Scaled Measurements of Multipath Propagation and Navigations Systems - a Practical Example for ILS

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Abstract—**This contribution presents measurements in a scaled measurement environment with a scale of 1:144 to analyze the compatibility between the localizer array of the instrument landing system and proposed construction measures in front of it, that are planned to reduce wake turbulences of aircraft. Key features of the measurement system are a reconfigurable waveguide antenna toolkit to provide original radiation characteristics of the instrument landing systems at the scaled higher frequency of 16 GHz and a receiving system that automatically moves according to a landing approach. Several measurements with distinct parameter variations confirm the compliance of the constructions with constraints of avionics and present a practical example of this scaled measurement method for multipath propagation and navigation systems.**

Keywords—multipath propagation, instrument landing system, scaled measurements, navigation systems

I. INTRODUCTION

The instrument landing systems (ILS) provides aircraft in landing approach with their correct position with respect to both the middle of the runway (ILS localizer) as well as the correct glide slope angle to touchdown (ILS glide slope). The horizontal guidance is provided by an antennas array at the end of the runway that emits amplitude modulated (AM with 90 Hz and 150 Hz) signals the intensities of which are equal for a receiver along the middle of the runway. A detailed description for the ILS function principle is not given here. Instead, it is referred to [1] which also includes a fundamental validation of the scaled measurement approach used in this contribution. The radiation pattern of the ILS, however, that is symmetric with respect to the middle of the runway, can lose its symmetry and consequently the correct landing course information, if multipath propagation occurs. Consequently, it is important for a safe flight operation to prevent multipath propagation, thus reflection on other objects, e.g. taxing aircraft near the runway or large buildings at the airport environment. This is usually done by introducing so-called ILS restriction areas, where no additional reflecting objects are allowed to be during landing procedures. In fact, this is a common constraint for any other navigation systems, like the very high frequency (VHF) omnidirectional radio range (VOR) or radar and an important field of EMC in avionics. Recent aerodynamic studies showed that landing and departure intervals of aircraft, that are limited due to the presence of wake turbulences, can be shortened by so-called plate lines that are places at the ends of a runway [2]. Such plate lines for reducing wake turbulences for a higher throughput at airports can be realized by large canvas covers as described in [2]. They are illustrated in Fig. 1 which also shows the ILS localizer array and visible wake turbulences of an aircraft.

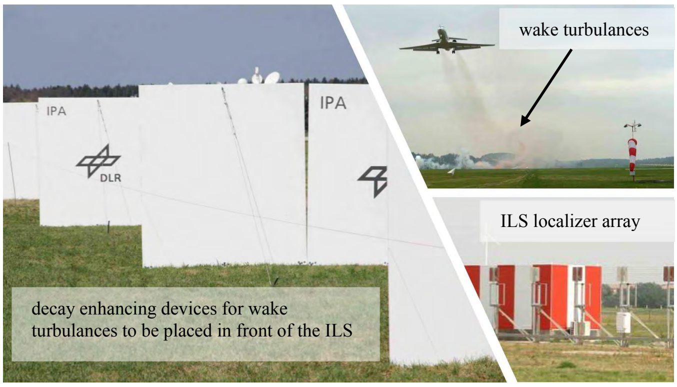

Fig. 1. Illustration of wake turbulences, the ILS localizer and plate lines in front of the localizer to to enhance the decay of wake turbulences.

Such measures for improving an airport efficiency however must not affect the integrity of the ILS localizer. In particular, this is a difficult scenario, because the reflectivity of such plate line structures cannot be simulated under far field assumption which are often used. Thus, an EMC analysis has been done be the means of scaled measurements. The scaled measurement approach uses the physical property that the wave propagation only depends on the ratio of wavelength and object dimensions, at least for metallic-like structures without dispersion. This method has been developed and validated [1] in the scaled of 1:144 where VHF frequencies translate into microwaves at around 16 GHz. The key issue of the measurement system is the development of a scaled ILS operating at 16 GHz that contains both the correct horizontal guidance information and a radiation pattern that is the same as the original ILS pattern. Those aspects are explained in detail in [1], [3] and [4].

II. MEASUREMENT SETUP AND INVESTIGATED SCENARIOS

The plate lines are realized with small metal plates as an upper estimate for ILS disturbances. They can be arranged in a row with a HF-transparent foam fixture as shown in Fig. 2c) Plate line elements of two different sizes are used. The small plate line elements (SPLE) have a size of 6.25 cm x 3.125 cm (unscaled 9 m x 4.5 m) and larger plate elements (LPLE) of double size.

