General Analysis of Leaky Section Cables for Multi-Band Aircraft Cabin Communications with different Measurement Techniques

Short title: Analysis of Leaky Section Cables by Measurement

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Abstract—A leaky section cable (LSC) functions both as a transmission line and as an antenna. Thus this cable type can be applied as a radiating respectively receiving antenna for multi-band aircraft cabin communications like WLAN, GSM, UMTS, DECT X2X. The system integration process requires detailed information about the radiation and transmission behaviour as well as the interference potential of the leaky cable in a large frequency range. Therefore, different, partly novel measurement techniques will be presented, which can be been used to determine the parameters of the radiating cable. The measurements in the different test sides have been carried out in frequency domain respectively in time domain.

Keywords: Leaky section cable; GTEM cell measurement; Open area test side; Transient measurements

1. Introduction

Next generation of aircraft will provide more convenience for passengers, including personal communications facilities. Thus it will be possible to use portable electronic devices (PEDs) in the cabin, such as laptops or mobile phones [1]. In order to enable wireless communication for these PEDs, an onboard system like a wireless local area network (WLAN) has to be built up. For this purpose the cabin may be equipped with a so called leaky section cable (LSC), which can be used as an antenna for WLAN and other applications like GSM, UMTS and DECT X2X. Detailed information about the radiation and transmission behaviour of the leaky section cable (see Fig. 1) are required for the system integration process. Furthermore, the interference potential of the cable should be well known in order to avoid parasitic effects. The different applications are working on different frequencies according to the standards, thus the investigations have been performed in the frequency range from 450 MHz up to 6 GHz.

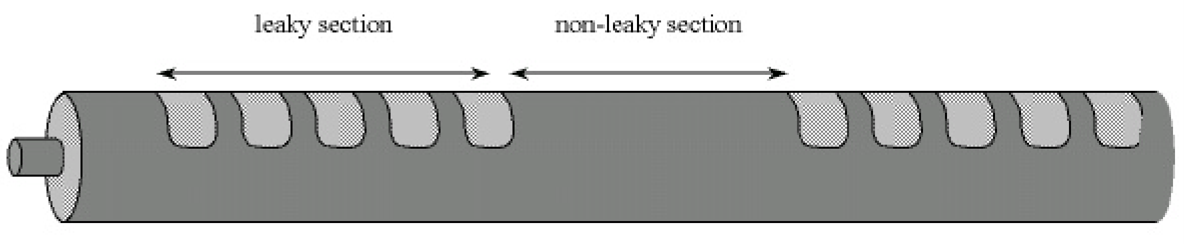

Fig. 1. Principle buildup of a leaky section cable (LSC)

Different measurement techniques have been used to determine the leaky section cable parameters: Radiation measurements in the near and far field have been carried out with continuous wave (CW) signals. Furthermore the transmission behaviour of the cable has been measured. Additionally near field and transmission measurements have been performed with fast transient pulses, which have got double exponential character and are well suited for measurements in time and frequency domain.

2. Measurement Setup

The principles of three partially novel measurement techniques and their setup will be presented below. These different techniques were used to determine the following information about the radiation and transmission behaviour of the LSC: Circular radiation patterns were obtained for different frequencies by Gigahertz transverse electromagnetic mode (GTEM) cell measurements as well as by open area test side (OATS) measurements. The near field scanning technique was used to analyze the distribution of the electric field strength along the cable. In addition the attenuation of leaky section cable was measured.

2.1. GTEM Cell

The circular radiation pattern of the leaky section cable was obtained by the GTEM cell measurement with CW signals. For this purpose a cable with a length of 1 m is positioned inside the GTEM cell according to Fig. 2. It consists of two non-leaky sections at the beginning and at the end of the cable, the middle section is the leaky section which works as transmitting antenna. The cable is orientated perpendicular to the ground plane of the cell and held by a special test fixture that consists of a guide bush at the septum and a feedthrough in the ground plan. This setup allows rotations of the cable around its axis. The beginning of the cable is fed by the tracking generator of a network analyzer, the end is matched with its characteristic impedance. The port of the GTEM cell is connected to the network analyzer mentioned above. Thus it is possible to determine the transfer function of the system that consist of the leaky cable and the GTEM cell. The radiation pattern for each frequency is a polar chart with the magnitude of the transfer function against the rotation angle. The measurements have been carried out in the frequency range from 450 MHz up to 6 GHz.

