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# Minimum Attenuation

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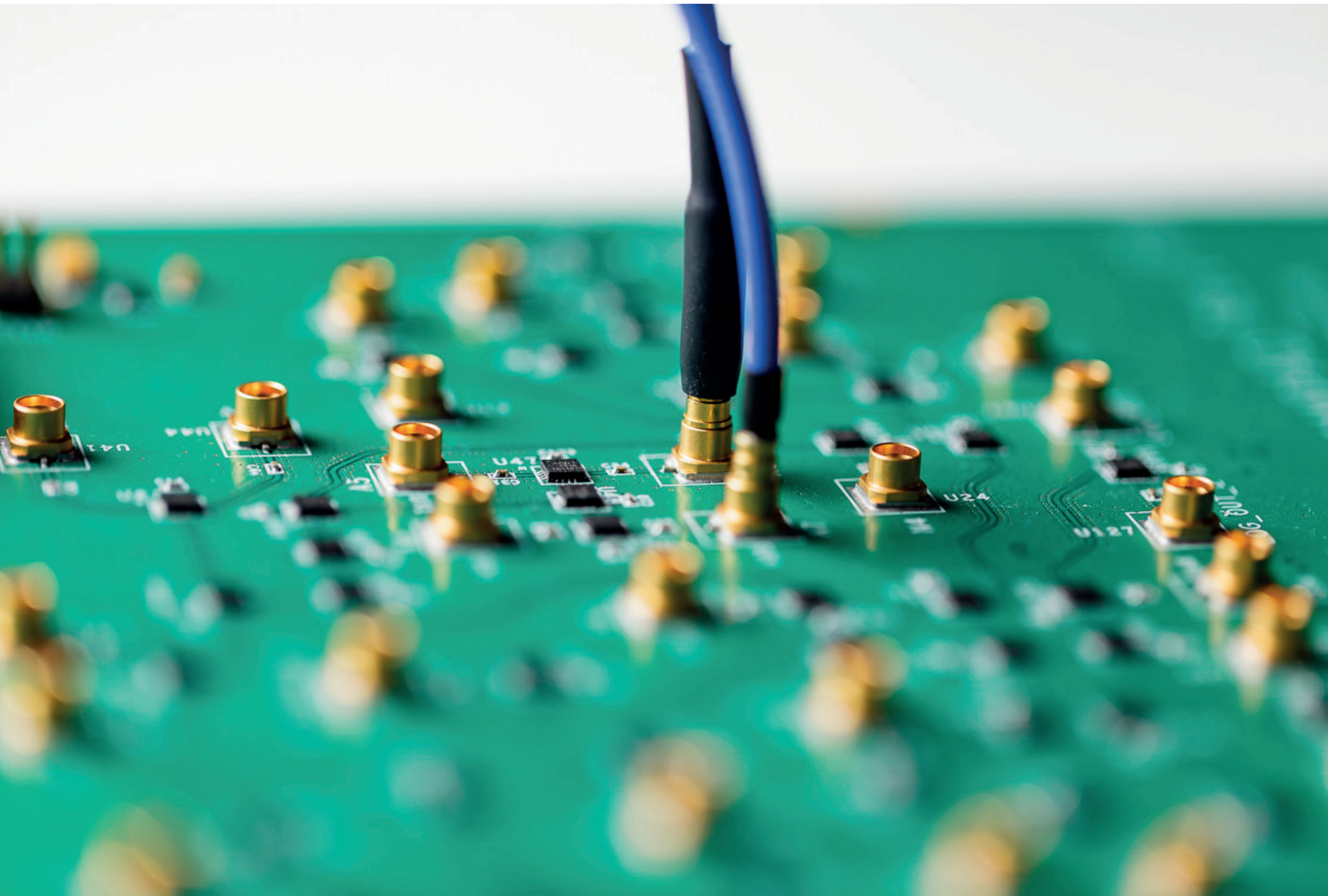
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## Introduction

Coaxial cables are used in many different areas. Depending on the place of use, the most important criterion is undistorted signal transmission with regard to the signal form or only minimal attenuation. The smallest possible attenuation value is then desired. But how large is it in relation to the maximum frequency to be transmitted?

To find out more about this, we first look at the properties of the coaxial cable.