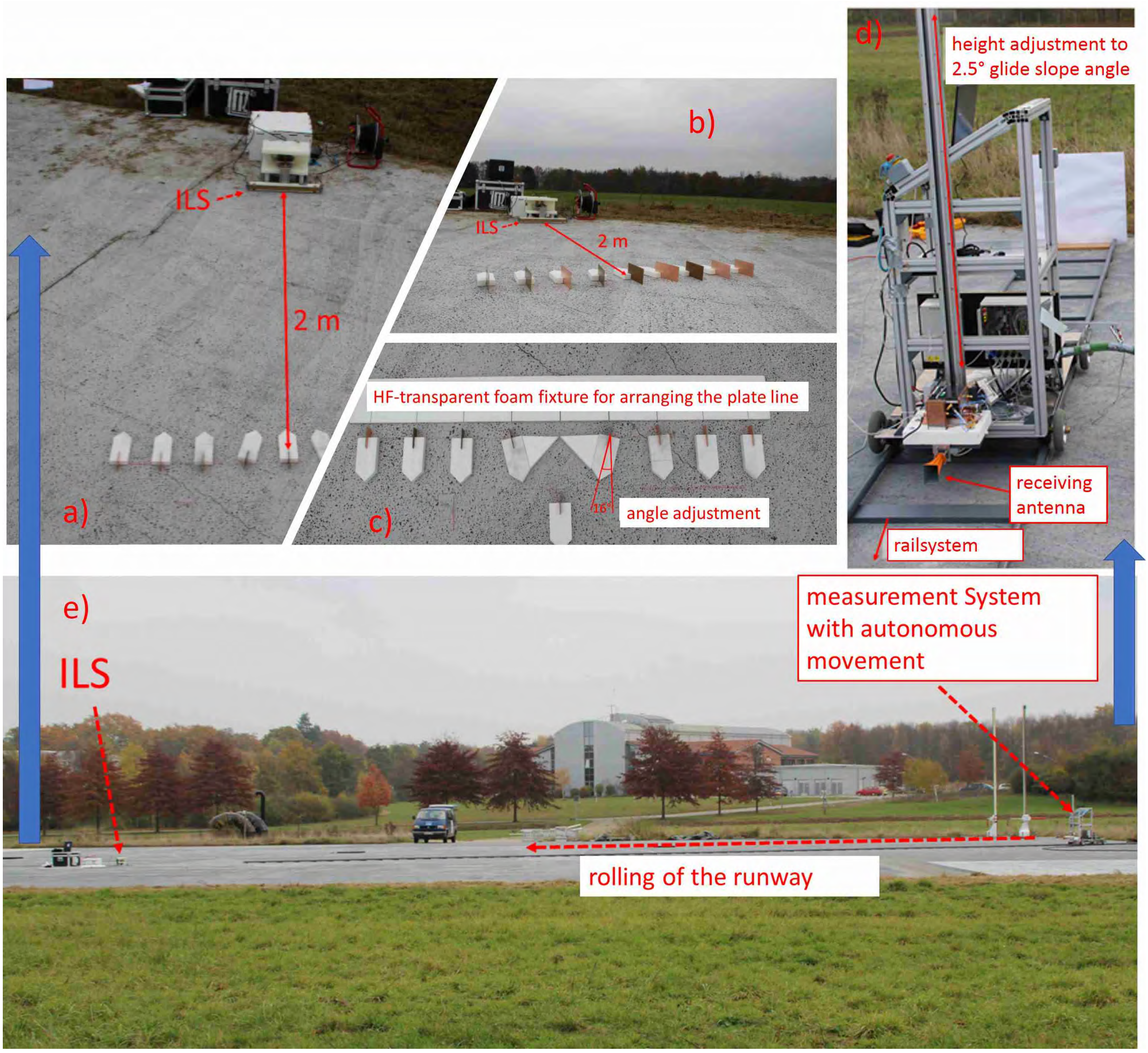

Fig. 2. Scaled measurement environment at the opean area test site. a) small plate line elements in front of scaled ILS; b) larger plate line elements in front of ILS; c) fixture to arrange plate line elements; d) autonomously driving measurement system with automatic height adjustment according to glide slope angle; e) total view for the scenario roll of the runway.

