A Slotted Waveguide Setup as Scaled Instrument-Landing-System for Measuring Scattering of an A380 and Large Objects

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***Abstract*— At an airport the instrument-landing-system (ILS) provides aircraft on landing approach with both the lateral and vertical guidance to the runway. It is known that the lateral landing course information (localizer) can be disturbed due to reflections on large aircraft taxiing near the runway. Investigating such disturbance scenarios in a scaled setup requires an accurate and flexible modelling of a scaled ILS.**

This paper presents an antenna setup consisting of two slotted waveguides as scaled localizer of the instrument landing system. The design itself allows individual pattern forming to be applicable to various ILS at different airports.

Measured antenna patterns correspond well to simulations demonstrating the feasibility of this approach.

Additionally, measurements of ILS disturbance scenarios with large objects, such as an A380, a B747 and a sphere are presented for landing approaches. This paper compares the scattering behaviour of the mentioned aircraft and focuses on how to specify the influence of individual scatterers, e. g. the fuselage or the tail fin.

I. Introduction

The instrument landing system (ILS) provides aircraft during landing approach with the information about their position relative to the middle of the runway. It is known that this landing course signal can be disturbed due to reflections on large taxiing aircraft on ground, such as the Airbus A380 or the Boeing 747 [1]. For an assessment of such a bistatic scattering scenario in terms of safety aspects at a real airport a scaled measurement setup has been suggested in [2] with microstrip antenna arrays. Keeping the actual scaling concept this paper presents a new antenna setup consisting of two slotted waveguides allowing individual pattern forming. For a detailed description of the scaled ILS function principle and how to assess measured deviations from an ideal landing course with internationally defined tolerances it is referred to [2].

II. Scaled Scattering Scenario

Fig. 1 shows the typical geometry of ILS disturbance scenarios.

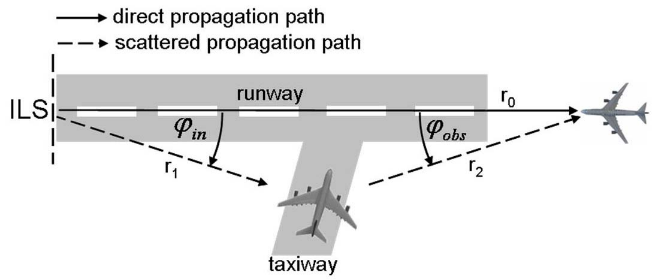

Fig. 1 ILS scattering scenario

The actual landing course information propagating directly to an aircraft on landing approach at a distance r_0 is jammed due to reflections on a taxiing aircraft located at the distance r_1 at an angle φ_{in} to the runway. The distance r_2 as well as the observation angle φ_{obs} can be calculated from these parameters.

For scaling such scenarios a factor of 1:144 is chosen, where aircraft models are commercially available. The aircraft models are made conductive by attaching copper foil on their structure of resin. This scaling factor sets the original ILS frequency of about 110 MHz to 15.9 GHz, where a scaled ILS is designed as described in the following.

III. Design of Two Slotted Waveguides as Scaled ILS

For real ILS the landing course signal is the difference in depth of modulation (ddm) of two sidebands with same intensity in the middle of the runway. In the scaled ILS the sideband characteristics of the amplitude modulation is represented with two main lobes pointing symmetrically slightly off the middle to the runway. These main lobes are made distinguishable by choosing two different frequencies with a spacing of only 1.5 kHz.

The designed scaled ILS system consists of two slotted waveguides WR62. The initial idea of a slotted waveguide with horizontal polarization has been suggested in [3] with a pair of slots as single radiating element . The geometry of the slots was optimized with CST Microwave studio [4]. In an antenna array consisting of several slotted pairs the individual feeding amplitude of a single element can be adjusted by covering the pair of slots individually with metal.

Fig. 2 shows the simulation model of a slotted pair as single element in the array and the metal cover for manipulating its exciting amplitude. The metal cover has a thickness of 2 mm suitable for its manufacturing process.

