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## Return Loss

### **About the author**

Stefan Burger received his engineering degree from the Offenburg University of Applied Science in 1986. He remained a research associate at the university until 1990. He then transferred to the research and development department of Endress + Hauser in Maulburg.

Until 2001, he was involved in the development of level measuring devices based on RADAR. Among other things, he was responsible for the support of the RADAR modules as well as the development of antennas and pressure-resistant RF components.

From 2001 to 2011, he worked on filters and duplexers for base stations as well as SAW filters at Panasonic Electronic Devices in Lüneburg. He was responsible for the “Lifetime and Power Durability” simulation.

In 2012, he founded his own company, Delta Gamma Consultant ([www.delta-gamma.com](http://www.delta-gamma.com)), in Hampton, Australia. Since 2014, he has been working as an exclusive consultant in the area of RF and measurement technology for el-spec GmbH in Geretsried, Germany.

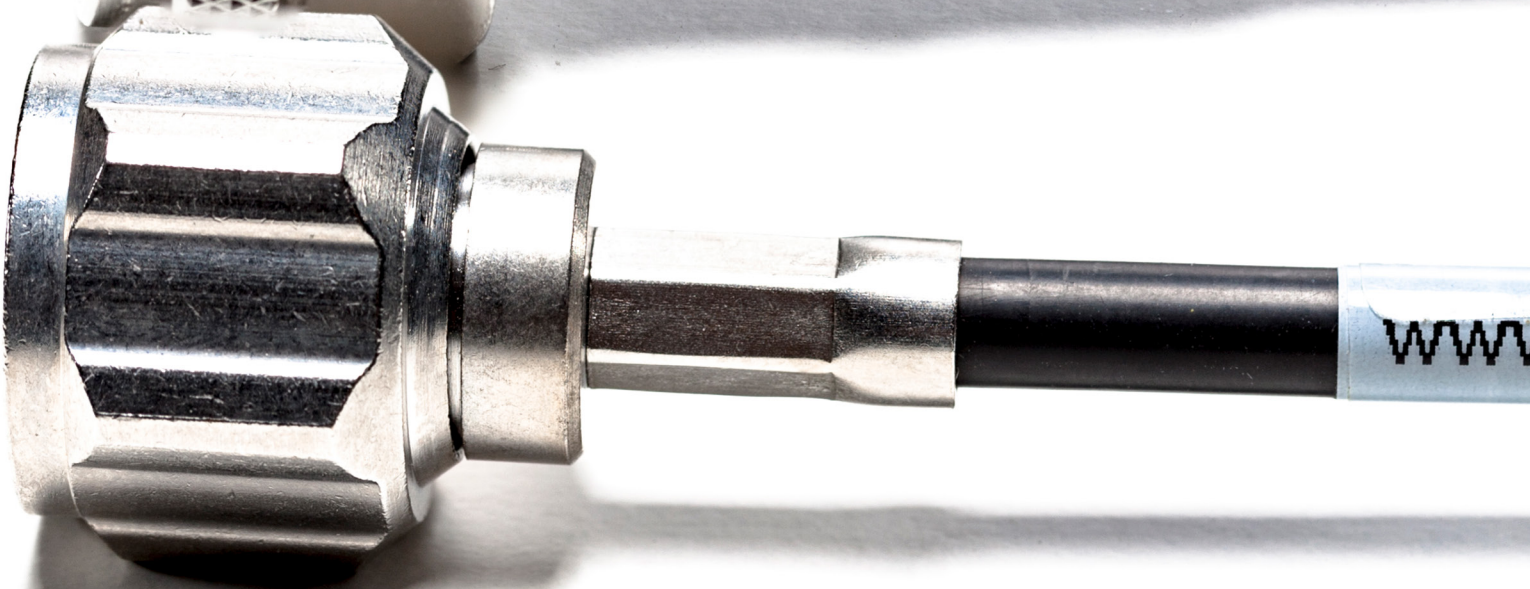
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## Return Loss

Dipl. Ing. (FH) Stefan Burger | Delta Gamma RF-Expert

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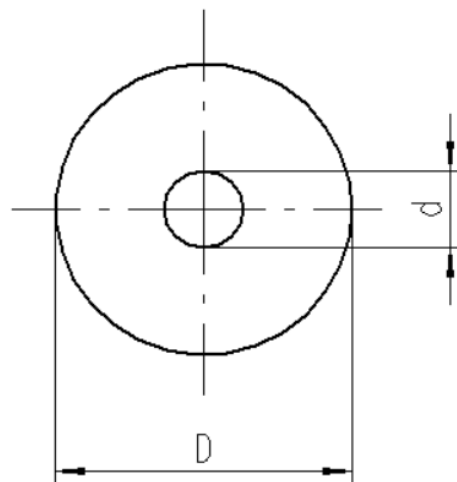
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## Introduction

One of the essential features of high-frequency components and systems is the adaptation of the ports. A vectorial network analyzer (VNA) is generally used to define them. With this, adjustments of 60 dB can readily be measured. These high adjustment values are not measured because the VNA has even better values but rather because its systematic errors are calculated by calibration with a known calibration kit. However, the individual parts of the calibration kit also introduce uncertainties, which also limit the measurement accuracy. It is also questionable whether an adjustment of 60 dB is the true value.

One of the most widely used calibration kits for adjustment measurements consists of an open, short, and load. Relevant is the system impedance, which is usually  $50\Omega$ ; in contrast, systems for broadcasting applications usually have an impedance of  $75\Omega$ .