Fig. 3 shows the measurement scenarios that needed to be analyzed. It takes into account, that a runway is used in both landing directions. Additionally, inherent to the measurement setup, the whole landing approach is divided into two phases, i.e. landing approach and rolling of the runway. Fig. 2 shows the measurement setup of the scaled environment at the open area test site of Germany's national metrology institute in Braunschweig. It is important to note, that one landing approach in a scaled distance of about 65 m to the ILS only takes about 2 min for one plate line configuration. Because of this short measurement time a lot of measurements can be conducted, especially with a variety of parameter constellations. For example, in Fig. 2 a)-c) it can be seen, that some plate line elements intentionally have been placed asymmetrically as another worst-case assumption, since a fully symmetric scenario would not have any disturbances.

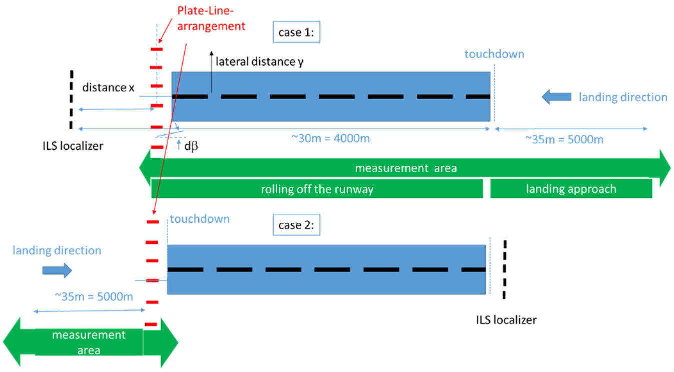

Fig. 3. Overview of investigated scenarios with positions of the plate lines.

III. PERFORMANCE OF THE SCALED ILS

Following graphs show the performance of the scaled ILS operating at 16 GHz. The ILS localizer consists of two components, i.e. the course signal and the clearance signal. The latter (Fig. 5) covers a wider angular range with respect to the middle of the runway and consequently is much less directive than the course signal (Fig. 4) which only covers an area of ±5°. Both graphs show the original ILS signal to be synthesized and measurement results for the two amplitude modulated components marked as 90 Hz and 150 Hz. Such components are the results of multiplying the carrier signal of the antenna array with the AM sidebands that vary in space according to the horizontal angle relative to the runway middle where the 90 Hz and the 150 Hz component have the same relative gain. The relationship between those relative gains and an according instrument current, internationally labeled as ddm (difference in depth of modulation) is explained further in [5] and [3].

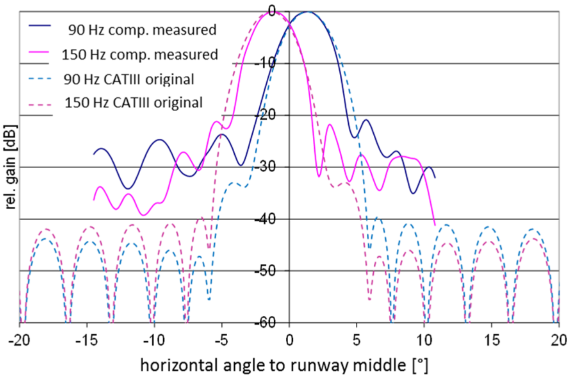

Fig. 4. Radiation characteristics of the scaled ILS course signal.

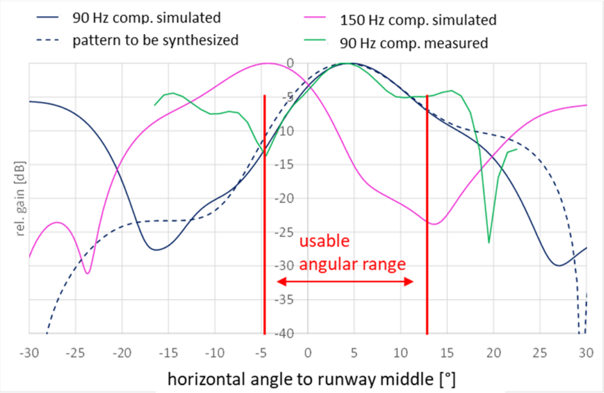

Fig. 5. Radiation characteristics of the scaled ILS clearance signal.

