The Power Electronic Environment on More Electric Aircrafts

A way to improve signal integrity by means of shielded cables

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There is a varied array of different interference sources in an aircraft and its engine, for example power electronics and generators. The frequency of such sources ranges from DC to MHz. It is essential that transmitted signals are not interfered with by any disturbance sources. On an aircraft, signal integrity is safety critical and, as such has to be ensured. In future aircraft and their engines, the number and the size of power electronics will increase significantly along with the number of disturbance sources. Shielding of signals on aircraft and their engines is an important topic if these technologies are to be utilised.

Kilometres of shielding are required to transmit signals through cables in aircraft. Today, the optical coverage, or shield damping, parameters are used to describe a cable's quality and signal integrity. This paper introduces the concept of cable transfer impedance for aircraft applications. It will be discussed why the cable transfer impedance allows a significant improvement of the signal integrity and, how a weight reduction can be achieved.

1 Introduction

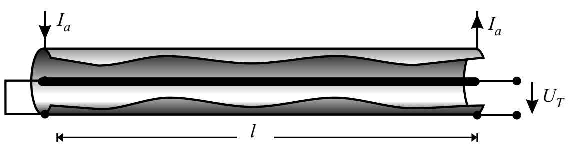

Abbildung 1: Shielded cable

To determine the interference coupling into a coaxial cable knowledge of the transfer impedance is necessary.

Fig. 1 shows an arrangement that allows the determination of the cable transfer impedance. The Figure shows a shielded cable. The inner line is located in the middle of the cable. The cable is surrounded by a shield. The shield consists of a very good conducting material e.g copper. Copper braids are very common. An insulator disconnects the shield and the inner line. The signal will be transmitted between inner line and the shield. In the arrangement in Fig. 1 an electrical current is forced on the outer shield. On the left hand side the inner line is connected to the shield. On the right hand side the voltage U_T can be measured. The current on the shield causes disturbance inside the cable, due to the shield being not ideal (e.g. In a copper braid one will find small holes). The measured voltage is proportional to these disturbances. The transfer impedance is defined by:

$$Z'_T = \frac{U_T}{I_a\ l} \tag{1}$$

The disturbance signal U_T inside the cable is divided by the disturbances causing the current I_a. U_T is also divided by the cable length to make Z_T independent of cable length. This is denoted by the tick $'$. Therefore Z'_T purely describes the quality of the cable.

For example: Let us consider the shield as ideal. A forced current on the shield would not cause any disturbance inside the cable. This would result in voltage $U_T = 0$ and therefore also in transfer impedance $Z'_T = 0$. Thus, equation (1) points out the higher the transfer impedance the worse the quality of the cable. Please not that the transfer impedance is frequency dependent and therefore a complex quantity.

2 Measurering the transfer impedance

In this section the Current Line Input Impedance Method (CLIIM) is presented [1]. The CLIIM allows the determination of the transfer impedance up to a high frequency range. The arrangement of the CLIIM is shown in Fig. 2.

A Cable Under Test (CUT) is mounted on a bar made of copper as shown in Fig. 2. The system is driven by a voltage U_0 between the bar and the cable shield. This voltage U_0 produces a current $I_a(x)$ in the cable. At the left-hand side, the inner conductor is terminated inside the cable by an impedance Z_1. The cable shield at the right-hand side is connected to the ground plane by a solid copper bracket. Typical dimensions used

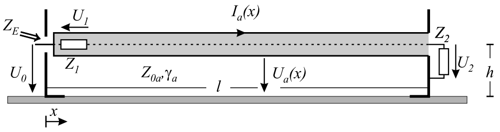

Abbildung 2: Current Line Input Impedance Test Fixture.

for this arrangement are: length $l = 80$ cm and height $h = 2$ cm. The voltage U_2 is measured at the load impedance Z_2. This voltage U_2 also can be described by the formula [2]:

$$U_2 = Z_2 \, \frac{1}{p} \int_0^l I_a(x) Z_T' [Z_1 \sinh(\gamma x) + Z_0 \cosh(\gamma x)] dx, \qquad (2)$$

where

$$p = (Z_1 Z_2 + Z_0^2) \sinh(\gamma l) + Z_0(Z_1 + Z_2) \cosh(\gamma l) \; . \qquad (3)$$

The characteristic impedance Z_0 and the propagation factor γ are normally given by the cable manufacturer or can be measured using well established techniques. The load impedances Z_1 and Z_2 should have the same value as the characteristic impedance Z_0 of the cable to reduce reflections. Thus, only the current $I_a(x)$ and the transfer impedance Z_T' are unknown in eq. (2).