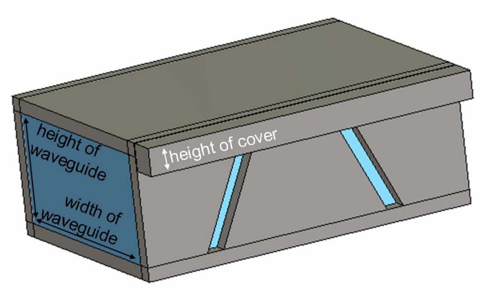

Fig. 2 Single element in a slotted waveguide

Fig. 3 shows the simulated gain of a single element as a function of its cover height. There is a minimum height of 0.5 mm to ensure a mechanical realization.

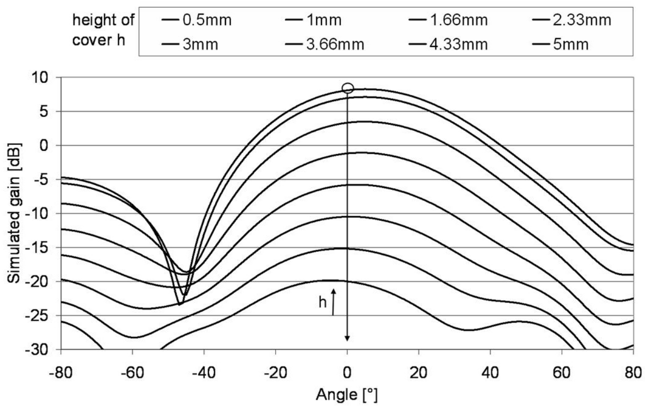

Fig. 3 Gain of single element depending on cover height

For heights larger than 1 mm the gain G can well be described according to:

$$G_{dB} = -6.84 \frac{dB}{mm} \cdot h + 14.53\ dB \qquad (1)$$

as the squared exciting amplitude of a slotted pair. With this function a blind is designed covering waveguides with seven slotted pairs to have an amplitude tapering with a Hamming window function. Fig. 4 shows a manufactured waveguide and the covering blind. The spacing between slotted pairs is one wavelength in the waveguide. At its end the waveguide is short-circuited such, that each slotted pair is excited twice to increase radiation efficiency.

Fig. 4 Slotted waveguide with blind for amplitude tapering

As scaled ILS Fig. 5 shows the fixture for both waveguides that can mechanically be twisted against each other with an offset angle to adjust their main lobes respectively 5° or 10° to the middle of the runway.

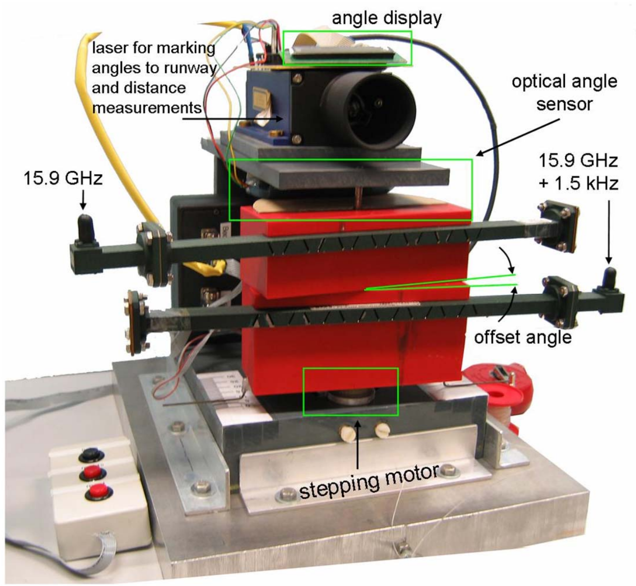

Fig. 5 Fixture with both waveguides as scaled ILS

The fixture can automatically be rotated with a stepping motor. The rotating angle is monitored with an optical sensor system. In the following, measurements of the scaled ILS patterns are presented.