Fig. 2. LSC in GTEM cell

Fig. 3. Near field measurement

Fig. 4. Open area test side

2.2. Near Field Measurements

The near field scanning technique was used to obtain the distribution of the electric field strength along the cable with CW signals. Fig. 3 shows the measurement setup: A special test fixture made of synthetic material and wood holds the leaky section cable and the electric field probe. The electric field probe is positioned below the LSC and consist of a conical dipole antenna and a balun [2]. The radiating slots of the LSC are orientated towards the field probe. The tracking generator of a network analyser feeds one end of the LSC, the other end is matched with the characteristic impedance of the cable. The output of the field probe is connected to the other port of the network analyzer. For transient measurements, the setup is varied in some details: The network analyser and the dipole antenna are replaced by pulse generator, oscilloscope and conical monpol probe.

2.3. OATS Measurements

OATS measurements took place at DLR site in Oberpfaffenhofen (Germany) under good weather conditions and aimed to obtain the radiation characteristics of a LSC antenna in far field. Phase and amplitude records were taken for parallel and perpendicular polarisation at multiple positions along and around a 3.5 m long straight LSC cable at every 50 MHz in the frequency range of 700 MHz to 2.5 GHz. More exactly at intervals of 0.2 m along the cable and every 0.5° around it with a wideband receiver antenna placed at a radial distance of 5 m. Fig. 4 shows a whole view of the installation. A wooden support held the cable from its back side at 12 cm distance. A mechanical structure held vertically both, the cable and its wooden support, and rotated over the longitudinal axis of the cable while keeping constant the distance between the LSC and the receiver. The LSC was fed by a CW signal in one extrem and adapted at the end.

2.4. Attennuation Mesaurements

For attenuation measurements the leaky section cable is unrolled and positioned on the concrete floor of the laboratory. Both ends of the cable were connected to the ports of a network analyser and the scattering parameter $\underline{S}_{21}$ was measured. $\underline{S}_{21}$ is transfer function of the cable and the connectors at each end.

3. Measurement Results

This section includes the measurement results of the different techniques described in chapter 2 and their evaluation. The results will be presented separately for CW and transient signals.

3.1. Continuous Wave Measurements

3.1.1. Circular Radiation Pattern via GTEM cell measurement

The radiation pattern for each frequency is a polar chart with the magnitude of the transfer function against the rotation angle. It is dependent on the frequency and the rotation angle. The rotation angle is given by the angle scale at the feedthrough in the ground plane of the cell. The rotation angle 0° in the following radiation pattern represents the direction in which the slots in the outer conductor are orientated towards the cell port. Fig. 5 shows representative examples of radiation pattern at 900 MHz, 1.75 GHz and 5.24 GHz.

