Calibration of Vertical Monopole Antennas (9kHz - 30MHz)

Schwarzbeck, Dieter
An der Klinge 29
D 69250 Schoenau / Germany
support@schwarzbeck.de
www.schwarzbeck.com

Introduction

Active vertical monopole antennas have become very popular in the EMC community within the last decades. They are mentioned in several EMC standards, e.g MIL STD 461, ANSI C63.5, IEEE 291, CISPR 16-1-4 and CISPR 25 and many others. Most available designs have a vertical rod of typically 1 m length, some models come with 41 inch rods (1.04 m), others have telescopic elements to set up a variable length. Many models are equipped with a metallic counterpoise of 0.6 x 0.6 m. Nearly all available vertical monopole antennas are battery driven to avoid difficulties with multiple reference ground conditions. The vertical rod is followed by an amplifier with an input impedance in the order of 100 kΩ to a few MΩ. The output of this (or a following) amplifier is usually well matched to the 50 Ω system. In the context of this document, these amplifiers are also called 'matching unit'. Some monopole antenna designs allow the use of a plug-in divider directly at the rod, which is sometimes very useful when strong signal levels are present or to identify overload situations. The plug-in divider at the front-end of a monopole antenna can not be replaced adequately by a switchable step attenuator at the input of an EMI-receiver, since the plug-in divider protects the whole broadband semiconductor circuitry of the monopole antenna itself.

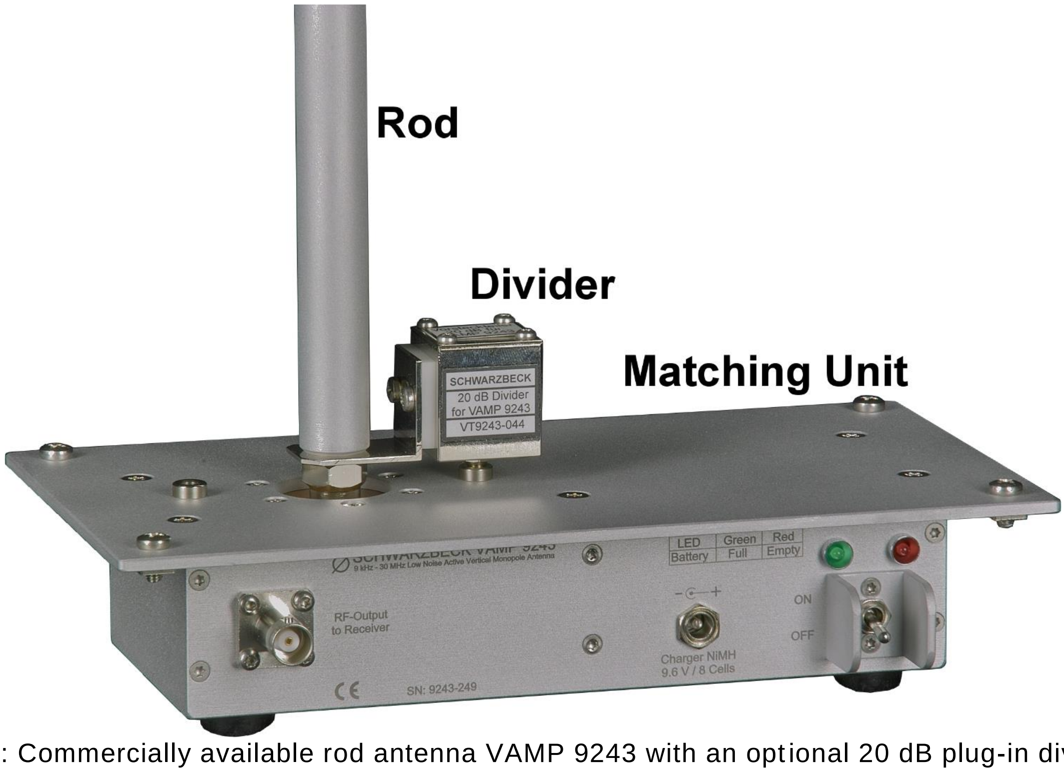

Fig. 1: Commercially available rod antenna VAMP 9243 with an optional 20 dB plug-in divider. A counterpoise of 0.6 x 0.6 m (not shown) can be connected to the horizontal flange plate.