IV. Measurements of Scaled ILS

Measurements are done at the open area test site at the national metrology institute (PTB) in Germany. Fig. 6 shows the antenna patterns of the uncovered waveguides as needed for the calibration of the ILS. In this calibration procedure a probable correction of the feeding power is obtained to set both main lobes to the same intensity. It also yields the direction of the middle of the runway as intersection of both patterns between the main lobes.

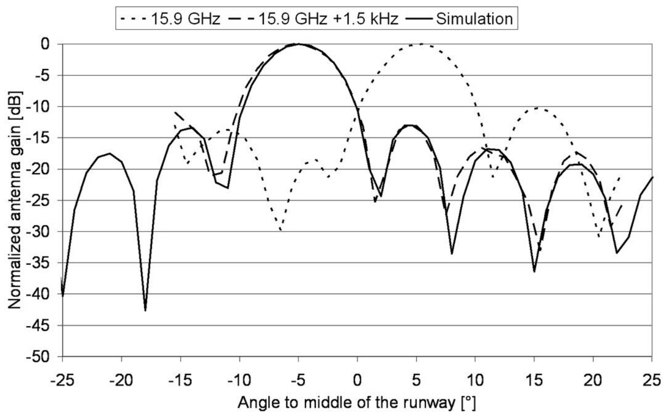

Fig. 6 Antenna patterns without blend

Fig. 6 shows the typical side lobe level of about -13 dB the minimization of which is achieved with the blinds.

Fig. 7 shows antenna patterns where the blinds are attached to the waveguides.

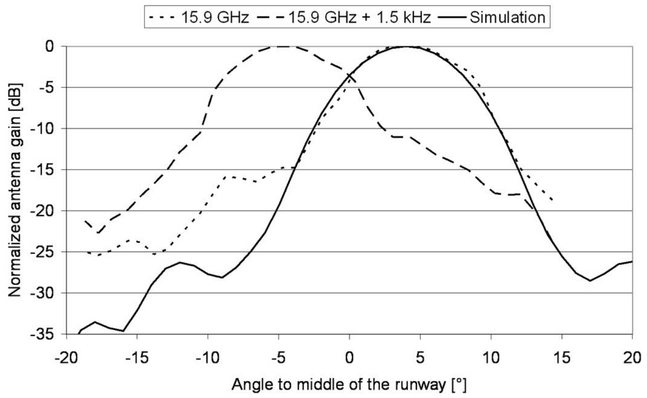

Fig. 7 Antenna patterns with blend

It can be seen that the side lobe level can be optimized with the blind. Both measurements are in good agreement to the simulation. This demonstrates an effective way of pattern forming for the scaled ILS just by attaching different blinds on the slotted waveguides. In Fig. 8 the actual landing courses of the scaled ILS with and without blind are plotted in dependency on the angle to the middle of the runway. In this scaled setup the landing course is the angle dependent ratio between the single antenna patterns. The ideal landing course in the direction of the middle of the runway is 0 dB with positive values to the right of the runway and negative values to the left.

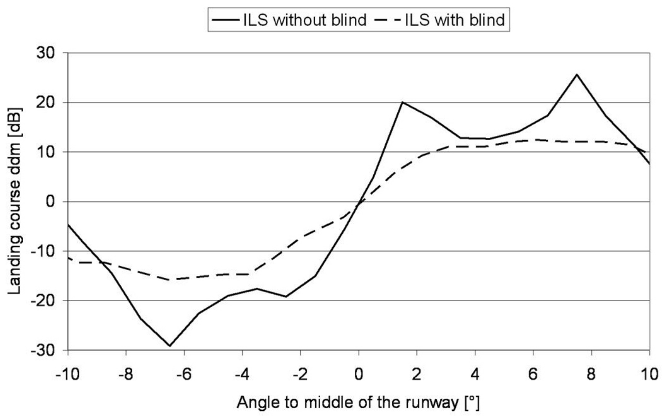

Fig. 8 Landing course characteristic of the scaled ILS

In the following, measurements of realistic scattering scenarios are presented with the scaled ILS where the ideal landing course is disturbed due to scattering of objects near the runway.

