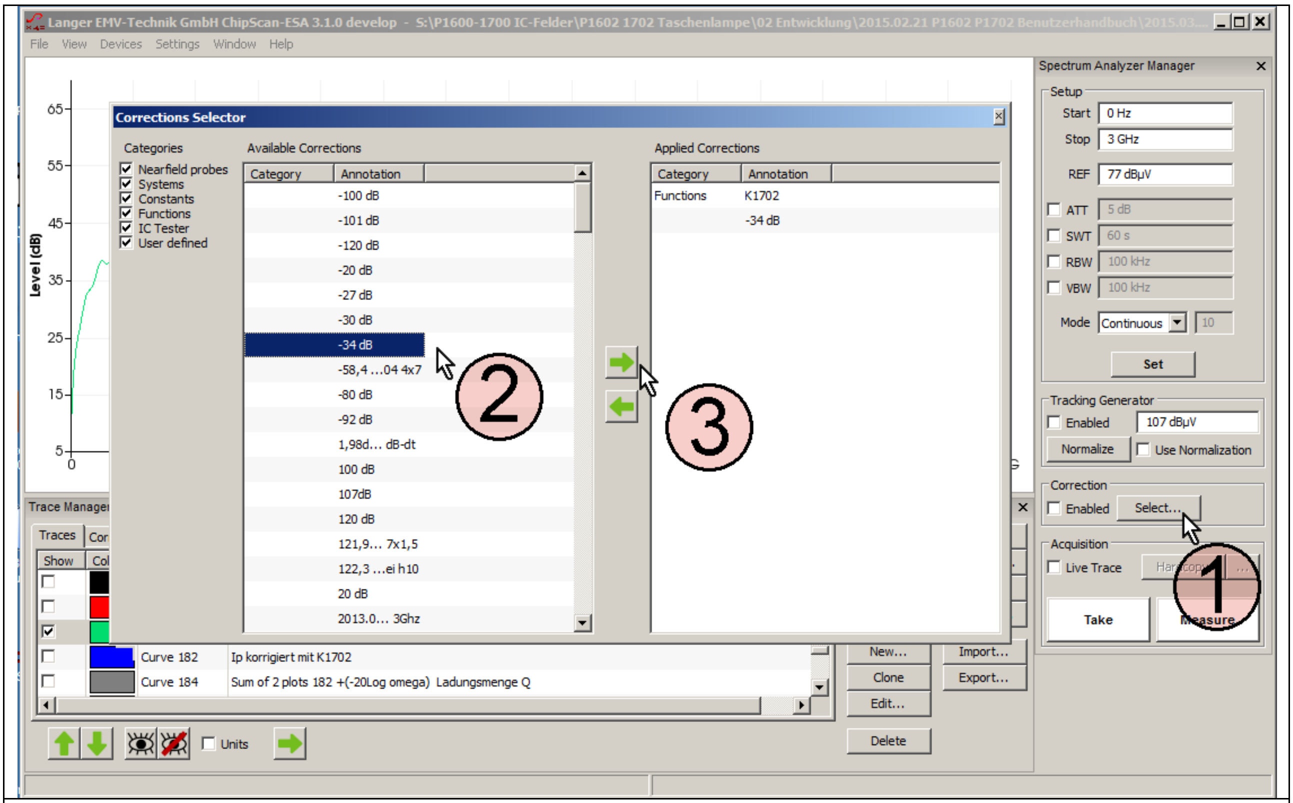
Color	Annotation	Comment
	Curve 242	Curve 240 (Copy) (smoothed) 300MHz K1702W Edit smoothed = K1702
	Curve 246	'Curve 242' * -1 Übertragungsfunktion
	Curve 247	
	Curve 248	Korrekturkurve -34 dB

Figure 78 Storing and naming the new curve -34 dB in the "Traces" list.

Only the two end points have to be entered in the editor to create a linear function. In this example these are 0 GHz: -34 dB and 3 GHz: -34 dB. Enter the correction curve in the "Traces" list of the "Trace Managers" with OK **Figure 78** ①. It appears at the bottom of the list ② and you can add a name in the free text field of the "Comment" column. Copy the correction curve to the "Corrections" list with the "Arrow right" key ③ where you can assign it to a category ("Categories") and sort it with ↑,↓.

4.3.3.2 Using the correction curve -34 dB during the measurement

You can find the correction curve -34 dB in the "Corrections" list of the "Trace Manager".
Click the "Select" button (mouse cursor ① **Figure 79**) under "Correction" in the "Spectrum Analyser Manager" to select the correction curve.



Available Corrections

Category	Annotation
	-100 dB
	-101 dB
	-120 dB
	-20 dB
	-27 dB
	-30 dB
	-34 dB
	-58,4 ...04 4x7
	-80 dB
	-92 dB
	1,98d... dB-dt
	100 dB
	107dB
	120 dB
	121,9... 7x1,5
	122,3 ...ei h10
	20 dB
	2013.0... 3Ghz

Applied Corrections

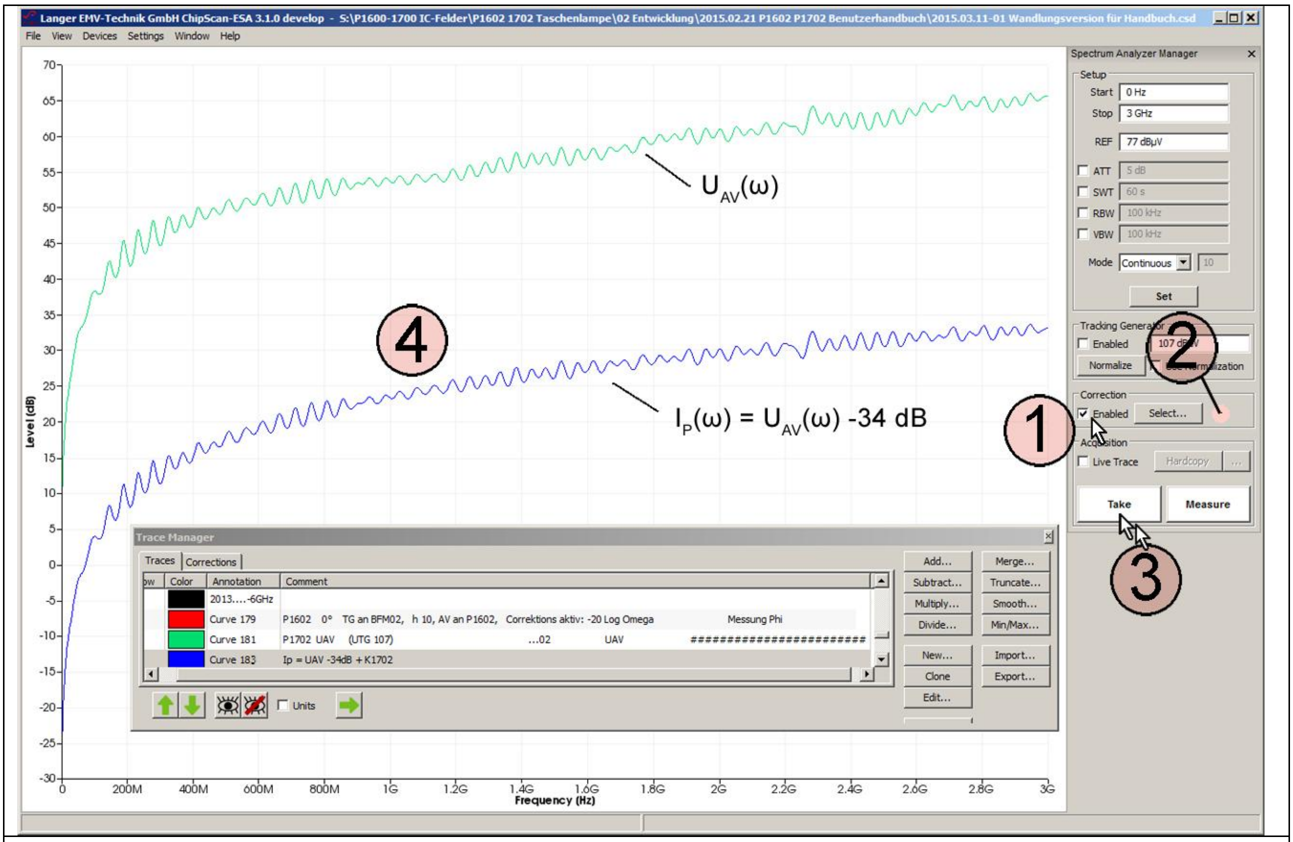
Category	Annotation
Functions	K1702
	-34 dB

Show	Col		
☐	■		
☐	🟥		
☑	🟩		
☐	🟦	Curve 182	Ip korrigiert mit K1702
☐	■	Curve 184	Sum of 2 plots 182 +(-20Log omega) Ladungsmenge Q

Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Continuous 10
☐ Enabled 107 dBµV
☐ Use Normalization
☐ Enabled

Figure 79 Measuring the voltage $U_{AV}(\omega)$ and applying the correction curve -34 dB leads to the current $I_p(\omega)$ in the measurement result Curve 182.

The "Corrections Selector" window opens **Figure 79**. Click and activate the correction curve -34 dB with the mouse cursor ②. Click the "Arrow right" ③ button to move the correction curve to the "Applied Corrections" list.
Activate the "Enabled" box in the "Correction" field in the "Spectrum Analyser Manager" with the mouse cursor ① **Figure 80**. The field ② flashes when the correction is active. Click "Take" or "Measure" (mouse cursor ③ **Figure 80** to transfer the current measurement curve ④ $I_p(\omega)$ from the spectrum analyser to the PC. The calculation **Eqn 39** $I_P(\omega) = U_{AV}(\omega) – 34$ dBΩ is performed at the same time and the correction curve K1702 applied. The curve $I_P(\omega)$ is added to the bottom of the "Traces" list in the "Trace Manager".
A measurement log can be kept in the free text field of the "Comment" column.
Delete the check mark from the "Enabled" box if you only want to measure $U_{AV}(\omega)$; the field ② then stops flashing.