Other designs offer possibilities (not recommended) to switch the lower cut off frequency below 9 kHz (e.g. to 30 Hz), with the negative effect of permanent overload of the matching unit caused by excessive noise being radiated by power lines everywhere nowadays. In contrast to dipoles, which are symmetrical antennas, the nature of a monopole antenna is to be unsymmetric above earth. The monopole antenna measures the vertical polarized E-field component of an electromagnetic field.

The question of calibration came along with the increasing popularity of active rod antennas. If we consider the wavelengths λ in the frequency range of interest we have λ = 33.3 km at 9 kHz and λ = 10 m at 30 MHz, therefore the rod antenna of 1 m length can be regarded as electrically very small compared to the wavelength. This fact allows to regard voltage or current distributions along the rod to be linear instead of damped sinusoidal with negligible error.

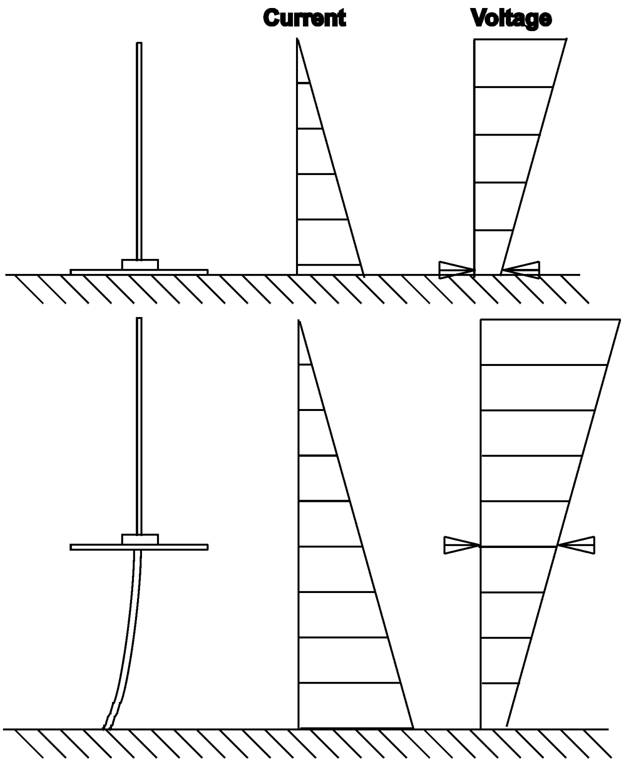

Fig. 2: Current and Voltage Distribution along a vertical rod antenna. The top of the sketch shows the counterpoise connected to the groundplane, the lower part indicates an elevated rod antenna

There are several methods to calibrate vertical active monopole antennas:

- Standard field method on an open area test site
- Standard field method in a stripline
- Equivalent Capacity Substitution Method (ECSM)

The standard field method requires a known field with good uniformity over a certain volume in which the rod antenna under calibration is placed. With the known fieldstrength E and the measured output voltage of the rod antenna V_R, the antenna factor F_A (all in logarithmic measure) is given as:

$$E = V_R + F_A \qquad (1)$$

Special care is needed to generate and investigate the standard field because of several reasons: As indicated above, the wavelengths at the frequencies of interest are relatively long compared to the distance between field generating device and rod antenna under test. Therefore most calibration setups are located in the near field of the source. The free space impedance of 377 Ω, which describes the relationship between E- and H-fieldstrength under farfield conditions, is not valid in the near field region. One solution to overcome this problem at least in the lower frequency range is the use of a TEM-cell or a stripline.

Standard field method in a stripline

Fig. 3 shows a large unsymmetrical stripline with a monopole anntenna inside.