*Fig 1: Dimension of a coaxial cable*

## Impedanz standard

Support-less coaxial air cables are used as the standard for the impedance. The impedance can be calculated analytically using Equation (1) if the dimension of the cable is known.

$$Z_0 = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{\mu_0}{\epsilon_0 \cdot \epsilon_r}} \cdot \ln \frac{D}{d}$$

$$\epsilon_0 = \frac{1}{\mu_0 \cdot c^2}$$

$$\mu_0 = 4 \cdot \pi \cdot 10^{-7} \frac{N}{A^2}$$

$Z_0$  : Impedance

$\epsilon_0$  : Electrical field constant

$\mu_0$  : Magnetic field constant

$c$  : Speed of light (299,792,458 m/s)

$\epsilon_r$  : Relative permittivity of air 1.00059

$D$  : Diameter of the shield

$d$  : Diameter of the inner conductor

These cables are manufactured with the utmost precision. The following affect the impedance:

- Tolerance of the shield diameter
- Tolerance of the inner conductor diameter
- Humidity
- Surface roughness to higher frequencies

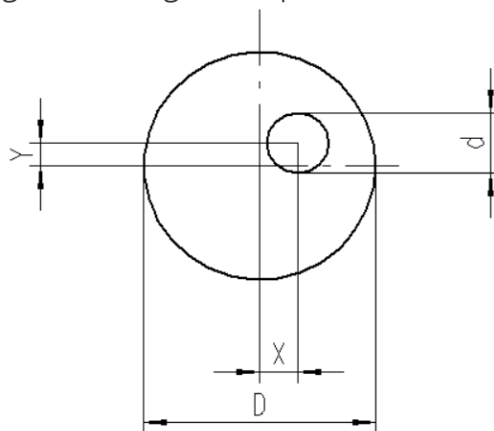


Fig. 2: Coaxial cable with eccentric inner conductor position

Furthermore, the inner conductor is not exactly centered. This influence can be calculated using Equation (4).

Unless the measurements are carried out at extreme temperatures or high altitudes, humidity has the greatest atmospheric effect on the impedance. To estimate the influence, the permittivity values of dry and 100% saturated air from [1] were used to calculate the impedance.

The resulting values have been calculated for the 7.0 mm and 1.0 mm connectors (Table 1) assuming a measurement uncertainty of 1 m. As expected, the achievable adjustment decreases with decreasing coaxial systems because the uncertainty remains constant at 1 m. The eccentricity has almost no influence and can even compensate for the effects resulting from dioptric errors. On the other hand, the humidity has a small yet noticeable effect on the 7 mm plug. This applies only in the case of extreme values (0 or 100%), which should be avoided. In the case of smaller systems, the influence of air humidity will be reduced because the mechanical tolerance is the dominant component.

Table 1: Achievable return loss depending on different influencing variables

Type	D mm	d mm	Z nominal $\Omega$	RL tolerance dB	RL eccentric dB	RL humidity dB
7 mm	7.0	3.0397	50.00	70.879	70.876	69.862
1.0 mm	1.0	0.434	50.03	52.732	52.745	52.675

## Measurement uncertainty

When measuring the adjustment with the VNA, additional factors increase the uncertainty of the measurement. These include:

- Reproducibility when connecting the measuring object
- Frequency drift
- Noise
- Temperature drift
- Phase and damping changes of the measuring cables – if they are moved
- Dynamic range of the VNA
- Linearity

Manufacturers specify the uncertainties for their measuring instruments. These are guaranteed by measuring with measuring instruments that are affiliated with national standards. In Germany, the National Metrology Institute in Braunschweig is responsible for the standards. The uncertainties of the affiliated national institutes are stored and can be viewed at the Bureau International des Poids et Mesures ([kcbd.bipm.org](http://kcbd.bipm.org)).





The PTB [2] guarantees a measurement uncertainty for the reaction measurement of 0.003 with a reaction factor of 0.0–0.2 with a coverage range of 95% (which corresponds to –48.0 dB). The Federal Institute of Metrology, Switzerland, [3] guarantees a measurement uncertainty of 0.002 with a reaction factor of 0.0–0.4 with a coverage range of 95% (which corresponds to –50.5 dB).

As the frequency increases, the accuracy decreases and reaches a guaranteed value of –35.9 dB at 67 GHz. It is only valid if measurements are performed directly at the port of the VNA because further uncertainties will otherwise be added by the measuring cable.

As can be seen from this comparison, there are differences between countries. If high accuracy is required, it is recommended to compare the values. VNAs are usually calibrated at an accredited laboratory, which normally cannot offer this accuracy.

In Germany, they can be found at the German Accreditation Office [4] with regard to their measurement possibilities and the accuracy achieved. For example, Rhode & Schwarz GmbH & Co. KG, (Graf Zeppelin-Strasse 18, 51147 Cologne) specifies a measurement uncertainty of –47.1 dB, whereas Rosenberger Hochfrequenztechnik GmbH & Co. KG (Hauptstraße 1, 83413 Fridolfing) specify an uncertainty of –43.1 dB at best (November 2016). Furthermore, the manufacturers of the measuring devices specify typical uncertainties of the VNAs. For example, the ZVB of Rohde & Schwarz is 0.009 (which corresponds to –40.0 dB). The ZVA of Rohde & Schwarz is 0.005 (–44.4 dB) at best.

## Measured value with measurement uncertainty

What is the measurement of 60 dB mentioned in the introduction? If a VNA is calibrated and the calibration load is then connected, a calibration kit can be used to measure adjustment values of 60 dB for which the load is not characterized. In the calibration for the load 50  $\Omega$  is calculated, even if it is really 50.05  $\Omega$ , for example. What is displayed is the adjustment to the actual value and not to 50  $\Omega$ . The uncertainty is to be added to this value in order to obtain the range in which the actual value lies.



## Legal

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