To determine the current $I_a(x)$ in the cable shield, transmission line theory is used. The first step is to determine the characteristic impedance of transmission drive line formed by the CUT and the copper bar. This is then used to calculate the current flow in the shield. The characteristic impedance of the drive line is determined in the low frequency range where the cable shield and the copper bar can be assumed to be a lossless transmission line. The propagation factor outside the cable is considered to be as in a vacuum: $\gamma_a = \sqrt{-\omega \mu_0 \varepsilon_0}$. The copper bracket at the right-hand end behaves like a short circuit at low frequencies. Therefore at low frequencies the CUT and the copper bar are considered to be a short circuited transmission line. The characteristic impedance can now be determined by [3]:

$$Z_{0a} = \frac{Z_E}{\tanh(\gamma_a l)}. \qquad (4)$$

The input impedance Z_E can easily be measured, for example by using an S-parameters test set. The characteristic impedance Z_{0a} determined in the low frequency range is also valid in the high frequency range because the characteristic impedance is frequency independent for a lossless transmission line. At high frequencies the copper bracket at the right hand end of the arrangement cannot be considered to be a short circuit. The bracket has an unknown impedance. To compute the current for a transmission line terminated by an unknown impedance one can use [3]:

$$I_a(x) = \frac{U_0}{Z_E} \cosh(\gamma_a x) - \frac{U_0}{Z_{0a}} \sinh(\gamma_a x) \; . \qquad (5)$$

The input impedance Z_E is measured. Now the current $I_a(x)$ can be computed. Substituting the current $I_a(x)$ in eq. (2) leads to

$$U_2 = \frac{Z_2}{p} \int_0^l U_0 [\frac{1}{Z_E} \cosh(\gamma_a x) - \frac{1}{Z_{0a}} \sinh(\gamma_a x)] \cdot Z_T' \cdot [Z_1 \sinh(\gamma x) + Z_0 \cosh(\gamma x)] dx \; . (6)$$

The transfer impedance Z_T' and the exciting

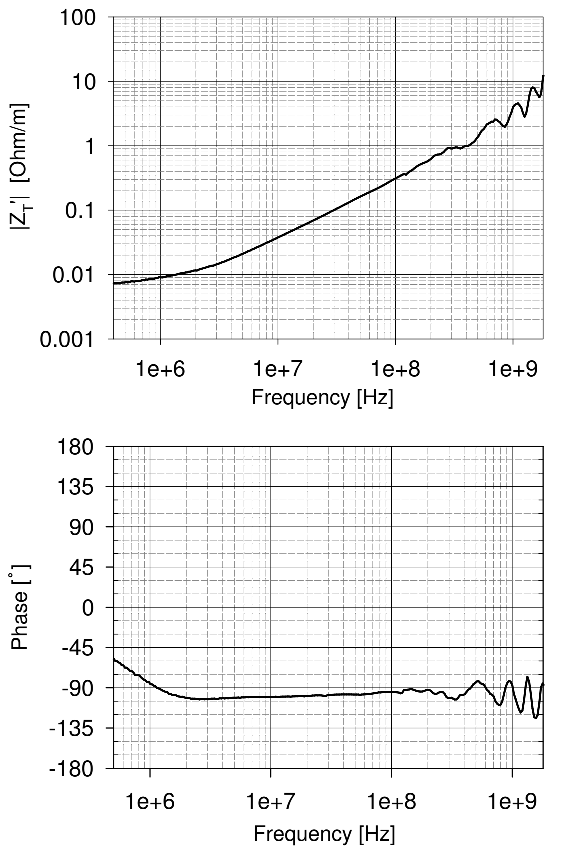

Abbildung 3: Transfer impedance of braided shield (type RG 213).

voltage U_0 are independent of x. Thus, equation (6) can more simply be written as:

$$\frac{U_2}{U_0} = F_L \cdot Z'_T \qquad (7)$$

where

$$F_L = \frac{Z_2}{p} \int_0^l \left[\frac{1}{Z_E}\cosh(\gamma_a x) - \frac{1}{Z_{0a}}\sinh(\gamma_a x)\right] \cdot [Z_1 \sinh(\gamma x) + Z_0 \cosh(\gamma x)] dx \; . \qquad (8)$$

The coupling factor F_L can be found by a combination of measurement and computation. The ratio U_2/U_0 can be measured. Now, the transfer impedance Z'_T can be determined by using equation (7).

In summary, the following steps were used to determine the transfer impedance:

- mount the cable over the copper bar;
- measure the input impedance and the ratio U_2/U_0 (the easiest way is to measure the S-parameters);
- compute the transfer impedance.