V. Measurement of Scattering Scenarios

During a landing approach the intensities of both frequencies are measured with a spectrum analyzer. Without any disturbing object both frequencies have the same power in the spectrum, thus their ratio ddm is 0 dB. With a scattering object placed at 5° the power P at one frequency is a superposition of the direct and scattered signals. Due to its directional pattern the scattered part of the signal of the other frequency is negligible. Thus, in the disturbance scenario the measured landing course is the ratio of the direct path plus the scattered one and the direct path only, according to:

$$ddm = \left[\frac{\sqrt{P_{direct}} \pm \sqrt{P_{scattered}} \cdot e^{j\varphi}}{\sqrt{P_{direct}}} \right]^2 \qquad (2)$$

with a phase difference φ between the direct and scattered path. Fig. 9 shows a typical measurement setup for such scattering scenarios with aircraft models of an A380 and a B747 and a metallic sphere with 50 cm diameter. Objects are placed at a scaled distance r_1=15 m to the ILS and an angle of φ_{in}=5° to the middle of the runway. The middle of the runway is marked with a chalk line after calibration and highlighted in Fig. 9 for a better visibility.

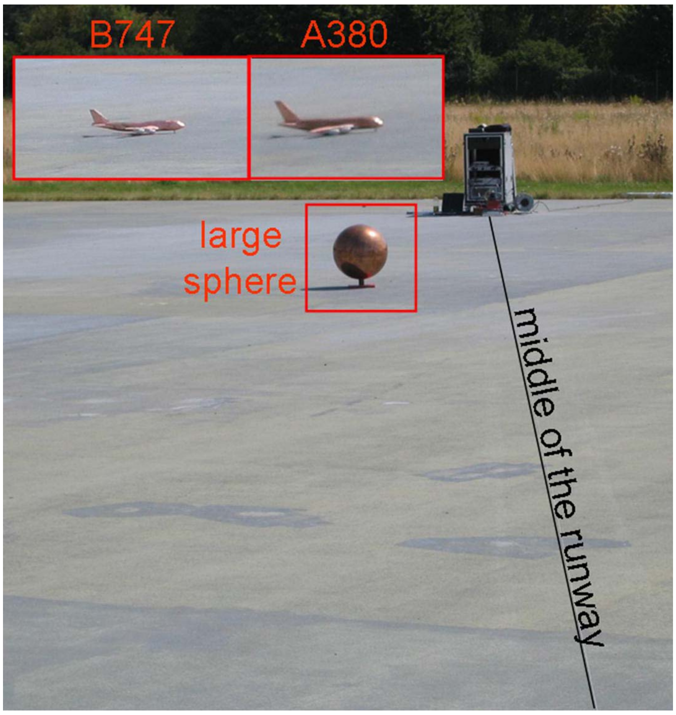

Fig.9 Measurement scenarios with different objects

Due to the vertical arrangement of the slotted waveguides the influence of ground reflections are different for both waveguides. Consequently, measurements without any scattering object are the reference for an ideal landing approach on the 0°-direction at the middle of the runway.

Fig. 10 shows measurement results of the landing course that is influenced by the scattering objects. In that configuration the scaled ILS is covered with blinds. The receiving micro-strip patch antenna, is moved from 53 m to 20 m at a constant height of 50 cm.