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wandlungsversion für Handbuch.csd

Spectrum Analyzer Manager

Setup
Start 0 Hz
Stop 3 GHz
REF 77 dBµV
☐ ATT 5 dB
☐ SWT 60 s
☐ RBW 100 kHz
☐ VBW 100 kHz
Mode Continuous 10

Tracking Generator
☐ Enabled 107 dBµV

Correction
☑ Enabled

Acquisition
☐ Live Trace

Trace Manager

ow	Color	Annotation	Comment
	⬛	2013….-6GHz	
	🟥	Curve 179	P1602 0° TG an BFM02, h 10, AV an P1602, Correktions aktiv: -20 Log Omega Messung Phi
	🟩	Curve 181	P1702 UAV (UTG 107) …02 UAV ########################
	🟦	Curve 183	Ip = UAV -34dB + K1702

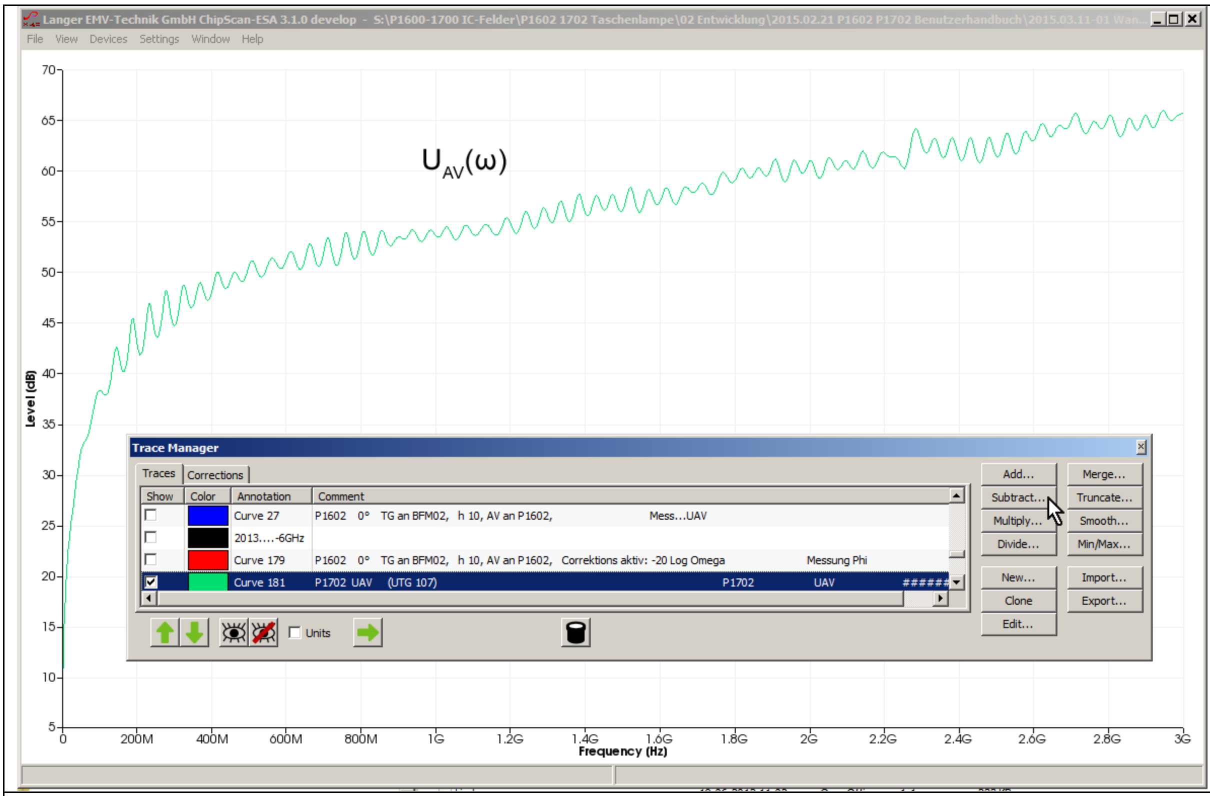
☐ Units

Figure 80 Measuring the voltage $U_{AV}(\omega)$ and applying the correction curve -34 dB leads to the current $I_p(\omega)$ in the measurement result Curve 183 ④.

The curve number is counted automatically (Curve 183) under "Annotation".

4.3.3.3 Using the mathematical operation -34 dB after the measurement

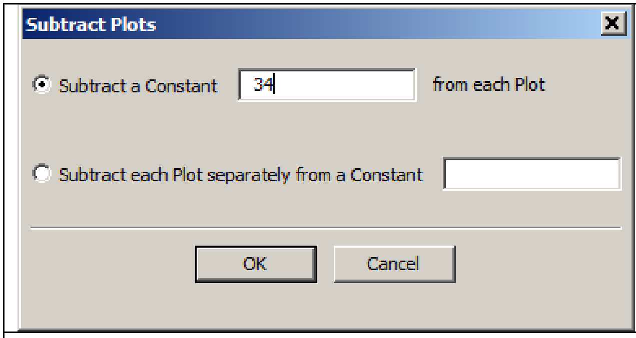
The mathematical operation "Subtract a constant from each plot" has to be used for this purpose. Activate the plot $U_{AV}(\omega)$ in the "Trace Manager" (Curve 181 high-lighted blue **Figure 81**). Open the "Subtract Plots" window under the mathematical operation "Subtract…", mouse cursor **Figure 81**. Enter the constant 34 dB to be subtracted **Figure 82**. Click OK to add the calculation result U_{AV}-34 dB to the bottom of the "Trace Manager" list (**Figure 83** Curve 182).



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuch\2015.03.11-01 Wan...

Show	Color	Annotation	Comment
☐	🟦	Curve 27	P1602 0° TG an BFM02, h 10, AV an P1602, Mess…UAV
☐	⬛	2013….-6GHz	
☐	🟥	Curve 179	P1602 0° TG an BFM02, h 10, AV an P1602, Correktions aktiv: -20 Log Omega Messung Phi
☑	🟩	Curve 181	P1702 UAV (UTG 107) P1702 UAV ######

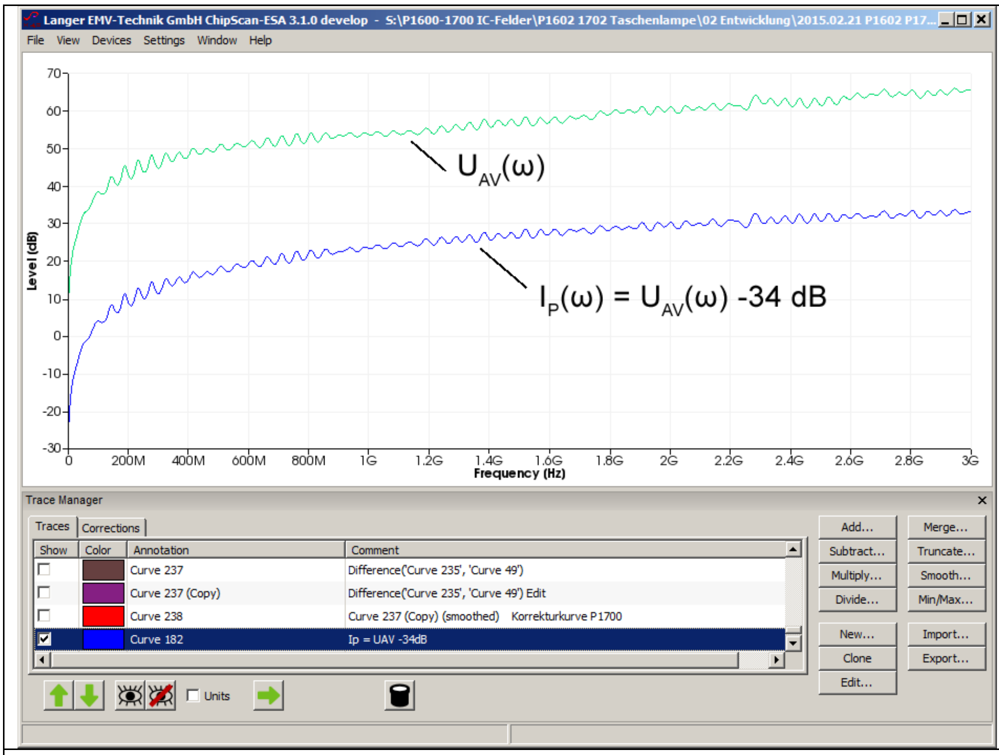
Figure 81 Opening the mathematical operation "Subtract…" and applying it to Curve 181 $U_{AV}(\omega)$.



● Subtract a Constant 34 from each Plot

○ Subtract each Plot separately from a Constant

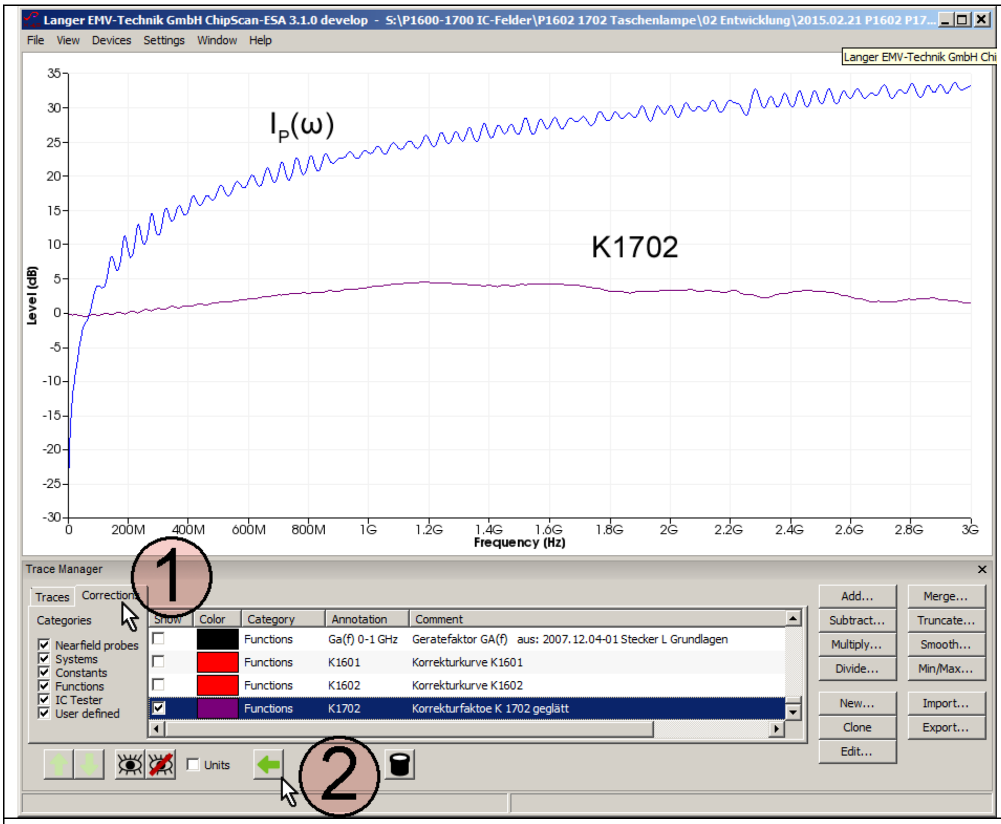
Figure 82 Entering the constant 34 (34 dBΩ) to be subtracted.