The Current Line Input Impedance Method allows a fast determination of the transfer impedance. Calibrating of the test fixture is not necessary. Nevertheless, this method yields high accuracy results into the GHz range. For example the transfer impedance (magnitude and phase) of a cable (type RG 213) is shown in Fig 3. In the low frequency range the transfer impedance is nearly equal to the resistance of the cable. In the higher range the transfer impedance increases proportionally to the frequency. This is due to the inductive coupling. This means high frequency leads to worse shielding effects.

3 The optical coverage

In this section the Influence of the optical coverage is described. The optical coverage is a quantity that depends on the amount of shielding material e.g. copper. The common understanding is that the higher the optical coverage the higher the qualities of the shielded cable.

In an experiment the screen of a RG 213 cable has been degenerated step by step. The undegenerated braid of a RG 213 cable consists of 24 wire groups each of 8 wires. At the first test, from each wire group one wire was pulled out (RG 213-1). At the second test, two wires were removed (RG 213-2) and so on. This means the optical coverage has been reduced step by step. Fig. 4 shows the results.

The curve RG 213 indicates the typical behaviour of a coaxial cable with a braided shield. In the low frequency range the transfer impedance is equal to the DC resistance of the screen. In the higher range the magnitude increases. The phase decreases and stabilizes at appr.-110°. The magnitude of the RG213-1 cable is a little bit lower than the magnitude of the RG213, and

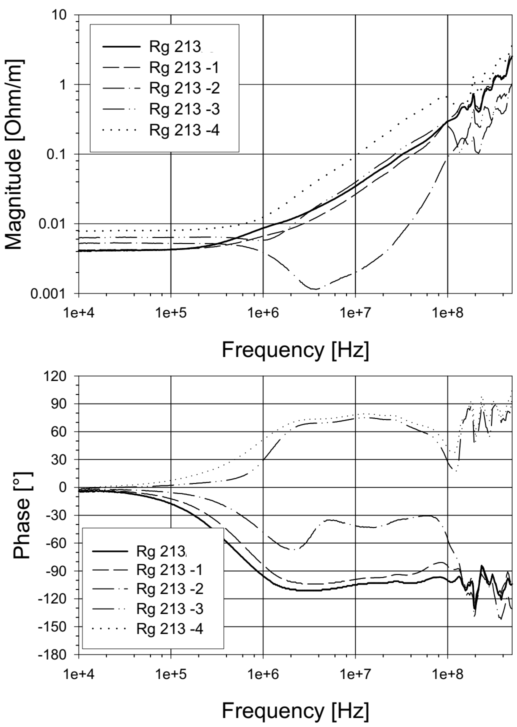

Abbildung 4: Transfer impedance of RG 213 samples

the phase comes up to -105°. A very different behaviour can be seen with the RG213-2 cable. Above 1 MHz the magnitude decreases and the phase remains stable at appr.-45°.

A reduction of the screen coverage of 25% of the RG213 yields the lower transfer impedance, which means an optimised cable screen. Or in other words: Reducing the amount of copper by 25% and also the weight led to better shielding effects up to factor 10. The magnitudes of the curves RG213-3 and RG213-4 increase faster than that of the RG213. The optical coverage is not optimal.

4 Conclusion

The transfer impedance describes the exact quality of a shielded cable. A very good means to measure the transfer impedance is the Current Line Input Impedance Method (CLIIM). The measurement results presented show that the quality of a cable can be improved by reducing the amount of copper. Optimisation of cables can lead to both better shielding effects and reduced weight. These findings show great potential in the application of Electrical Systems for More Electric Aircrafts and More Electric Engines.

5 References

Literatur

[1] R. Tiedemann, "Current Flow in Coaxial Braided Shields" *IEEE Transactions on Electromagnetic Compatibility*, vol. EMC-45, no. 2, 3. August 2003.

[2] A. Smith, *Coupling of external Electromagnetic Fields to Transmission Lines.* John Wiley and Sons, 1987.

[3] H.-G. Unger, *Elektromagnetische Wellen auf Leitungen.* Heidelberg: Hthig, 2. Auflage., 1986.

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About the Author

Roland Tiedemann was born in Hamburg, Germany in 1970. He studied electrical engineering at the Universität Hannover and at the Technische Universität Hamburg-Harburg. In 2001 he received doctorate in engineering at the Technische Universität Dresden. After that time he worked for the automotive industry. Since 2005, he joint the Controls Engineering Department at Rolls-Royce Deutschland.