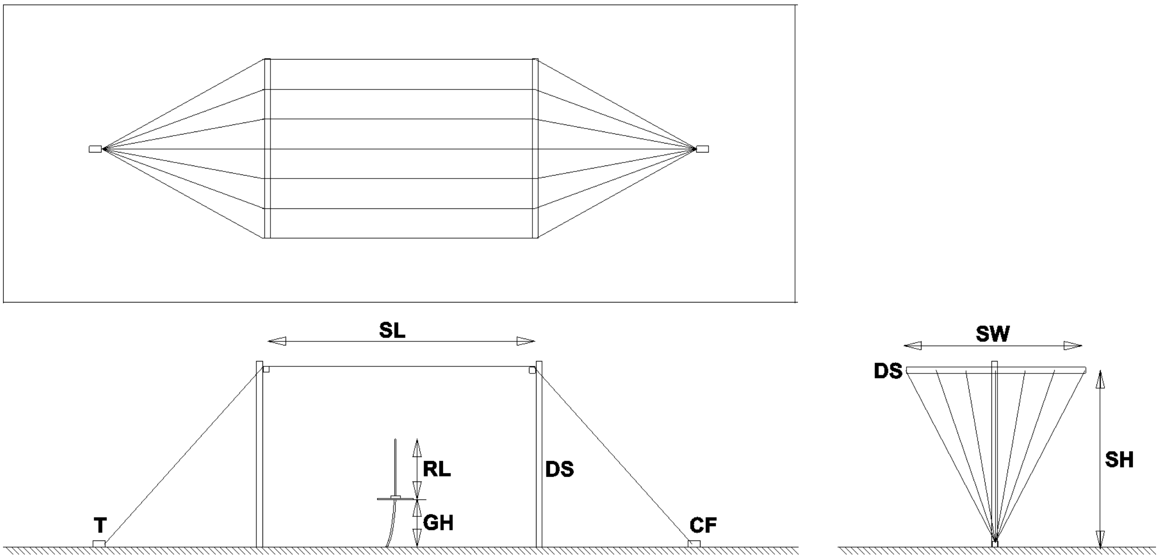

Fig. 3: Unsymmetrical stripline to generate a known standard field for calibration

Key:
T: Termination
CF: Coaxial Feed with Impedance matching
DS: Dielectric Support
SL: Septum Length
SH: Septum Height
SW: Septum Width
GH: Groundplane Height
RL: Rod Length

The TEM-cell or stripline can generate a standard field with E- and H-fields being orthogonal and with an impedance of 377 Ω. The electrical fieldstrength E inside can be calculated as the ratio of the voltage across the septum V_S divided through the septum height SH.

$$E = \frac{V_S}{SH} \tag{2}$$

The characteristic impedance Z_0 of the transmission line depends mainly on the septum width and septum height.

$$Z_0 = \frac{120\pi\Omega}{\frac{SW}{SH} + 1.393 + \frac{2}{3}\ln\left(\frac{SW}{SH} + 1.444\right)} \tag{3}$$

Typical values for the transmission line impedance are around 126 Ω, if the septum width and height are approximately equal. For best field uniformity along the longitudinal extent of the stripline it is advisable to terminate it with its characteristic impedance. The disadvantage of the TEM-cell method is caused by the dimensions of the rod, which should not be larger than a third of the cell's septum height. If we consider the typical rod length of 1 m, the required septum height of the unsymmetrical stripline is 3 m, a Crawford TEM-cell would have an overall height of 6 m! Such large striplines or even Crawford TEM-cells are rarely available and only useable below 20 MHz. As a rule of thumb, the septum height of the stripline should be smaller than a fifth of the wavelength at the highest frequency of interest.

Standard field method on an open area test site
An alternative to the use of striplines is to generate the standard field by means of a passive vertical monopole antenna for transmission. The transmission monopole antenna, marked as TXM in Fig. 4 can simply be a vertical rod.