Show	Color	Annotation	Comment
☐	🟫	Curve 237	Difference('Curve 235', 'Curve 49')
☐	🟪	Curve 237 (Copy)	Difference('Curve 235', 'Curve 49') Edit
☐	🟥	Curve 238	Curve 237 (Copy) (smoothed) Korrekturkurve P1700
☑	🟦	Curve 182	Ip = UAV -34dB

Figure 83 Curve 182, the current $I_p(\omega)$ is the result of the subtraction (Curve 181 $U_{AV}(\omega)$) -34 dB.

Before the correction curve can be used, it has to be moved from the "Correction" list **Figure 84** to the "Traces" list. Select the "Correction" list, mouse cursor ①, activate function K1702 and copy it to the "Traces" list with the "Arrow left" key ②.

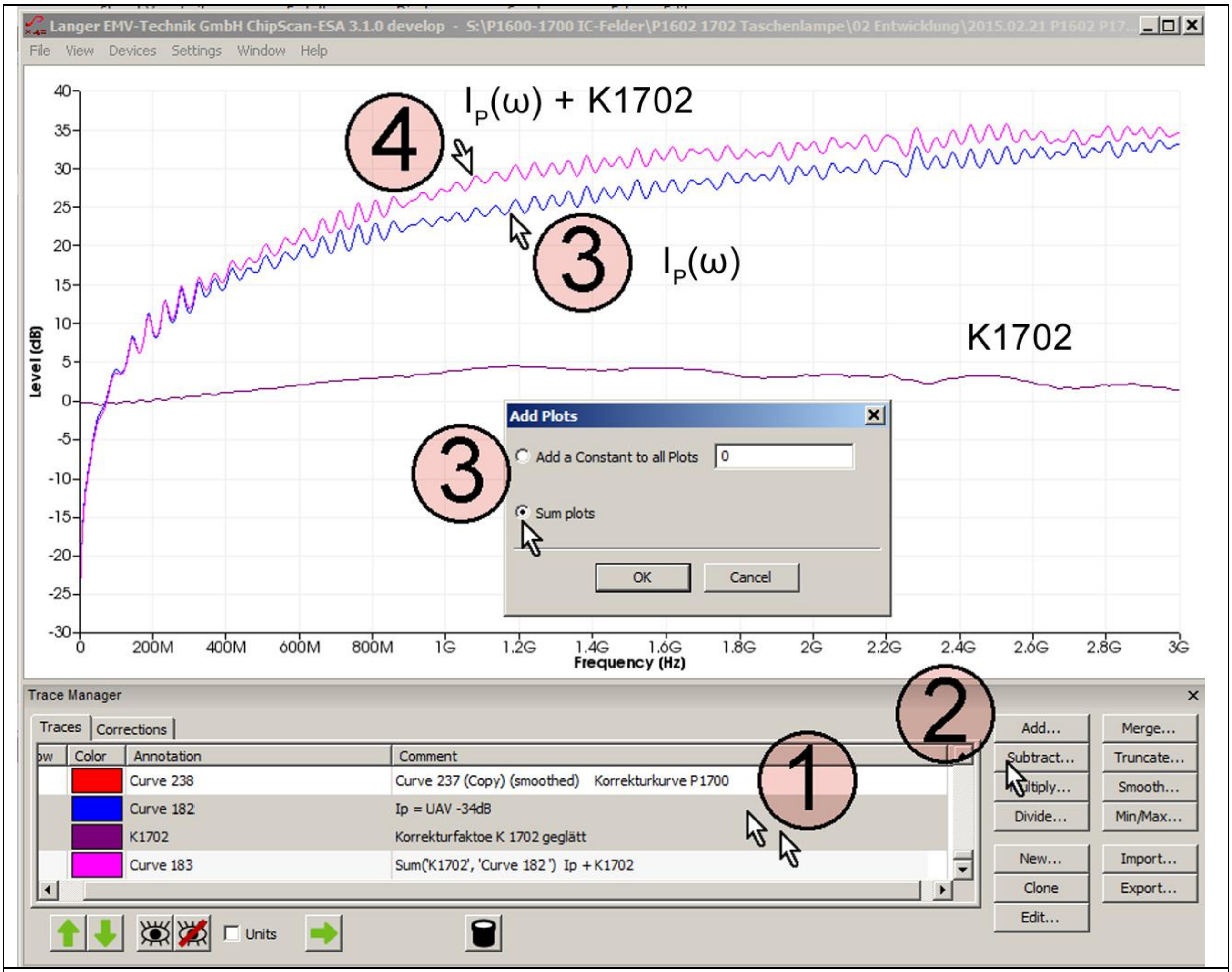


Categories
☑ Nearfield probes
☑ Systems
☑ Constants
☑ Functions
☑ IC Tester
☑ User defined

Show	Color	Category	Annotation	Comment
☐	⬛	Functions	Ga(f) 0-1 GHz	Geratefaktor GA(f) aus: 2007.12.04-01 Stecker L Grundlagen
☐	🟥	Functions	K1601	Korrekturkurve K1601
☐	🟥	Functions	K1602	Korrekturkurve K1602
☑	🟪	Functions	K1702	Korrekturfaktoe K 1702 geglätt

Figure 84 Copying the Correction curve K1702 from the "Corrections" list to the "Traces" list.

Activate Curve 182 $I_p(\omega)$ and Curve K1702 with the mouse cursor ①. Call up the mathematical operation "Add…" (mouse cursor ②). The "Add Plots" window opens. Activate "Sum plots" with the mouse cursor ③. Click OK to create the corrected current curve ④ from the uncorrected current curve $I_p(\omega)$ ③.


Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P17...

Add Plots

○ Add a Constant to all Plots 0

● Sum plots

Trace Manager

ow	Color	Annotation	Comment
	🟥	Curve 238	Curve 237 (Copy) (smoothed) Korrekturkurve P1700
	🟦	Curve 182	Ip = UAV -34dB
	🟪	K1702	Korrekturfaktoe K 1702 geglätt
	🟪	Curve 183	Sum('K1702', 'Curve 182 ') Ip + K1702

☐ Units

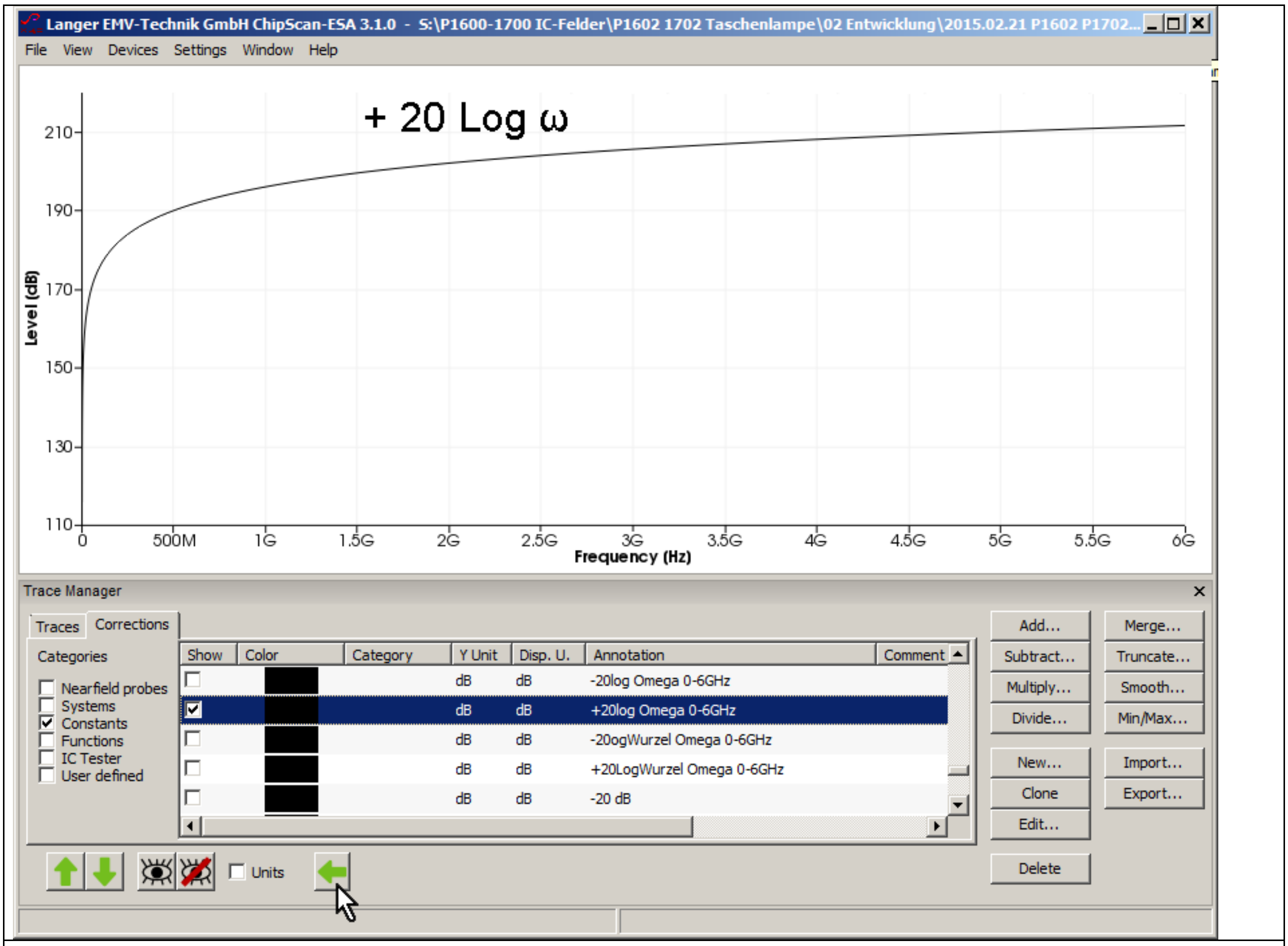
Figure 85 Curve 183, the corrected current $I_p(\omega)$, is the result of the addition (Curve 182 $I_P(\omega)$) + K1702.