IV. MEASUREMENT RESULTS

Measurements were done in several configurations for distances and plate line orientations. An important measurement for validation is a reference measurement that is done without any scattering object or plate line. In order to determine the influence of additional static objects in the close environment of the measurements, periodically such reference measurements are conducted and used for calibration to eliminate the influence [6]. In fact, it turned out the influence of the environment changes over time, very likely due to effects of humidity of plants at the border of the open area test site and the soil the surrounds the conductive ground of it. Some measurement examples are presented in Figs. 6-8 representing different configurations that illustrated in Fig.3.

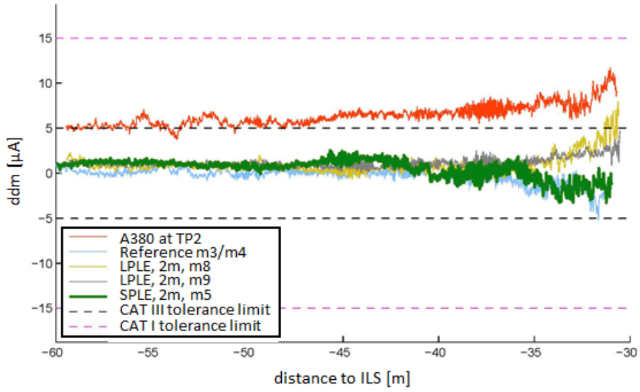

Fig. 6. Measured landing course disturbances for ILS localizer during a landing approach with the plate line near the localizer.

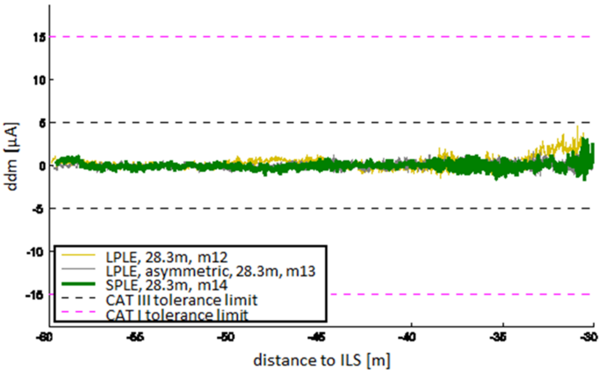

Fig. 7. Measured landing course disturbances for ILS localizer during a landing approach with the plate line at the other end of the runway.

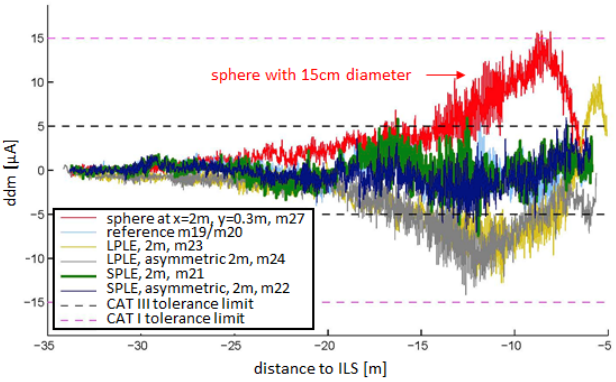

Fig. 8. Example measurement with scaled ILS clearance signal for the rolling of the runway scenario.

Following tables summarize measurement results for all configurations. The categories of disturbance levels are indicated in TABLE I in relation to internationally recommended tolerance limits [7]. Any scattering object and its position is related to several reference measurements given in the respective last four columns. It can be seen that for the ILS-course signal (TABLE II and TABLE IV) the results do not with the choice of the reference measurement for calibration whereas the for the clearance signal (TABLE III and V) of the ILS this appears relevant. For example, comparing the first measurement *m1* as shown I TABLE III, it is in tolerances with the succeeding measurement *m2*, but not with the *m9* which is conducted later. This is an indication that boundary conditions of the measurement environment change with time and the periodic reference for calibration are necessary. This effect is stronger for the ILS Clearance signal because it is much less directive and illuminates the boundary of the open area test site more efficiently than the course signal, in particular with its grating lobes that are inherent to the reconfigurable waveguide antenna toolkit as explained in [4]. Consequently, any measurement should be related to the reference measurement with shortest time interval to it. As additional scatterers for validation an A380 and a large sphere have been taken since a preceding validation with those objects has already been performed in [8].