Fig. 4: Standard field generation with vertical polarized transmit monopole on a conductive groundplane

Key:
TXM: Transmit Monopole Antenna
RXM: Receive Monopole Antenna
D: Distance

A better VSWR for the transmit antenna can be obtained using large biconical cages or collapsible cone elements instead of the rod. A further improvement is to use a voltage transformer to increase the feed voltage, especially in the low frequency range. The distance D between TXM and RXM should be set in a way that a good field uniformity can be provided at the location of the monopole antenna under calibration, designated as RXM in Fig. 4. A further antenna, preferably an active broadband dipole with small dimensions can be utilzed as a transfer standard to obtain a reference to absolute fieldstrength as well as to monitor the field uniformity in the surrounding of the intended location at which the rod antenna is placed later. A reliable rf-contact with low conductivity of both monolpoes to the conducting groundplane is essential, otherwise an unwanted sheath current will appear at the feedpoint of the radiating element and will cause standing surface waves along the coaxial feed cables. These sheath currents let appear the intentional radiating element electrically larger as it really is and have significant influence on the reproducability of the measurements. A good supression of the sheath currents is possible by burying the coaxial cables under the groundplane. Further a low conductive and circumferential grounding of the coaxial cables is helpful to keep sheat currents at a minimum.

Elevated monopole antenna
An interesting effect can be investigated, if the counterpoise of a monopole antenna is elevated above earth: The indicated fieldstrength values obtained from a monopole differ a lot compared to the fieldstrength readings obtained with an active biconical broadband dipole exposed to the same field conditions. Fig. 5 shows the setup.

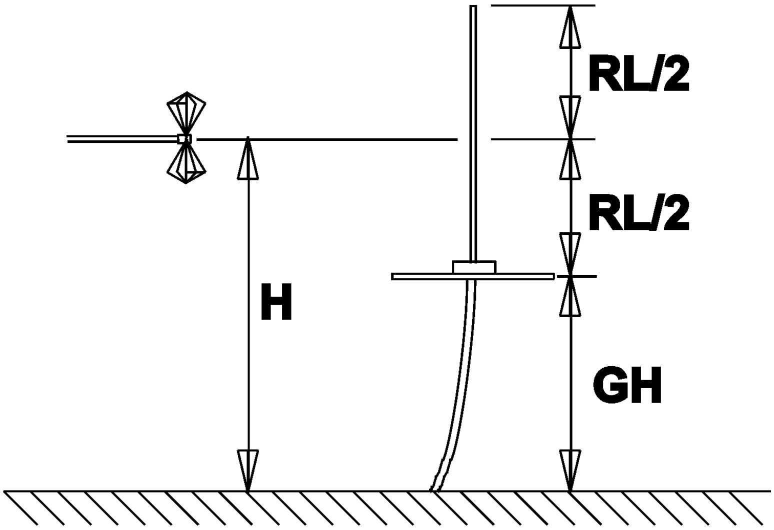

Fig. 5: Elevated monopole antenna and active biconical as transfer device for fieldstrength reference

The small active biconical antenna shows only little increase of fieldstrength when scanned in height whereas the monopole antenna provides a significant rise of fieldstrength when elevated. Obviously the monopole increases its effective area when elevated. In contrast the symmetrical biconical antenna does not. An explanation is given in Fig. 2, which shows the current and voltage distribution along the vertical rod. in the upper part of Fig. 2 the monopole's counterpoise is at groundplane height and connected to the groundplane itself. The lower part of Fig. 2 indicates the elevated rod with counterpoise and the resulting current and voltage distribution, which follows rules comparable to those of the theorie of transmission lines. The horizontal arrows are marking the location of the high impedant voltage pickup, which is realized by the matching unit of the monopole. Obviously the effective electrical size of the monopole antenna is increased by the size of the dropped coaxial cable. According to its unsymmetrical nature, the monopole antenna can not suppress common mode currents at all. Symmetrical antennas instead, with qualified baluns, can suppress unwanted common mode effects in the order of 50 dB or more, depending on the frequency range. That is the reason why monopole antennas should always be operated on ground level or at least with low inductive and short grounding to the absorber lined shielded enclosure. It is recommended to connect the 0.6 m squared counterpoise with a 0.6 m wide metal strip to the reference ground of the measurement facility, as stipulated by most existing standards. In situations, where a reliable bonding to ground is not possible, the height correction of the monopole is helpful to improve the measurement uncertainty. Fig. 6 shows the height dependant antenna factor correction for elevated, high impedant monopole antennas with ungrounded counterpoise. Grounding in this context does not mean the thin connection to ground via the outer conductor of the coaxial cable. An outer conductor of a coaxial cable with a length of a few meters is by far not low inductive enough to provide a reliable grounded condition. The typical outer inductance of a straight coaxial cable is in the order of 1 µH per meter, which leads to an inductive reactance of 188 Ω at 1 m cable length and 30 MHz.