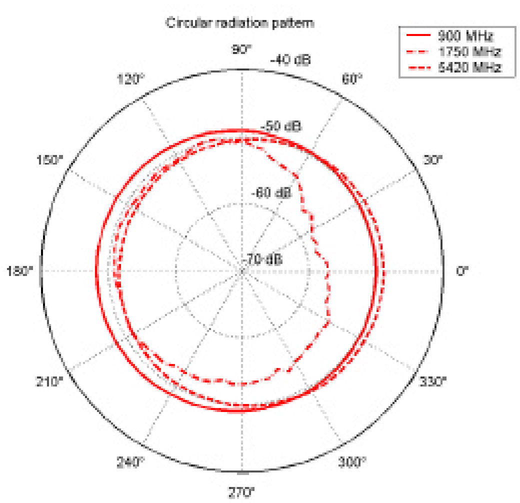

Fig. 5. Near field radiation pattern via GTEM cell

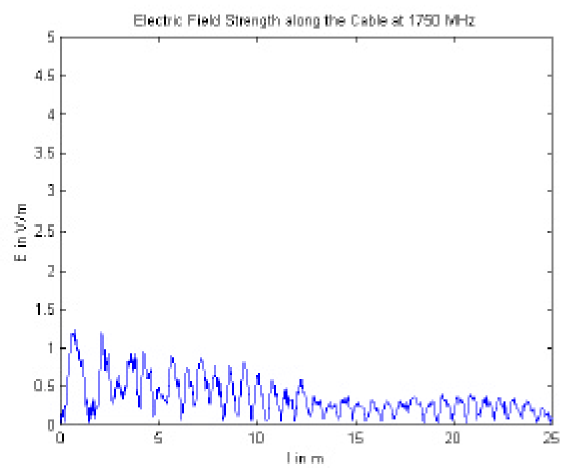

Fig. 6. Electric field strength at 1750 MHz

The circular radiation patterns for frequencies below 2 GHz illustrate that there is a small decrease (maximum 3 dB) compared with the main beam direction. For many frequencies this decrease is smaller than 1 dB. In the higher frequency range around 5 GHz the radiation pattern show main beams in backward direction.

3.1.2. Field Strength Distribution along the Cable

The distribution of the electric field strength along the cable was obtained with near field measurements. All measurements of the cable were performed with a constant rotation angle of the cable, therefore the slots in the outer conductor were orientated towards the field probe as well as possible. The measured magnitude of the transfer function (S_{21}-parameter) between the feeding port of the LSC and the connecting cable of the electric field probe can be converted to an electric field strength via:

$$E = E_0 \cdot 10^{[(S_{21} - S_{kalib})/20\text{dB}]},$$

where S_{kalib} is the calibration value of the used field probe. Fig. 6 shows the field strength distribution for a feeding power of 6 dBm at 1.75 GHz. Increasing the feeding power with the factor a effects an electric field strength that is $\sqrt{a}$ times higher. The electric field strength along the cable decreases exponentially as expected. The measured near field in a leaky section is larger than in a non-leaky section.

3.1.3. Circular Radiation Pattern via Open Area Test Side

One circular radiation pattern was obtained for each of the 37 frequencies studied, at 17 positions along the cable and for two polarisations, which resulted in more than 1200 radiation diagrams.

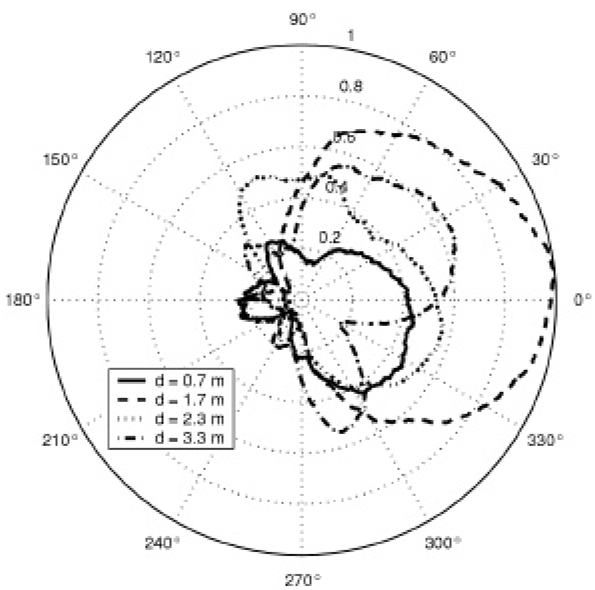

Fig. 7. Far field radiation pattern at 2 GHz (Parallel polarisation)