# 1 Coaxial cable parameters

The impedance of the coaxial cable is calculated as follows

$$Z_L = \frac{\mu_0 \cdot c_0}{2 \cdot \pi \cdot \sqrt{\epsilon_r}} \cdot ln \frac{D}{d} \tag{1}$$

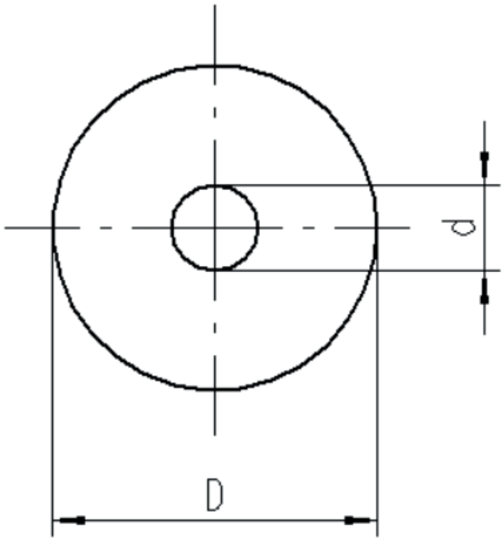



Figure 1: Cross-section of a coaxial cable

$Z_L$ : Impedance

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

$c_0$ : Speet of light $299\,792\,458 \frac{m}{s}$

$\epsilon_r$ : Permittivity of dielectric

$D$ : Shield diameter

$d$ : Inner conductor diameter

The attenuation along the line is determined by the ohmic resistance of the metals used and the dielectric losses of the insulator between the inner and outer conductor. They are calculated with the following equations:

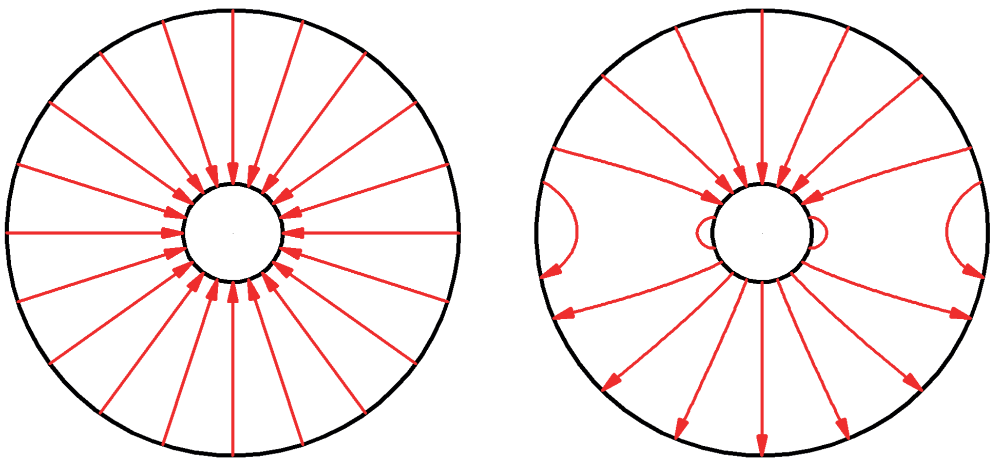
$$\alpha_R = \frac{20}{\ln(10)} \cdot \frac{\sqrt{\pi \cdot f \cdot \epsilon_0 \cdot \epsilon_r}}{\ln\left(\frac{D}{d}\right)} \cdot \left(\frac{1}{d \cdot \sqrt{\sigma_i}} + \frac{1}{d \cdot \sqrt{\sigma_o}}\right) \left[\frac{dB}{m}\right] \tag{2}$$

It should be noted that the equation is not suitable for calculating the true value at low frequencies. The resistance then tends towards zero. It is irrelevant for the analysis.

$$\alpha_R = \frac{20}{\ln(10)} \cdot \frac{\pi \cdot f \cdot tan\big(\delta(f)\big) \cdot \sqrt{\epsilon_{r(f)}}}{c_0} \left[\frac{dB}{m}\right] \tag{3}$$

From the equations, it can be seen, that the ohmic loss becomes smaller as the diameter is increased and inversely proportional to the conductance of the metal used. The dielectric losses, on the other hand, are independent of the geometry, decrease when an insulator with lower permittivity is used and are permittivity is used and are proportional to the loss angle of the material. Therefore, care should be taken to keep the losses of the insulator as low as possible.