4.3.4 Creating the correction curve K1702

The ideal curve of the capacitive excitation current $I_P(\omega)$ is the basis for creating the correction curve to correct the frequency response deviation of the ***P1702*** field probe. The correction curve is created from the difference between the measured and the calculated current curve $I_P(\omega)$.

$K1702 = I_P(\omega)_{calculated} - I_P(\omega)_{measured}$ Eqn 45

Calculation of $I_p(\omega)$:
From equivalent circuit diagram **Figure 75** and **Eqn 28** or **Eqn 30**:
$I_P(\omega) = \omega\, C_1\, U_{Pad}(\omega)$
$I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + U_{IC}(\omega)$
$I_P(\omega)$ can be calculated. Where $U_{Pad}(\omega) = U_{TG}(\omega)$. The capacitance C_1 **Figure 75** is approximately 10.6 fF for ***EPM 02***, h = 10 mm (**Eqn 32**). The calculation is performed on the logarithmic scale according to **Eqn** 30
$I_P(\omega) = 20 \text{ Log } \omega + 20 \text{ Log } C_1 + U_{Pad}(\omega)$.
The function 20 Log ω is available in the "Corrections" list of the Trace Manager.



Categories
☐ Nearfield probes
☐ Systems
☑ Constants
☐ Functions
☐ IC Tester
☐ User defined

Show	Color	Category	Y Unit	Disp. U.	Annotation	Comment
☐	■		dB	dB	-20log Omega 0-6GHz	
☑	■		dB	dB	+20log Omega 0-6GHz	
☐	■		dB	dB	-20ogWurzel Omega 0-6GHz	
☐	■		dB	dB	+20LogWurzel Omega 0-6GHz	
☐	■		dB	dB	-20 dB	

Figure 86 Activating the function 20 Log ω in the "Corrections" list of the Trace Manager.

Activate the function with a mouse click (blue) and copy to the "Traces" list by clicking the "Arrow left" button (mouse coursor). The calculation is performed in the "Traces" list with the mathematical function. The terms $20 \text{ Log } C_1 + U_{Pad}(\omega)$ have to be calculated with a pocket calculator beforehand.
First take the logarithm of the capacitance C_1 = 10.6 fF. Create 20 Log 10.6 EXP-15 with a pocket calculator (1 fF = $1 \cdot 10^{-15}$ F):

$20 \text{ Log } C_1 = 20 \text{ Log } 10.6 \text{ fF} = -279.49 \text{ dBF}$

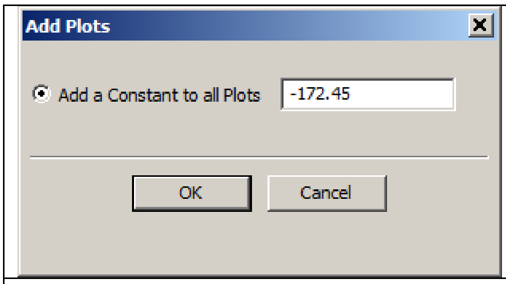
This value is added to $U_{Pad}(\omega) = U_{TG}(\omega) = 107$ dBµV:

107 dB -279.49 dB = -172.45 dB

The addition

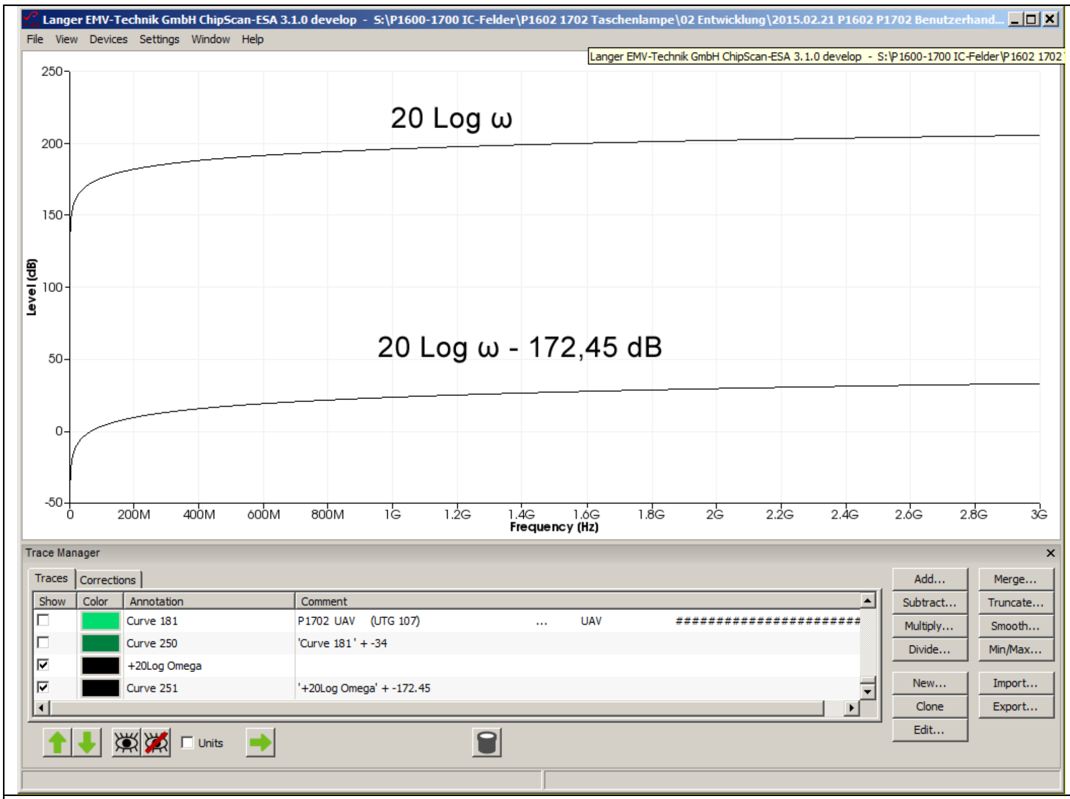
$I_P(\omega) = 20 \text{ Log } \omega - 172{,}45 \text{ dB}$

is performed in the mathematical function of the ***ChipScan-ESA*** software. Activate the curve "20 Log Omega" with a mouse click. Enter "-172.45" as the constant to be added under "Add..." **Figure 87**. Click OK to perform the addition. The result $I_P(\omega)$ appears at the bottom of the "Traces" list and as a curve (Curve 251) on the display **Figure 88**.



● Add a Constant to all Plots: -172.45

Figure 87 Addition of -172.45 dB to curve +20 Log Omega.



Show	Color	Annotation	Comment
☐	🟩	Curve 181	P1702 UAV (UTG 107) ... UAV ########################
☐	🟩	Curve 250	'Curve 181' + -34
☑	■	+20Log Omega	
☑	■	Curve 251	'+20Log Omega' + -172.45

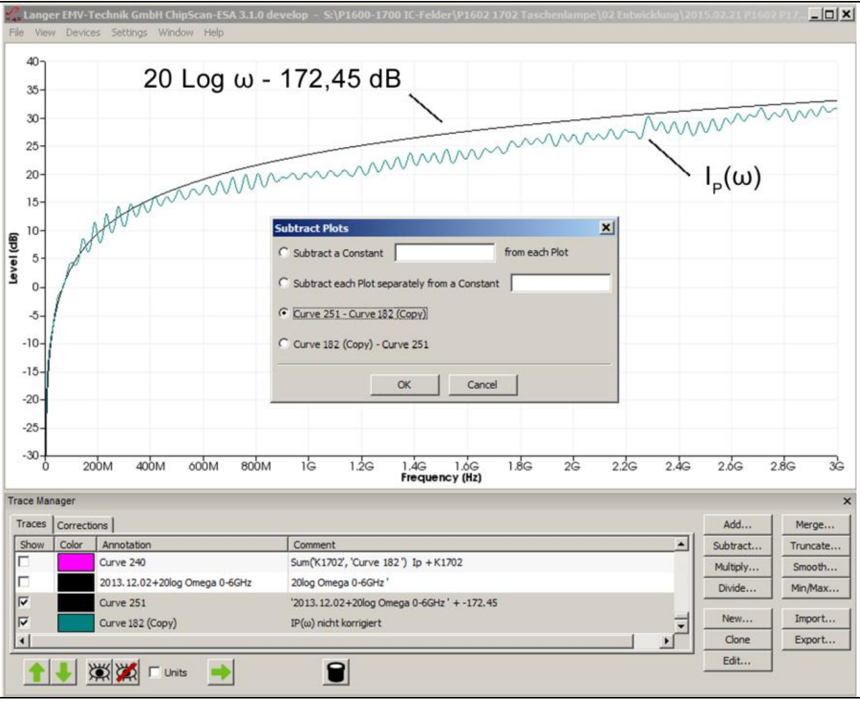
☐ Units

Figure 88 Result of the addition (Curve 251 $I_P(\omega)$) = 20 Log ω -172.45 dB.

The calculated curve of $I_P(\omega)$ in the form of Curve 251 is now available as a prerequisite to create the correction curve.

4.3.4.1 Creating the correction curve K1702W (special use for the measurement set-up Figure 74)

The difference between the calculated curve $I_P(\omega)$ from **Figure 88** and the measured curve $I_P(\omega)$ from **Figure 83** provides the correction factor K1702W. Activate both curves in **Figure 89** with a mouse click. The difference is determined with the mathematical operation "Subtract…" **Figure 89**. Select the curve (Curve 182) to be subtracted under "Subtract Plot". Click OK to add the calculated curve to the bottom of the "Trace" list and to show it on the display **Figure 90**.
K1702W includes the standing waves of the tracking generator and the ***EPM 02*** test source.



Subtract Plots

○ Subtract a Constant ☐ from each Plot
○ Subtract each Plot separately from a Constant ☐
● Curve 251 - Curve 182 (Copy)
○ Curve 182 (Copy) - Curve 251

OK Cancel

Show	Color	Annotation	Comment
☐	🟪	Curve 240	Sum('K1702', 'Curve 182 ') Ip + K1702
☐	⬛	2013.12.02+20log Omega 0-6GHz	20log Omega 0-6GHz '
☑	⬛	Curve 251	'2013.12.02+20log Omega 0-6GHz ' + -172.45
☑	🟦	Curve 182 (Copy)	IP(ω) nicht korrigiert

Figure 89 Subtraction of the curves 182 ($I_P(\omega)$ measured) and 251, ($I_P(\omega)$ calculated).