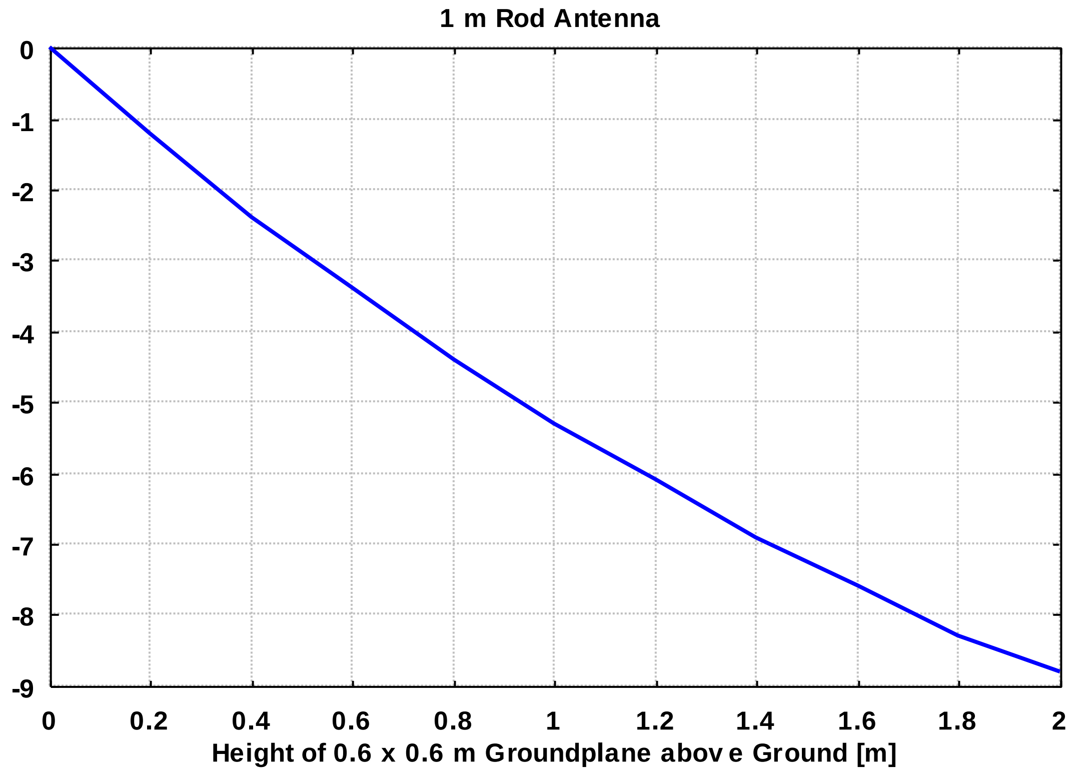

Fig. 6 Height dependant correction of the antenna factor for elevated rod antennas.

The height dependant characteristics apply to all commonly available monopoles of 1 m rod length, independant from manufacturer. The effect of height dependant antenna factor can also be seen in a similar way when rod antennas are calibrated in large striplines, although there are limitations in height and useable frequency range.

In general, symmetrical active antennas are superior to monopoles for measurement applications with high demands for low uncertainties.