TABLE I. CATEGORIES FOR DISTURBANCES

Categorie of disturbance level	Percentage of measured values outside respective tolreances	
	exceeding ±5 µA ≙ ±0,67 dB	exceeding ± 15 µA ≙ ±2 dB
IT	0%	0%
IT*	2%	0%
ATC3	10%	0%
ATC3!	100%	0%
ATC3!*	100%	2%
ATC1!	100%	100%

TABLE II. RESULTS FOR ILS COURSE, LANDING APPROACH

Position	Scattering object	measurement index	m3	m4	m10	m15
TP2: x=4.2 m, y=0.45 m	A380	m1	ATC3!	ATC3!	ATC3!	ATC3!
TP2: x=4.2 m, y=0.45 m	A380	m2	ATC3!	ATC3!	ATC3!	ATC3!
Reference		m3	-	IT*	IT	IT
Reference		m4	IT*	-	IT	IT
2 m to ILS	SPLE	m5	IT	IT	IT*	IT
2 m to ILS	SPLE	m6	IT	IT	IT	IT
2,1 m to ILS	SPLE	m7	IT	IT	IT	IT
2 m to ILS	LPLE	m8	IT*	IT	IT*	IT*
2 m to ILS	LPLE	m9	IT	IT	IT	IT
Reference		m10	IT	IT	-	IT
x=2 m, y=0,15 m	sphere	m11	ATC3!	ATC3!	ATC3!	ATC3!
TP18: 28.3m to ILS	LPLE	m12	IT	IT	IT	IT
TP18: 28.3 m to ILS, Asym.	LPLE	m13	IT	IT	IT	IT
TP18: 28.3 m to ILS	SPLE	m14	IT	IT	IT	IT
Reference		m15	IT	IT	IT	-

TABLE III. RESULTS FOR ILS CLEARANCE, LANDING APPROACH

Position	Scattering object	measurement index	m1	m2	m5	m9
Reference		m1	-	IT*	ATC3	ATC3
Reference		m2	IT*	-	IT*	ATC3
2 m to ILS	SPLE	m3	ATC3	ATC3	ATC3	ATC3
2 m to ILS, Asym.	SPLE	m4	IT*	ATC3	IT*	IT*
Reference		m5	ATC3	IT*	-	IT*
2 m vor ILS	LPLE	m6	ATC3	IT*	IT	ATC3
2 m vor ILS, Asym.	LPLE	m7	ATC3	ATC3	IT*	ATC3!
x=2 m, y=0,15 m	sphere	m8	ATC1!	ATC1!	ATC1!	ATC1!
Reference		m9	ATC3	ATC3	IT*	-
TP18: 28,3 m to ILS	SPLE	m13	ATC3!	ATC3!	ATC3	IT*

TABLE IV. MEASUREMENT RESULTS FOR ILS, COURSE ROLL OFF

Position	Scattering object	measurement index	m16	m17	m20	m24
Reference		m16	-	IT*	IT*	IT*
Reference		m17	IT*	-	IT*	IT*
2 m to ILS	SPLE	m18	IT*	IT*	IT*	IT*
2 m to ILS, Asym.	SPLE	m19	IT*	IT*	IT	IT*
Reference		m20	IT*	IT*	-	IT*
2 m to ILS	LPLE	m21	IT*	IT*	IT*	IT*
2 m to ILS, Asym.	LPLE	m22	IT*	IT*	IT*	IT*
Reference		m24	IT*	IT*	IT*	-

TABLE V. MEASUREMENT RESULTS FOR ILS, CLEARANCE ROLL OFF

Position	Scattering object	measurement index	m19	m20	m25	m26
reference		m19	-	IT*	IT*	IT*
reference		m20	IT*	-	IT*	IT*
2 m to ILS	SPLE	m21	IT*	IT*	IT*	IT*
2 m to ILS, Asym.	SPLE	m22	IT*	IT*	IT*	IT*
2 m to ILS	LPLE	m23	ATC3!	ATC3!	ATC3!	ATC3!
2 m to ILS, Asym.	LPLE	m24	ATC3!	ATC3!	ATC3!	ATC3!
reference		m25	IT*	IT*	-	IT
reference		m26	IT*	IT*	IT	-
x=2 m, y=0,3 m	sphere	m27	ATC1!	ATC3!*	ATC3!*	ATC3!*

V. CONCLUSION

This contribution presents a practical example of a scaled measurement approach to investigate multipath propagation issues. The proposed method of scaled measurements has been applied and validated to similar issues, e.g. wind turbines and the VOR [1]. In future work the scaling principle is extended to other navigation systems at higher frequencies. This practical example demonstrates that sensitive areas are touchable by sophisticated scientific means without any degradation of flight safety, but for a benefit of an airport's economy.

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