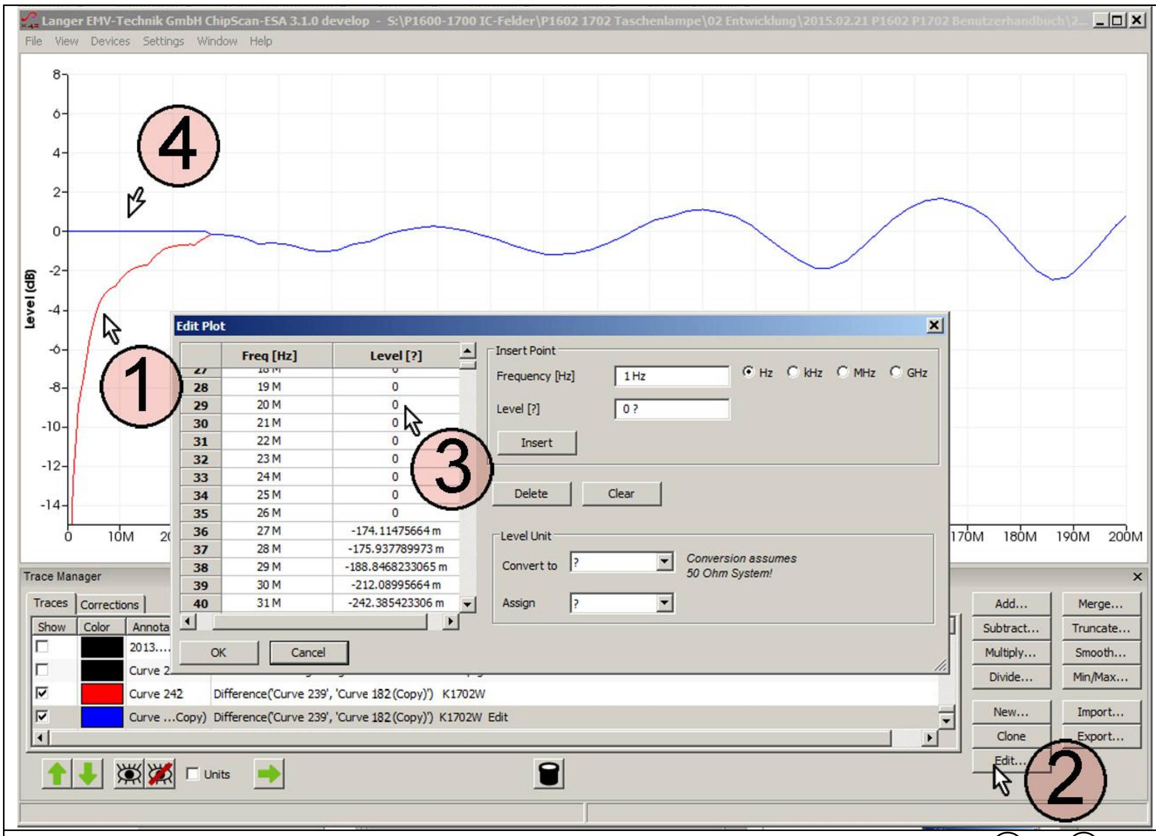
Show	Color	Annotation	Comment
☐	⬛	2013.12.02+20log Omega 0-6GHz	20log Omega 0-6GHz '
☑	⬛	Curve 251	'2013.12.02+20log Omega 0-6GHz ' + -172.45
☑	🟦	Curve 182(Copy)	IP(ω) nicht korrigiert
☑	🟥	Curve 242	Difference('Curve 251', 'Curve 182(Copy)')

Figure 90 The correction factor K1702W is the result of the subtraction Curve 182 – 251.

The resulting correction curve can be corrected in the editor (Edit…) below the lower limit frequency.
If the precise capacity C_1 of the device under test is not known, the calculated current curve $I_P(\omega)$ can be matched to the measured curve $I_P(\omega)$ by adjusting C_1.

4.3.4.2 Creating the correction curve K1702 (general use)

The correction curve K1702W **Figure 90** has to be smoothed to determine K1702. The curve of $I_P(\omega)$ is incorrect for frequencies < 27 MHz. It reaches the noise margin. The correction curve thus sinks significantly in this range **Figure 91** (mouse cursor ①). This deviation can be corrected by hand in the editor. Copy the Curve 242 to produce Curve 242 (Copy). Mark this with the mouse cursor. Call up the editor (mouse cursor ②). Correct the level from 0 dB to 27 MHz by hand in the "Edit Plot" window (mouse cursor ③). Click OK to modify the Curve 242 (copy) accordingly (mouse cursor ④).
Mark the Curve 242 (copy) with the mouse cursor ① **Figure 92**. Call up the mathematical operation "Smooth…" **Figure 92** (mouse cursor ②). The "Smooth Plot" window opens. Set a bandwidth of 300 MHz for smoothing (mouse cursor ③). The result is added to the bottom of the "Traces" list. It also appears as a curve ④ on the display **Figure 92**.



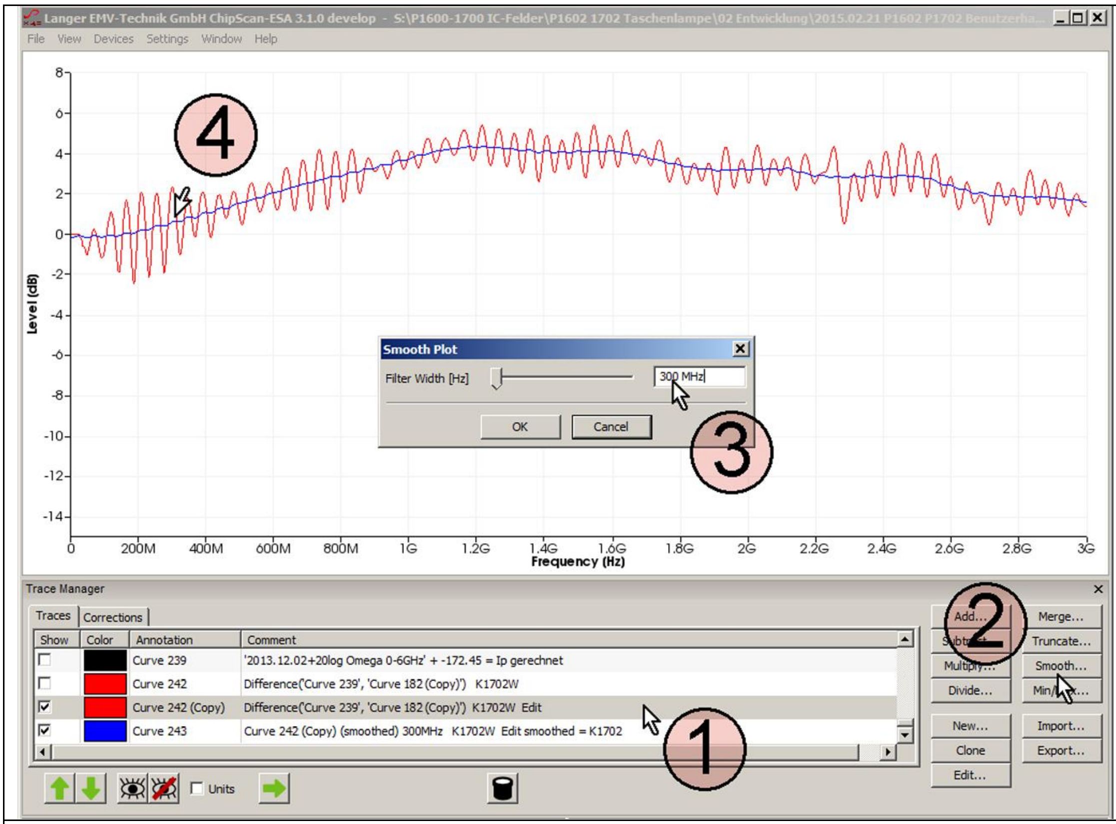
	Freq [Hz]	Level [?]
28	19 M	0
29	20 M	0
30	21 M	0
31	22 M	0
32	23 M	0
33	24 M	0
34	25 M	0
35	26 M	0
36	27 M	-174.11475664 m
37	28 M	-175.937789973 m
38	29 M	-188.8468233065 m
39	30 M	-212.08995664 m
40	31 M	-242.385423306 m

Insert Point
Frequency [Hz] 1 Hz ● Hz ○ kHz ○ MHz ○ GHz
Level [?] 0 ?

Level Unit
Convert to ?
Conversion assumes 50 Ohm System!
Assign ?

Show	Color	Annota		
☐	⬛	2013.…		
☐	⬛	Curve 2		
☑	🟥	Curve 242	Difference('Curve 239', 'Curve 182 (Copy)')	K1702W
☑	🟦	Curve …Copy)	Difference('Curve 239', 'Curve 182 (Copy)')	K1702W Edit

Figure 91 Correcting the correction curve K1702 < 27 MHz by hand in the editor (① -> ④).