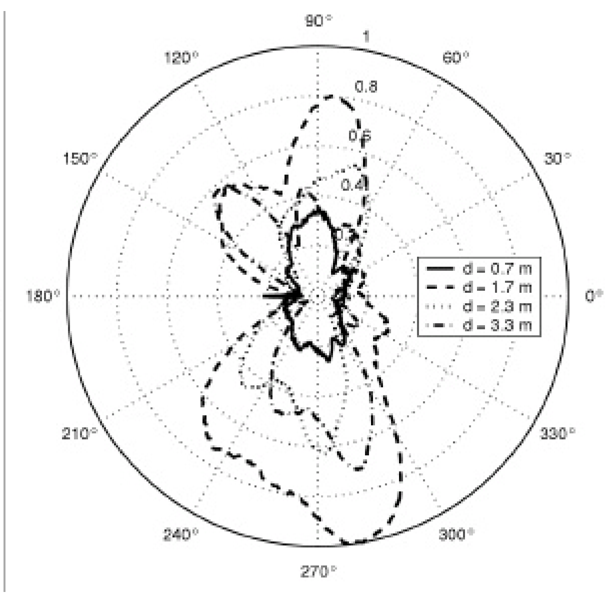

Fig. 8. Far field radiation pattern at 2 GHz (Perpendicular polarisation)

As a representative example of the results Fig. 7 and Fig. 8 plot the radiation pattern at 2 GHz at four distances from the feeding point of the cable. The polar plot represents the module of the electric field strength normalised to the maximum measured at this frequency. 0° indicates the direction in which the cable slots are oriented. In most of the radiation patterns for parallel polarisation, and as it can be seen in Fig. 7, a single and wide main lobe appears with a tendency towards 0°, but big variations of the maximum up to ±60° happen. Moreover, the maximum contribution occurs in ca. 60% of the cases around the center of the cable (for $d \in [1.6, 1.8]\,\text{m}$) and almost always the minimum contribution are for $d < 0.5\,\text{m}$. In seldom occasions there is radiation between 120 and 240°. Regarding the radiation patterns for perpendicular polarisation much more uniformity is found for $f \geq 1.15\,\text{GHz}$. In all cases two clear radiation nulls exist at 0 and 180°. Two inhomogenous 60° wide lobes approximately oriented towards 100° and 270° use to appear in these diagrams. For lower frequencies irregular shapes have been obtained with neither clear zeros nor maximums in any direction.

Therefore, it would be extremly difficult to predict the received power when a LSC antenna is used as a transmitter in a dense environment where many reflections occur, as it happens inside an aircraft. Nevertheless, as it was expected, there is clearly a better coverage situation in a range of ±90° from the slots orientation and far from the cables extremes.

3.1.4. Attenuation Measurement

Fig. 9 shows the magnitude of transfer function (scattering parameter S_{21}) of leaky section cable, which is 35.7 m long. The attenuation of the cable increases towards higher frequencies and is larger than 50 dB in the frequency range above 3.5 GHz. Please note that the total attenuation D has got the opposite sign : $D = -S_{21}$.