The diameter of the line cannot be increased arbitrarily, because otherwise higher modes become capable of propagation. The diameter should be chosen so that that just above the maximum frequency to be transmitted is the cut-off frequency of the TE11 mode. It can be calculated with the following equations
equations below.



(a) TEM Mode (b) TE11 Mode

Figure 2: Electrical Field of TEM und TE11 Mode

$$\left(J_0(x\cdot A)-J_2(x\cdot A)\right)\cdot\left(Y_0(x)-Y_2(x)\right)-\left(Y_0(x\cdot A)-Y_2(x\cdot A)\right)\left(J_0(x)-J_2(x)\right)=0 \tag{4}$$

$$A=\frac{R}{r} \tag{5}$$

$$f_c=\frac{x\cdot c_{0\cdot(A+1)}}{(R+r)\cdot 2\cdot\pi\cdot\sqrt{\epsilon_r}} \tag{6}$$

$J_n$ : Bessel function of the first type

$Y_n$ : Bessel function of the second type

$R$ : Screen radius

$r$ : Inner conductor radius

## 2 Attenuation of an air coaxial cable

The minimum attenuation will be for a coaxial cable, which has no or minimal dielectric losses. For this example, we assume air as the dielectric, with no losses. The metal is assumed to be silver with $\sigma_i = 5{,}16\cdot 10^7\ \frac{S}{m}$ assumed.
The maximum frequency to be transmitted should be 18 GHz and the impedance of the cable 50 Ω. By rearranging equation (1), we obtain the diameter ratio:

$$\frac{D}{d}=e^{\left(\frac{Z_L\cdot 2\cdot\pi}{\mu_0\cdot c_0}\right)}=2{,}3023 \tag{7}$$

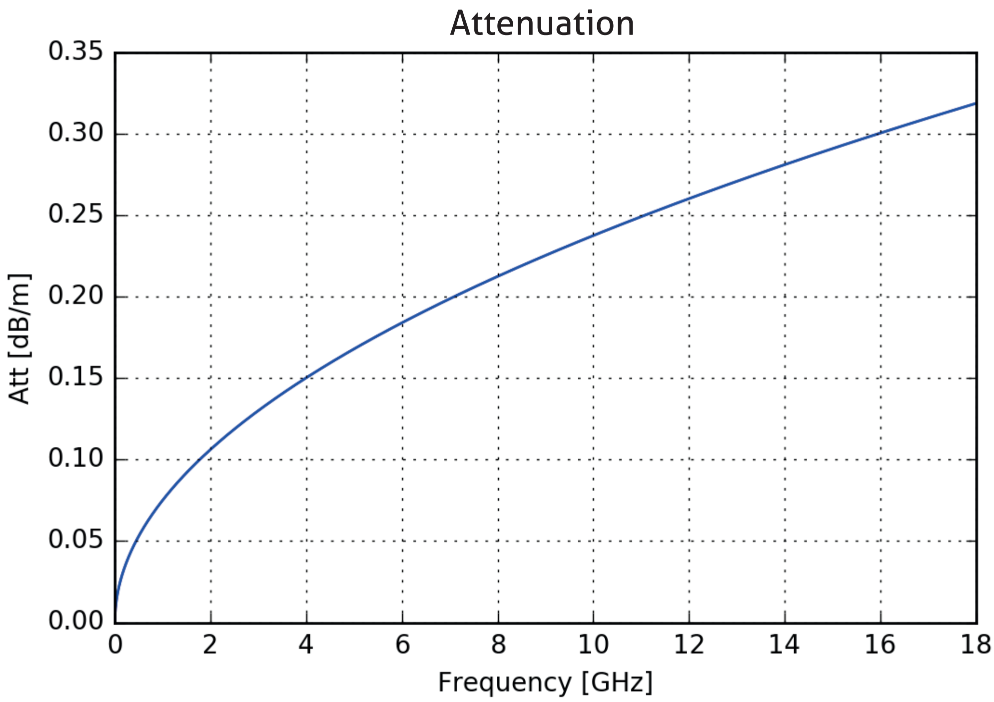
By substituting the ratio in equation (4) and varying x until the equation becomes zero, the diameters are determined at the cut-off frequency equal to 18.1 GHz. The diameter of the screen is D = 7.5 mm.
For such a cable the minimum attenuation is 0.318 dB/m. This means the surfaces of the metal are absolutely smooth and the inner conductor is held concentrically without supports.