Smooth Plot

Filter Width [Hz] 300 MHz

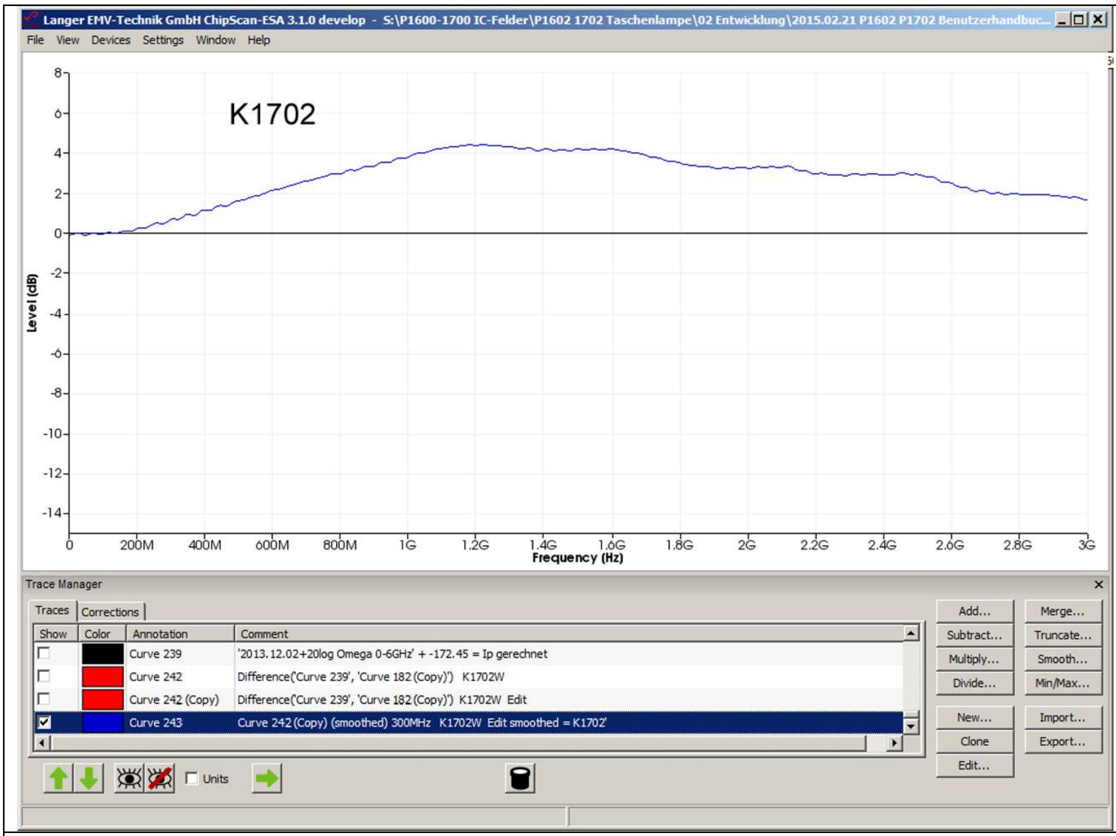
Trace Manager

Traces | Corrections

Show	Color	Annotation	Comment
☐	■	Curve 239	'2013.12.02+20log Omega 0-6GHz' + -172.45 = Ip gerechnet
☐	🟥	Curve 242	Difference('Curve 239', 'Curve 182 (Copy)') K1702W
☑	🟥	Curve 242 (Copy)	Difference('Curve 239', 'Curve 182 (Copy)') K1702W Edit
☑	🟦	Curve 243	Curve 242 (Copy) (smoothed) 300MHz K1702W Edit smoothed = K1702

Figure 92 Smoothing the correction curve K1702 with the "Smooth..." function.

Figure 93 shows the correction factor K1702 as Curve 243.



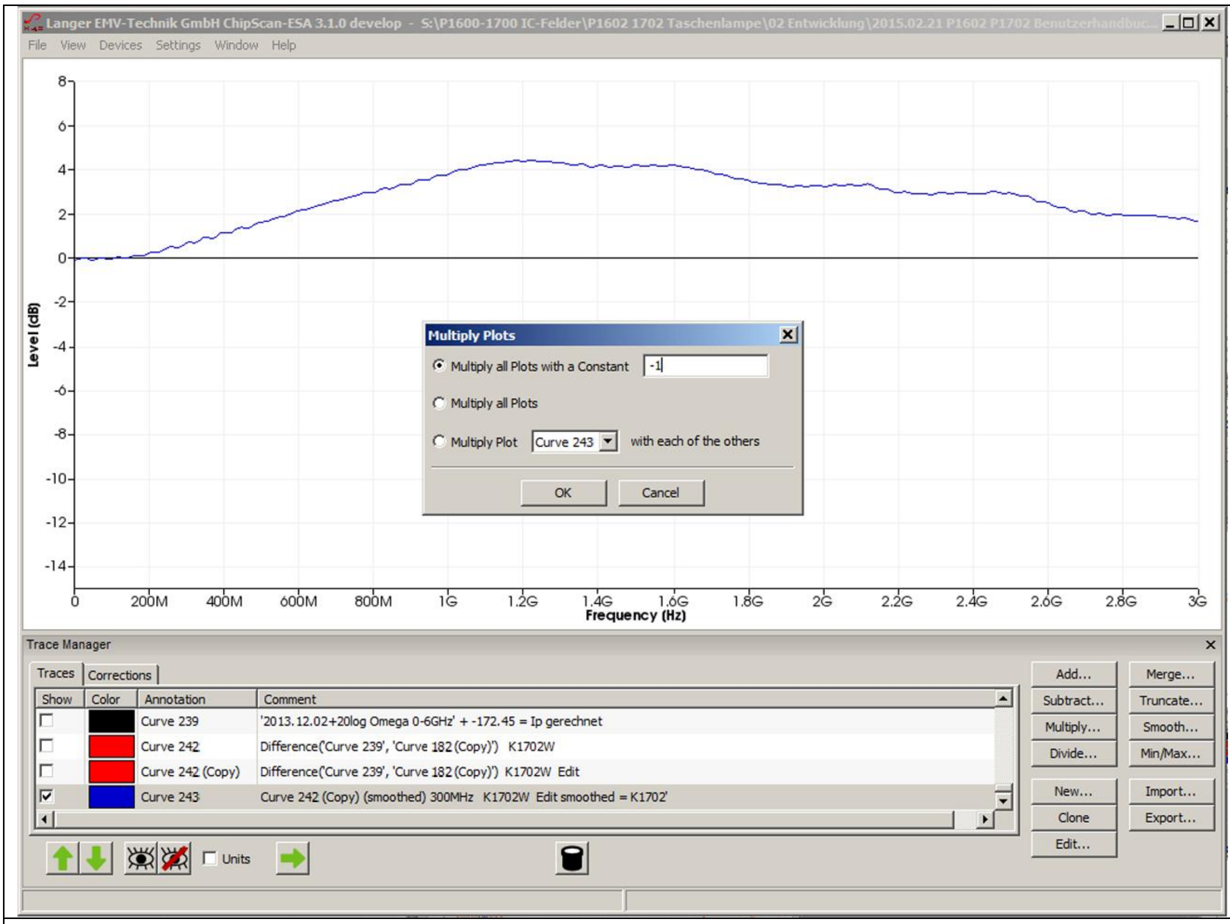
Trace Manager

Traces | Corrections

Show	Color	Annotation	Comment
☐	■	Curve 239	'2013.12.02+20log Omega 0-6GHz' + -172.45 = Ip gerechnet
☐	🟥	Curve 242	Difference('Curve 239', 'Curve 182 (Copy)') K1702W
☐	🟥	Curve 242 (Copy)	Difference('Curve 239', 'Curve 182 (Copy)') K1702W Edit
☑	🟦	Curve 243	Curve 242 (Copy) (smoothed) 300MHz K1702W Edit smoothed = K1702'

Figure 93 Correction curve K1702.

4.3.5 Frequency response of the P1702 field probe



Langer EMV-Technik GmbH ChipScan-ESA 3.1.0 develop - S:\P1600-1700 IC-Felder\P1602 1702 Taschenlampe\02 Entwicklung\2015.02.21 P1602 P1702 Benutzerhandbuc...

Multiply Plots

● Multiply all Plots with a Constant: -1

○ Multiply all Plots

○ Multiply Plot Curve 243 with each of the others

Trace Manager

Show	Color	Annotation	Comment
☐	■	Curve 239	'2013.12.02+20log Omega 0-6GHz' + -172.45 = Ip gerechnet
☐	🟥	Curve 242	Difference('Curve 239', 'Curve 182 (Copy)') K1702W
☐	🟥	Curve 242 (Copy)	Difference('Curve 239', 'Curve 182 (Copy)') K1702W Edit
☑	🟦	Curve 243	Curve 242 (Copy) (smoothed) 300MHz K1702W Edit smoothed = K1702'

☐ Units

Figure 94 Creating the transfer function from the correction curve K1702.
The calculation "Multiply all Plots with a Constant" (K1702 * -1) is performed with the "Multiply Plots" operation.

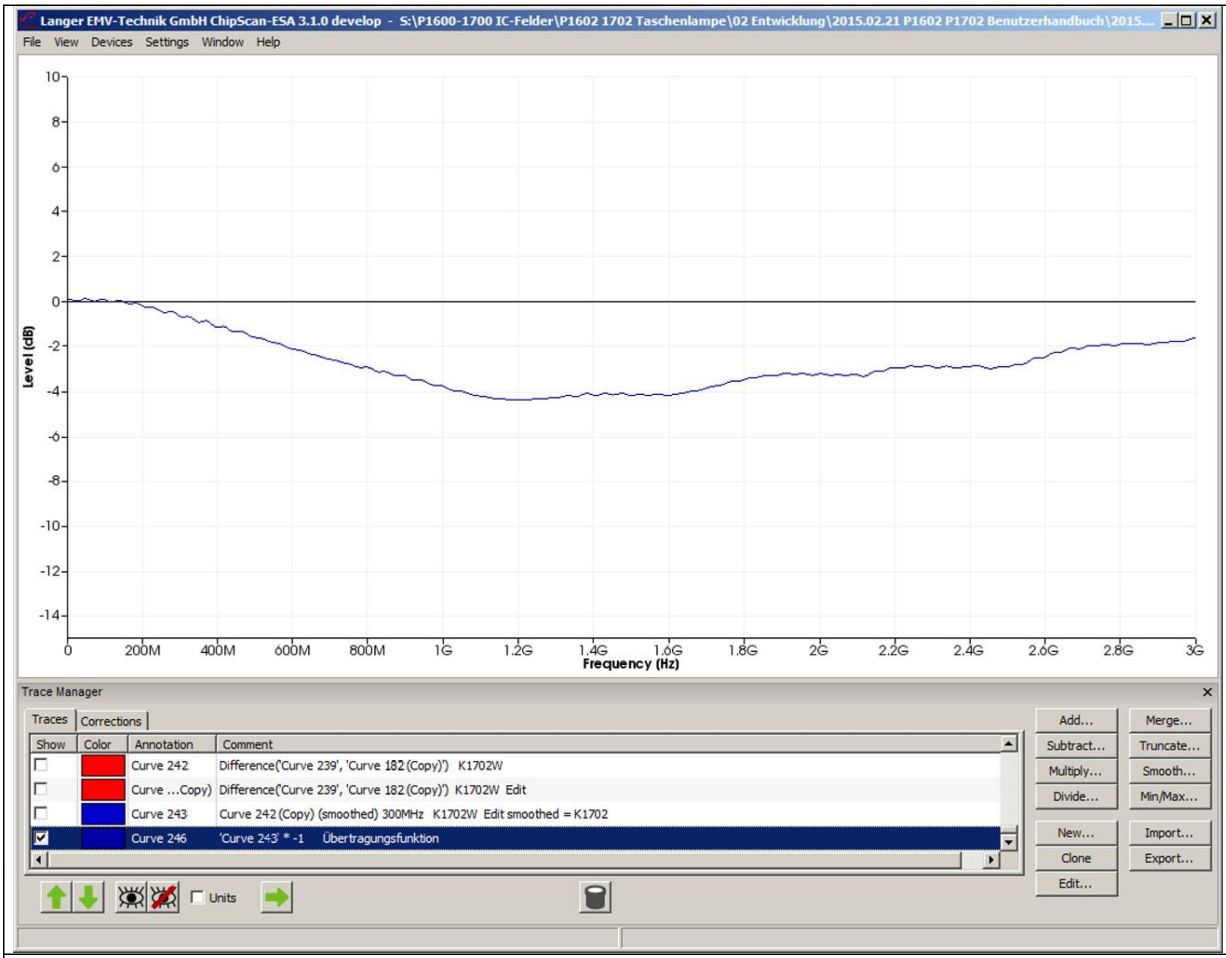
The transfer function represents the functional relationship between the actual and the measured excitation current $I_p(\omega)$. It is assumed that the actual excitation current corresponds to that calculated above. Transposing **Eqn 45** results in:

$$(I_p(\omega)t)_{\text{measured}} = (1/K1702) * (I_p(\omega))_{\text{calculadted}} \qquad \text{Eqn 46}$$