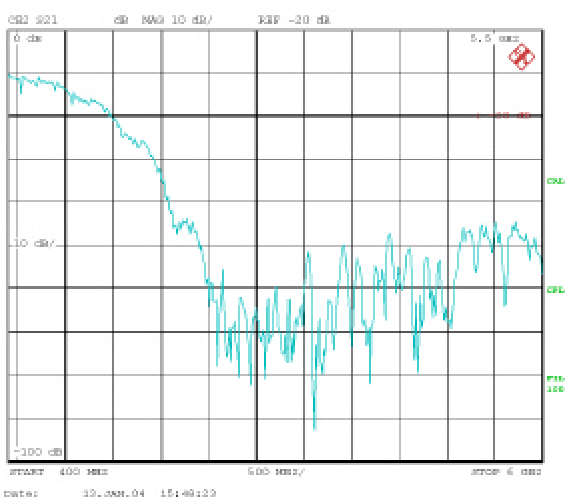

Fig. 9. Attenuation of cable with 35.7 m length

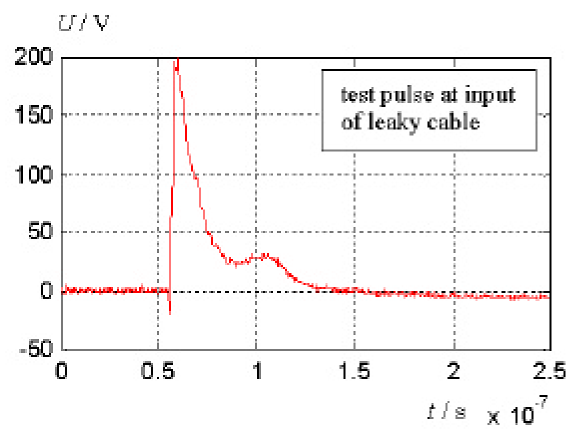

Fig. 10. Test pulse

3.2. Transient Signal Measurements

Fast transient pulses with double exponential character have been used to determine the radiation and transmission behaviour in time and frequency domain.

3.2.1. Transmission Behaviour

Fig. 10 shows a test pulse with a rise time of t_r = 5 ns. After transmission through a leaky section cable with a length of 10 m the pulse shape is nearly identical to the input pulse. Merely the amplitude is damped slightly (see Fig. 11).

The comparison of the spectral energy distributions shown in Fig. 12 confirms that the pulse shape is nearly unaffected by a transmission through the leaky cable. Both spectra are showing virtually identical characteristics.

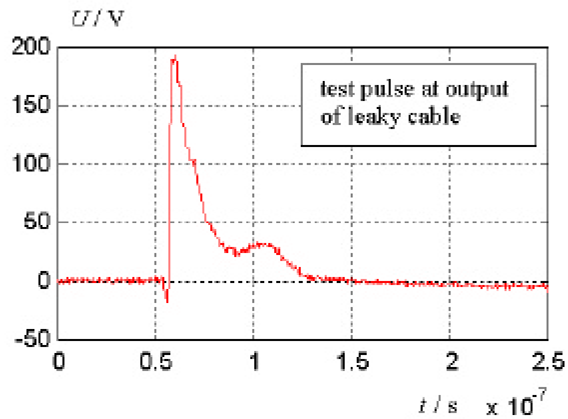

Fig. 11. Test pulse after transmission through LSC

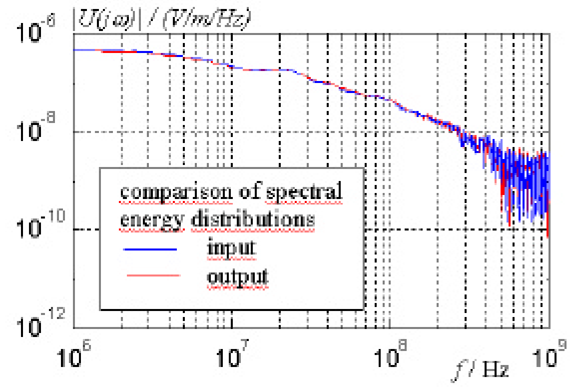

Fig. 12. Comparison of test pulse spectra at input and output port of LSC

3.2.2. Radiation Behaviour

The radiation behaviour has been measured with a conical E-field probe [2] at the leaky site and at the back of the leaky site, to determine the directional effect of the leaky section. Fig. 13 shows the electrical field strength at the leaky site.