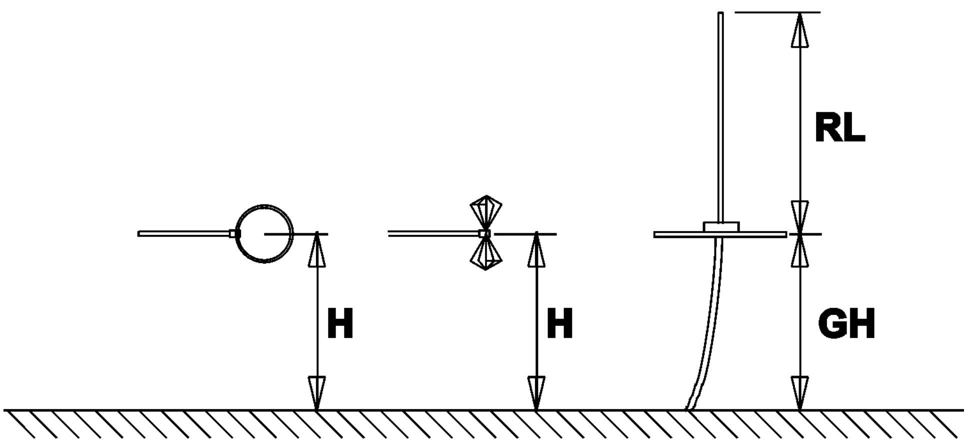

Fig. 7: Calibration setup, consisting of loop antenna, an active biconical and a rod antenna with elevated counterpoise.

Equivalent capacitor substitution method (ECSM)

All commercially available monopole antennas allow the vertical rod to be removed from the matching unit, which provides an important interface to calibrate the antenna by means of the ECSM (equivalent capacity substitution method). This calibration method has become very popular for performance checks of rod antennas in regular intervals made by the end user as well as for calibrations performed by calibration laboratories. The schematic setup is depicted in Fig. 8, a practical implementation of the calibration adapter is shown in Fig. 9 and a combination of matching unit and calibration adapter can be found in Fig. 10.

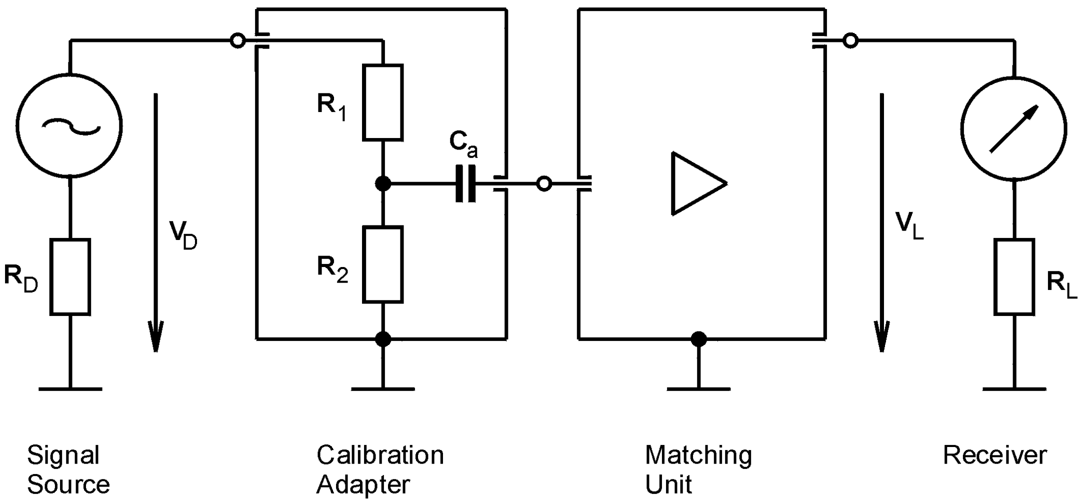

Fig. 8: Calibration setup for active rod antennas according to the ECSM

Fig. 9: Practical implementation of a source matched calibration adapter

Fig. 10: Combination of matching unit and calibration adapter

The calibration setup for monopole antennas is using a calibration adapter which incorporates the electrical height (length h) of the rod (represented by the resistors R_1 and R_2, as well as the rod capacitance Ca. The sum of the resistors R_1 and R_2 shall be 50 Ω to provide good impedance matching towards the source. The ratio of the resistors R_1 and R_2 is usually 1:1, this divides the drive voltage V_D by a factor of 2 (-6dB), which corresponds to the height correction factor for rods of 1 m length. Other rod lengths can be realized by adjusting the resitors R_1 and R_2 accordingly. See Fig. 11 and equation 5 for the most common rod lengths of 1 m and 41".