In a logarithmic form:

$$(I_p(\omega)t)_{\text{measured}} = (I_p(\omega))_{\text{calculated}} - K1702 \qquad \text{Eqn 47}$$

The transfer function is created from the correction curve **Figure 94** by inversion.
Figure 95 shows the frequency response of the field probe. It corresponds to the inverted correction factor. The frequency response relates to the physical quantities which are transferred from the test IC to the field probe. This may be the excitation current $I_P(\omega)$ or the charge $Q_{IC}(\omega)$.
It is the ratio between the excitation current $I_P(\omega)$ which was measured and that which actually flows or the charge $Q_{IC}(\omega)$.
The measurement error that can be derived from the frequency response can be eliminated by applying the correction curve to the measurement result (correction in the ***ChipScan-ESA*** software, see **4.3.3.2**, **4.3.3.3**).



Show	Color	Annotation	Comment
☐	🟥	Curve 242	Difference('Curve 239', 'Curve 182 (Copy)') K1702W
☐	🟥	Curve ...Copy)	Difference('Curve 239', 'Curve 182 (Copy)') K1702W Edit
☐	🟦	Curve 243	Curve 242 (Copy) (smoothed) 300MHz K1702W Edit smoothed = K1702
☑	🟦	Curve 246	'Curve 243' * -1 Übertragungsfunktion

Figure 95 Frequency response of the ***P1702*** field probe to be applied to the excitation current $I_P(\omega)$ or the charge $Q_{IC}(\omega)$.

4.4 Set-up of the test bench / system set-up

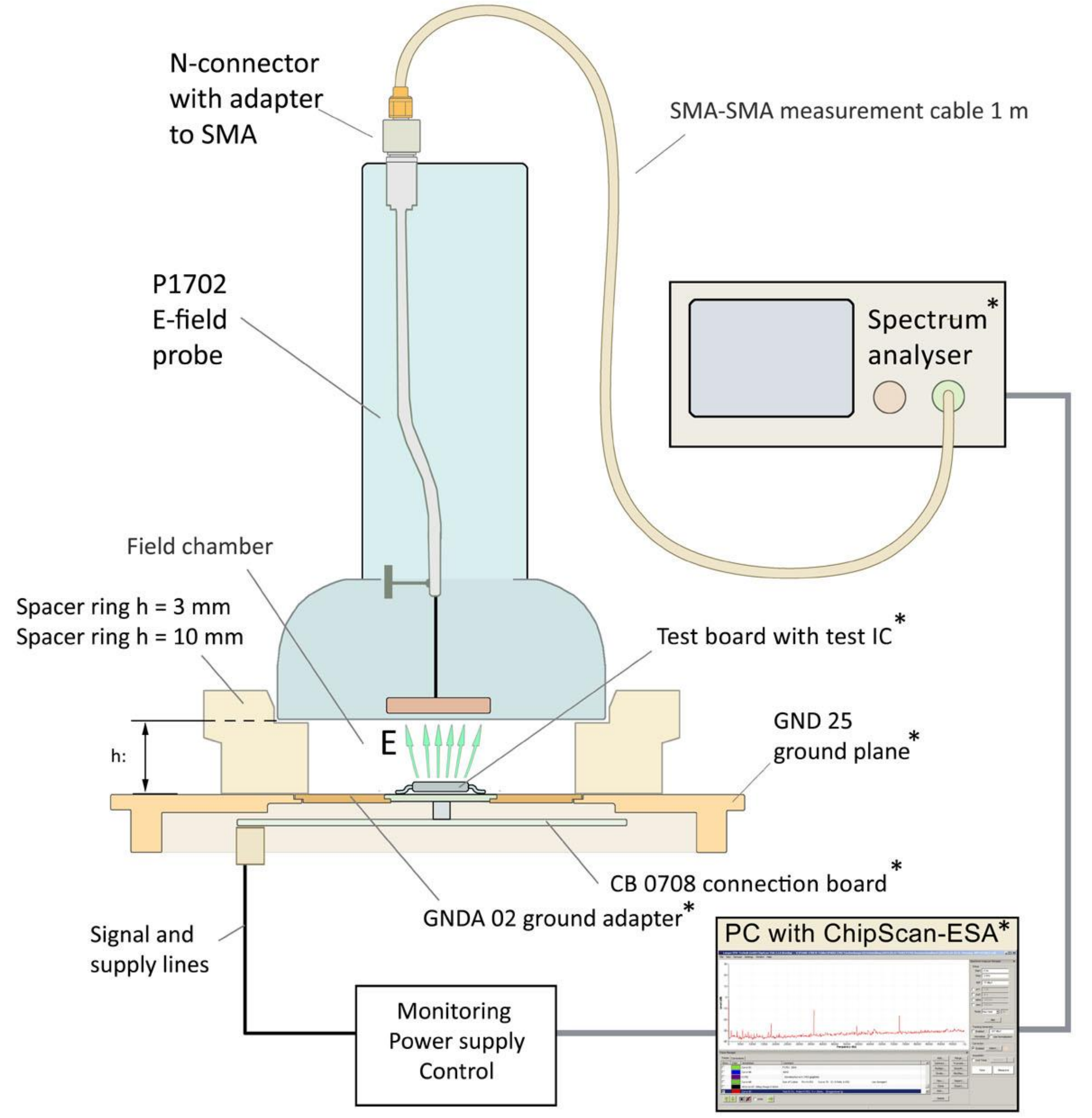


Figure 96 ***P1702*** field probe in the ICE1 test environment.

Components marked * are not included in the scope of delivery of the "RF field measurement on ICs" probe set.

All field probes included in the "RF field measurement on ICs" probe set are connected in the same way and require the same ***ICE1*** IC test environment set (www.langer-emv.com). **Figure 96** shows the set-up of the test bench with the ***ICE1*** IC test environment set (**Table 1**) and the ***P1702*** field probe as an example.
The test IC (**Figure 96)** generates an interference field. The capacitive excitation current which is driven by the field is picked up by the electrode of the ***P1702*** field probe, routed to the spectrum analyser and measured.
The measurement signal is provided at the N-connector output of the ***P1702***. The N-connector output is connected to the measuring cable via an **N/SMA** adapter. The other end of the measuring cable is connected to the AV port of the spectrum analyser. The spectrum analyser can be connected to the PC via GPIB, LAN/VXI or RS232.

The ***ChipScan-ESA*** software is connected to the spectrum analyser via the Device Manager (a dongle has to be used).

The test bench can be controlled by hand on the spectrum analyser or with the ***ChipScan-ESA*** control software from the PC via an interface. Manufacturing the test board is described in the "IC test instructions manual".
The test IC is mounted on a test board[9]. The test board is inserted into a ground adapter such as ***GNDA 02*** which is inserted into the ***GND 25*** ground plane. The test board is connected to the ***CB 0708*** connection board via connectors (**Figure 96**) (user manual of the ***ICE1*** IC test environment set[10]). A user-specific solution can be used to control, monitor and supply the test IC Instead of the ***CB 0708*** connection board. A corresponding connection has to be established to the test board. A (100 x 100) mm TEM cell print can be used instead of the test board and ground adapter. It has to be ensured that there are no components and short-circuitable lines at the top side in the area where the spacer ring rests. The top side should have a continuous ground plane except for the test IC.

Two different spacer rings are included in the scope of delivery of the "RF field measurement on ICs" probe set. The spacer rings have a height of 3 mm and 10 mm respectively. The height of the field source above the ground plane (and thus above the test IC) can be defined by selecting the respective spacer ring. A height of 10 mm is the preferred setting.
The 3 mm spacer ring can be used if the test IC's measurement signal is not strong enough with the 10 mm spacer ring. The electrode or electric conductor is closer to the test IC if the 3 mm spacer ring is used. The interference effect is thus increased with the same disturbance source. The proximity of the test IC to the field probe causes a stronger field distortion with 3 mm than with 10 mm. The measuring accuracy is thus higher when using the 10 mm spacer ring.
When using the 3 mm instead of the 10 mm spacer, the magnetic flux density is increased by the factor 2 and the electric field strength is increased by the factor 3 (ignoring the test IC interaction).
The chosen spacer ring is mounted on the ***GND 25*** ground plane (**Figure 96**). The P1600 or P1700 field probe is then inserted into the upper recess of the spacer ring. The P1600 magnetic field probe can be rotated in the spacer ring by 360°. The orientation of the electric conductor of the field probe to the magnetic field of the test IC can thus be changed by rotation (**Figure 5, Figure 12**).
The ***CB 0708*** connection board and the ***CU 22***[11] control unit are used to control the test IC.
The ***ICE1*** user manual provides information on how to use and wire these components. **Figure 97** shows the set-up of a practical test bench. Further devices such as an oscilloscope can be used if necessary.

The automated ***ICT1*** IC tester can be used to rotate the field probes in the P1600 series automatically. The magnetic field of the test IC can thus be measured gradually and automatically at defined angular directions.

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[9] "IC test instructions manual", mail@langer-emv.de

[10] ***GNDA 02*** ground adapter and ***GND 25*** ground plane are included in the ***ICE1*** IC test environment set www.langer-emv.com.
The test board is described in the "IC test instructions manual",mail@langer-emv.de.