# 3 Attenuation of a coaxial cable dielectric

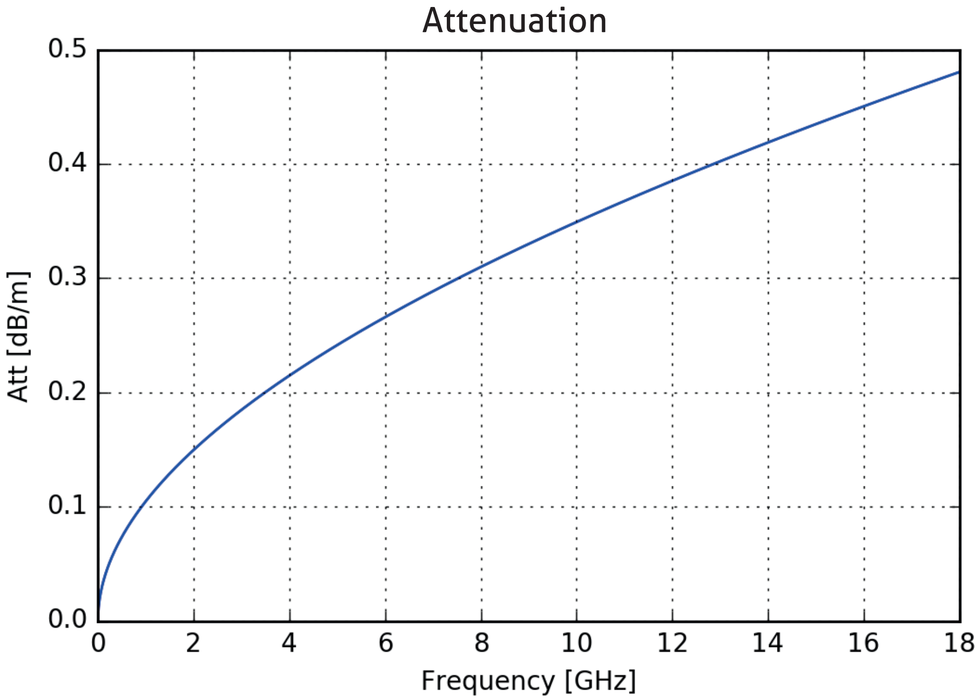
To keep the inner conductor concentric with the shield, it is sheathed with plastic. The influence of dielectric losses is reduced if as little of the plastic as possible is used. One possibility is to use a support that winds around the inner conductor in a spiral. The other possibility is to expand the plastic, e.g. foam it, to increase the air content.

In the example, expanded PTFE with a permittivity of 1.56 and a loss angle of $3 \cdot 10^{-5}$ is considered, as well as silver as the conductor material. As before, the diameter is designed so that the cut-off frequency is 18.1 GHz.

$$\frac{D}{d} = e^{\left(\frac{Z_L \cdot 2 \cdot \pi \cdot \sqrt{\epsilon_r}}{\mu_0 \cdot c_0}\right)} = 2{,}8336 \tag{8}$$




(a) Air




(b) ePTFE

Figure 3: Minimal Attenuation

The diameter of the screen is D = 6.4 mm and has a minimum attenuation of 0.48 dB/m at 18 GHz. attenuation of 0.48 dB/m at 18 GHz.

## 4 Influence of the surface roughness

In order to take into account, the influence of the surface roughness on the losses, various methods were applied, which, however, have no connection with measured variables. Optical or mechanical measuring methods are used to determine the roughness is determined and from this, e.g. $R_q$ or $R_a$ is calculated. They give the geometric or arithmetic mean value. Gerald Gold [2] published an approach in 2017 in which the additional losses are calculated as a function of the roughness $R_q$ . He verified the results with a measurement of a 1 metre stripline where the roughness was 0.4 µm and 1 µm. The attenuation increased by 7.8 % and 26.6 %.

Since the roughness is not known exactly, it will be somewhere in between. This results in a minimum attenuation at 18 GHz of 0.52 to 0.61 dB/m.

## Bibliography

[1] S. Burger: Koaxialkabel - Aufbau und Verwendung, Delta Gamma RF-Expert https://www.elspecgroup.de/whitepaper

[2] G. Gold, K. Helmreich: *A Physical Surface Roughness Model and Its Applications,* IEEE Transactions on Microwave Theory and Techniques, 2017, Vol. 65, pp 3720 - 3732

## Imprint

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