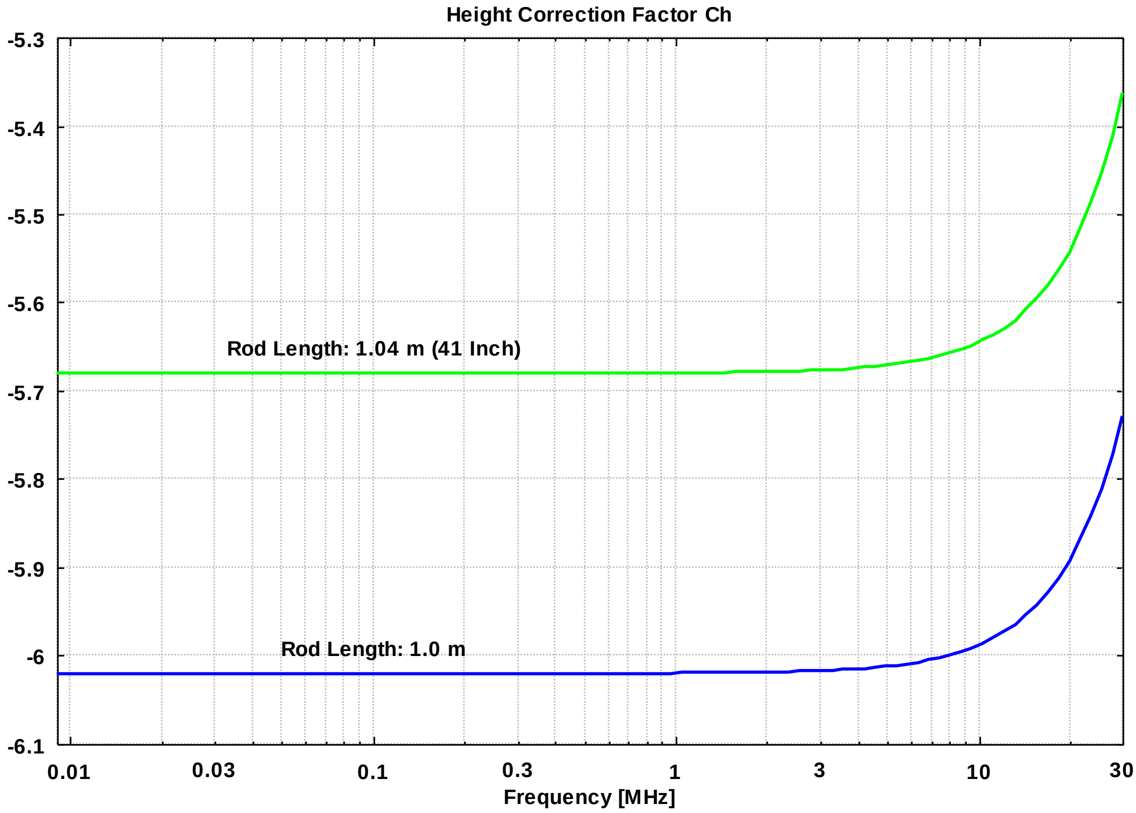

Fig. 11: Graphical presentation of equation 5 (Height correction factor Ch)

$$h_e = \frac{\lambda}{2\pi} \tan\left(\frac{\pi h}{\lambda}\right) \tag{4}$$

$$C_h = 20 \cdot \lg h_e \tag{5}$$

The capacitor Ca represents the self-capacitance of the rod, which is typically between 10 pF and 20 pF for rods of 1 m length, depending on the rod diameter. Fig. 12 shows the rod capacitance for several rod diameters, based on equation 6.