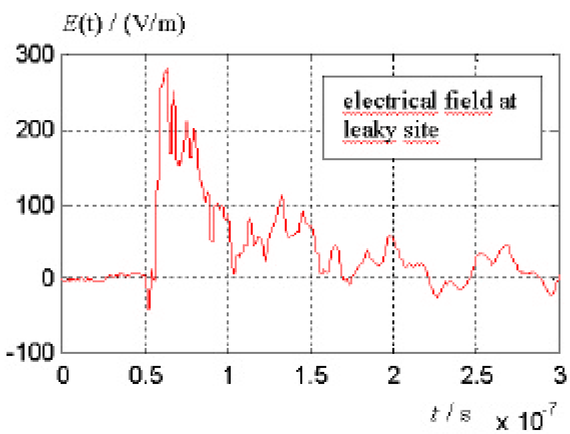

Fig. 13. Electrical field strength at leaky site

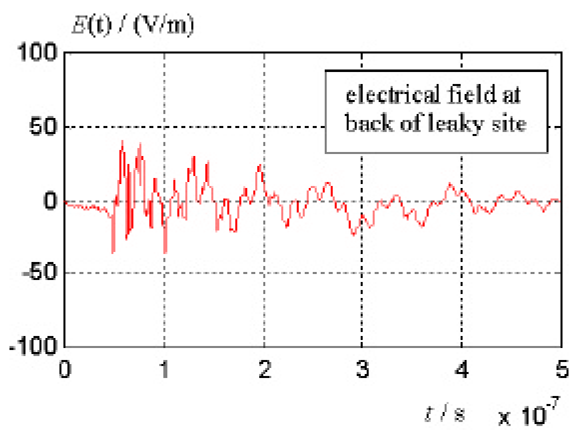

Fig. 14. Electrical field strength at back of leaky site

As expected the electrical field strength is much higher at the leaky site than at the back of the leaky site (see Fig.14). In time domain the amplitude is reduced by about 17 dB.

The analysis in the frequency domain shows that at the back of the leaky site most of the energy distribution below 1 GHz is reduced. Above 1 GHz the spectral energy distributions of the radiated fields at the leaky site and at the back of the leaky site are very similar (cp. Fig. 15 and Fig. 16). Furthermore at discrete frequencies (75 MHz, 150 MHz, 225 MHz, 300 MHz) the radiation of the electromagnetic fields is pronounced.

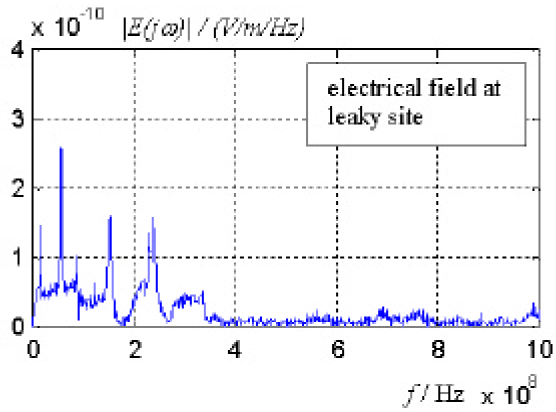

Fig. 15. Spectral energy distribution of the electrical field strength at the leaky site

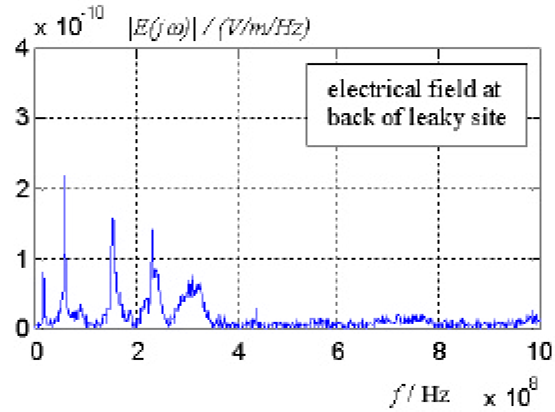

Fig. 16. Spectral energy distribution of the electrical field strength at the back of the leaky site

4. Summary

The radiation and transmission characteristics of the leaky section cable for multi-band aircraft cabin communications were investigated. Different methods were used to measure the radiation pattern in the near and far field, the distribution of the electric field strength along the cable and the total attenuation of the cable. The measurements were carried out both with continuous wave signals and transient signals.

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