[11] ***CU 22*** www.langer-emv.com

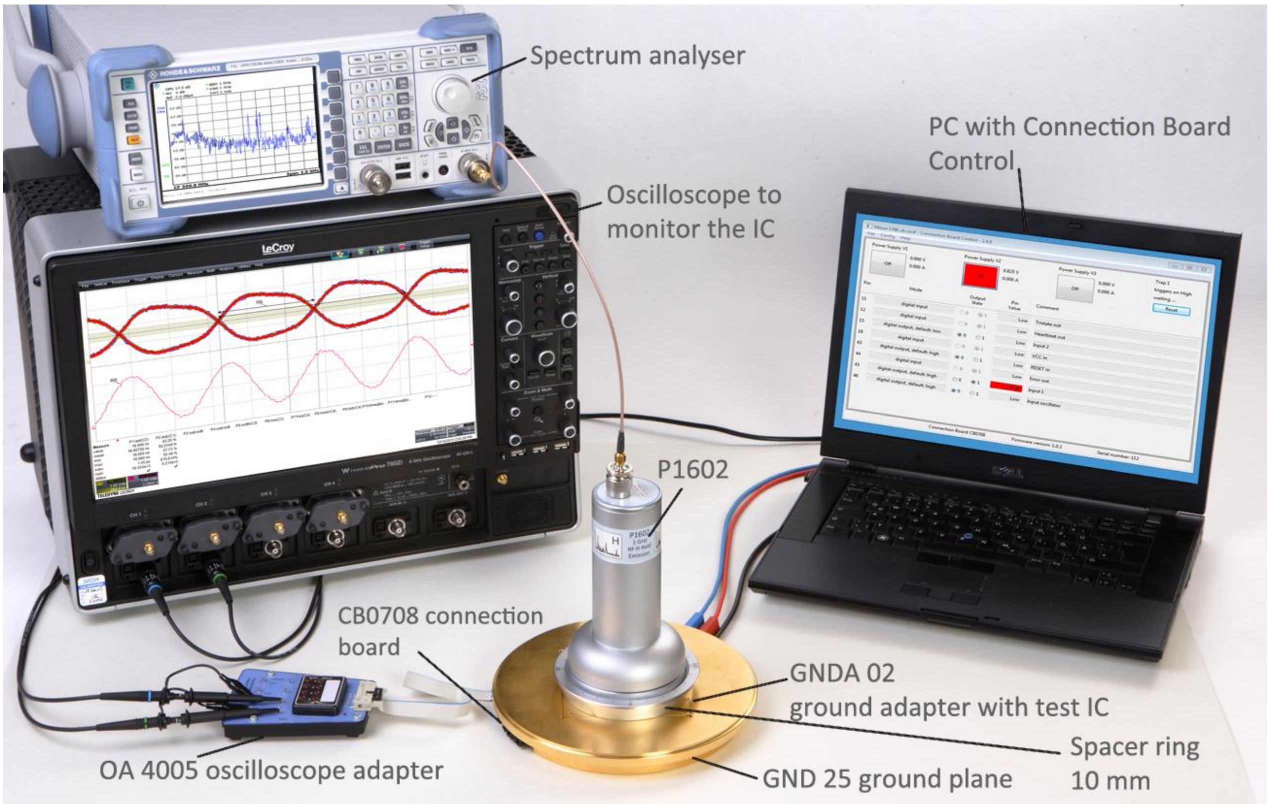

Figure 97 Test set-up with the "RF field measurement on ICs" probe set, the ***ICE1*** IC test environment and other devices. The oscilloscope is not necessary for RF-field measurement. It is used to monitor the device under test.

The devices listed in the table are described in their respective instruction manuals:

Task	**Instruction manual**
• Instructions for the development of the test board • Test procedure	IC test instructions manual (Langer EMV-Technik GmbH)
• GND 25 ground plane • CB 0708 connection board • OA 4005 oscilloscope adapter • Monitoring and controlling the test IC • CU 22 control unit	ICE1 user manual
• Spectrum analyser • PC	Operating instructions of the manufacturer

Table 1

4.5 Performance of the test

There are two ways to use the test bench:

1. **Manual control of the test bench**

The test bench is controlled via the user interface of the spectrum analyser and the control and supply unit of the test IC. The test IC's mode of operation is set on the user's control and supply unit. The spectrum analyser is set according to the manufacturer's operating instructions on either the control elements of the device or on the PC via remote control.

2. **Control of the test bench with ChipScan-ESA from a PC**

The control is described in the user manual of the "RF-field measurement on ICs" probe set. (support by Langer EMV-Technik GmbH, mail@langer-emv.de).

4.5.1 Test procedure

The test IC is switched to the respective operating state with the control and supply unit. The supply voltage and supply current are monitored. The respective measuring parameters (start, stop, span, BW, …) are set on the spectrum analyser. The measurement set-up is designed according to **4.4** (**3.3.1**, **3.3.2**, **4.3.1**, **4.3.2**). The measurement can be performed with the ***ChipScan-ESA*** Software or by means of customised applications. The ***ChipScan-ESA*** software can document the measurement process, apply correction curves and perform conversions.

The automatic ***ICT1*** IC test can be used to rotate the P1600 probe gradually and perform the measurement of the magnetic fields automatically (support by Langer EMV-Technik GmbH, mail@langer-emv.de).
Test procedures are described in the “IC test instructions manual” (mail@langer-emv.de).

4.6 Verifying the waveform

The field probes have to be calibrated every two years or prior to every major measuring job. The calibration is performed by Langer EMV-Technik GmbH or has to be carried out according to the 1600/1700 calibration instructions of Langer EMV-Technik GmbH.
Chapters **3.3.5** and **4.3.4** describe how the correction curve is created.

5 Safety instructions

This product meets the requirements of the following directives of the European Union: 2004/108/EC (EMC directive) and 2006/95/EC (low-voltage directive).

Read and follow the instructions in the user manual and keep this in a safe place for later reference. The device may only be used by personnel who are qualified in the field of EMC and who are eligible to carry out this work.

When using a product from Langer EMV-Technik GmbH, please observe the following safety instructions to protect yourself from electric shocks or the risk of injuries and to protect the devices used and the test IC from being destroyed.

- Observe the operating and safety instructions for all devices used in the set-up.
- Never use any damaged or defective devices.
- Carry out a visual check before using a measurement set-up with a Langer EMV-Technik GmbH product. Replace any damaged connecting cables before starting the product.
- The Langer EMV-Technik GmbH product may only be used for its intended purpose. Any other use is forbidden.
- People with a pace-maker are not allowed to work with this device.
- The test set-up should always be operated via a filtered power supply.

We cannot assume any liability for the destruction of test ICs!

6 Warranty

Langer EMV-Technik GmbH will remedy any fault due to defective material or defective manufacture, either by repair or by delivery of replacement, during the statutory warranty period.

This warranty is only granted on condition that:
- the information and instructions in the user manual have been observed.

The warranty will be forfeited if:
- an unauthorized repair is performed on the product,
- the product is modified,
- the product is not used according to its intended purpose.

7 Technical specifications

P1601, P1602, P1702 field probes	
Dimensions (height/width/depth)	(181 x 96 x 96) mm
Weight P1601 P1602 P1702 Field chamber insert	 760 g 745 g 710 g 45 g
Frequency range ***P1601*** ***P1602***, ***P1702***	0 – 1 GHz 0 – 3 GHz
Terminating resistor in the RF current path	without

7.1 Characteristics

7.1.1 Characteristics of the field probes in the P1600 series

7.1.1.1 Magnetic field probes in P1600 series, probe constants

h [mm]	$L_h´$ [pH/mm²]
3	24.4
10	12.4
	$u_{ind} = L_h´ \cdot A_{IC} \cdot di_P / dt$ $U_{ind} = L_h´ \cdot A_{IC} \cdot \omega \cdot I_P$

Table 2 Parameters of the field probes in the P1600 series

7.1.1.2 BPM 02

Bandwidth	3 GHz
Error	approx. 10 %
Transfer function	$I_{IC} = U_{TG}$ -49.55 dBΩ

Table 3 ***BPM 02***

7.1.2 Characteristics of the P1702 E-field probe 1702

7.1.2.1 P1702 E-field probes, probe constant

h [mm]	$C_1´$ [f F/mm²]
3	2.95
10	0.88
$I_P = C_1´ \cdot A_{Pad} \cdot \omega \cdot U_{IC}$	

Table 4 Parameters of the ***P1702*** field probe

7.1.2.2 EPM 02

Bandwidth	3 GHz
Error	approx. 10 %
Transfer function (h = 10 mm)	$Q_P(\omega) =$ -279.5 dBF + $U_{TG}(\omega)$

Table 5 ***EPM 02***

8 Scope of delivery

Pos.	Item	Designation	Qty.
1	Magnetic field probe	***P1601/P1602***	1/1
2	E-field probe	***P1702***	1
3	ChipScan-ESA software	**CS-ESA**	1
4	Spacer ring 3 mm	***D70 h03***	1
5	Spacer ring 10 mm	***D70 h10***	1
6	Field chamber insert	***FKE 30***	1
7	Measuring cable	***SMA-SMA 1 m***	1
8	Measuring cable	***SMA-SMB 1 m***	1
9	N/SMA adapter	***N-SMA***	1
10	Ḃ-field meter	***BPM 02***	1
11	Ė-field meter	***EPM 02***	1
12	Case		1
13	Quick guide		1
14	User manual		1

The scope of delivery may differ depending on the respective order.

9 Information on Recycling and Disposal

DE 80567526

In accordance with the WEEE Directive 2012/19/EU (Waste of Electrical and Electronic Equipment), the following must be observed:

At the end of its service life, this product should be taken to a suitable disposal facility for recycling and disposal. Do not dispose of with household waste.

10 Customer Service

Please contact us if you have any questions, comments or suggestions.

You can contact us:

Monday – Friday

8:00 Uhr bis 15 Uhr (CET)

Contact us at:

Address: Langer EMV-Technik GmbH
Nöthnitzer Hang 31
01728 Bannewitz
Germany

Internet: https://www.langer-emv.com/
E-mail: sales@langer-emv.de
Phone: +49 (0) 351-430093-0
Fax: +49 (0) 351-430093-22

Calibration

We recommend having the product calibrated every two years by the manufacturer Langer EMV-Technik GmbH or by a certified distributor.

11 Warranty

Langer EMV-Technik GmbH shall remedy all defects attributable to material or manufacturing faults within the statutory warranty period by repairing the product or supplying replacement parts.

This guarantee is only granted on condition that:

- the information and instructions in the operating instructions are observed.

The guarantee expires if:

- an unauthorized repair is carried out on the product
- the product is modified
- the product is not used as intended