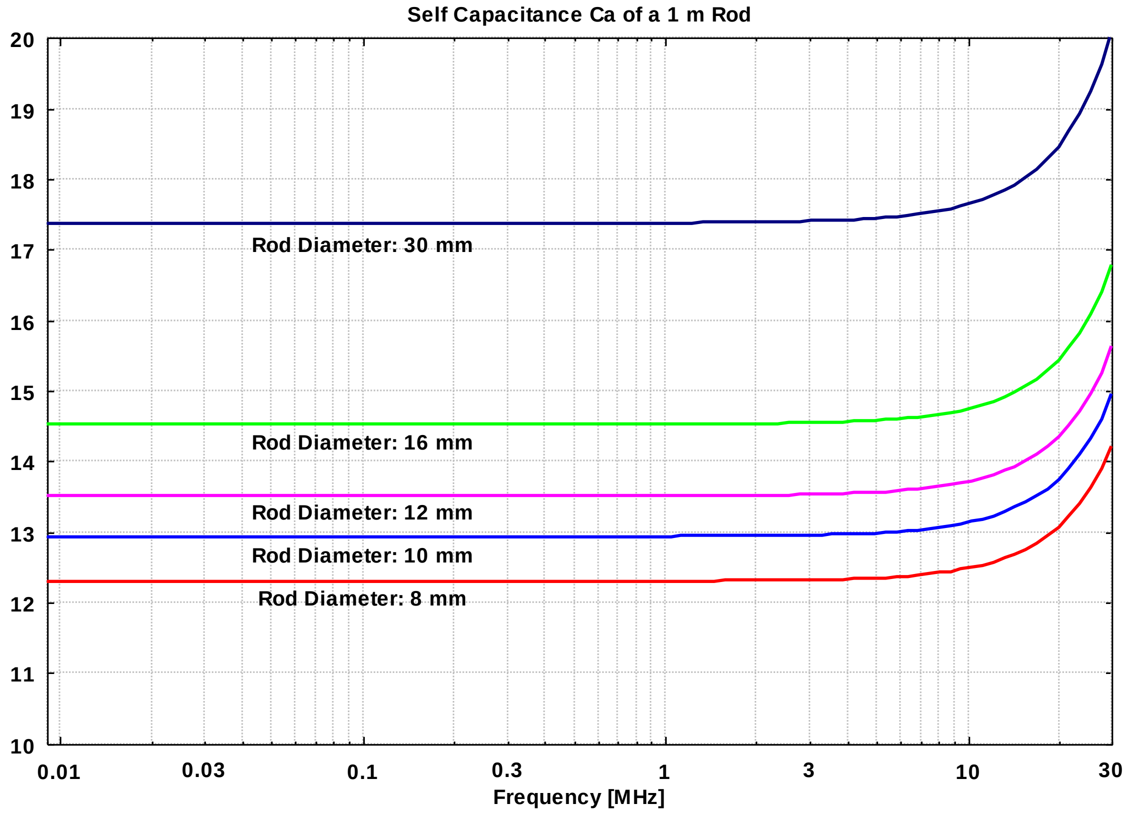

Fig. 12: Graphical presentation of equation 6 (Self-capacitance Ca of a 1 m rod)

$$C_a = \frac{55.6h}{\ln\left(\frac{2h}{a}\right)-1} \cdot \frac{\tan\frac{2\pi h}{\lambda}}{\frac{2\pi h}{\lambda}} \tag{6}$$

Together with the matching unit, which comes with an input capacitance of a few picofarad, a capacitive voltage divider is formed. The capacitive voltage divider is followed by a broadband amplifier, which is also located in the depicted matching unit. The broadband amplifier has to deliver V_L into a 50 Ω load.

The use of this kind of "source matched calibration adapter" leads to:

$$F_A = V_D - V_L \tag{7}$$

The main advantages of the ECSM are:

- Full frequency coverage from 9 kHz to 30 MHz
- Weather independant
- Economic

The ECSM has to be regarded as a relative method, which provides a frequency response. This frequency response requires a reference to an absolute value. The reference to a well known fieldstrength is usually provided by the manufacturer of the respective calibration adapter and rod antenna. It can be obtained by applying the standard field method on an open area test site or in a stripline as described above.