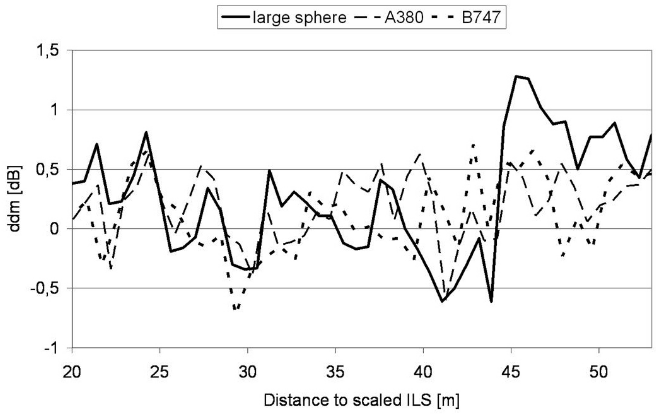

Fig. 10 Deviations from ideal landing course due to scattering objects

The minimum sensitivity of the setup, thus variations of the ddm without any object, is determined to 0.5 dB. Thus, only the large sphere seems to have significant scattering influence on the ideal landing course, whereas the scattering of both aircraft is marginally above the measurement sensitivity.

Additionally, measurements are done where the height of the receiving antenna varies with the distance to the touchdown on the runway, corresponding to a real landing approach. Fig. 11 shows measurement results for the large sphere placed at a distance of r_1=20 m at an angle of φ_{in}=5°.

In this setup the scaled ILS is operating without blind. Four different heights are chosen, equivalent to a vertical glide path angle of 2.5°. In Fig. 11 it is marked which section is taken for a later composition to an actual landing approach.

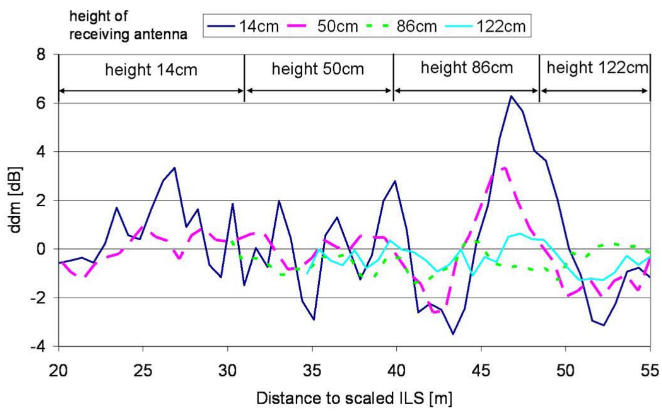

Fig. 11 Deviations from ideal landing course due to reflections on a large sphere

Measurements at a height of 14 cm have largest deviations up to over 6 dB. The scattering influence becomes less with increasing height, what is plausible as it is farer away from the forward scattering direction of the sphere. These results demonstrate, that serious landing course deviations can generally be measured in this setup. It is also obvious that a quasi three dimensional observation of such scattering scenarios is mandatory for an evaluation of the actual landing approach.

Fig. 12 summarizes the different sections to a complete landing approach. Additionally, results are displayed for an A380 placed at the same position with perpendicular orientation to the runway.

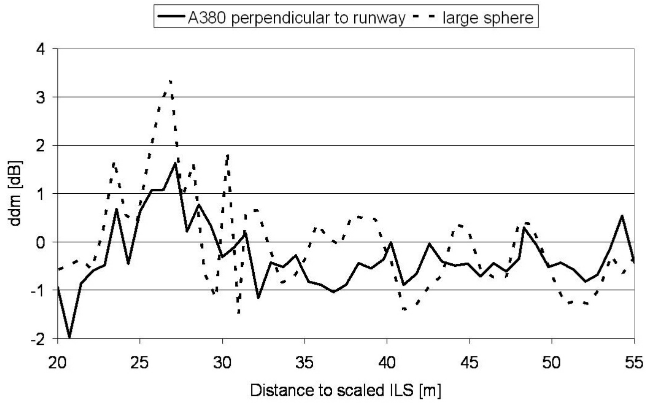

Fig. 12 Deviations from ideal on a landing approach

Exemplarily, these measurements show that a quantitative assessment of ILS disturbance scenarios due to scattering of aircraft on ground is possible in this setup.

Using this measurement principle of a differential landing course also allows comparative measurements of the scattering behaviour between two objects. In such a configuration two scattering objects are symmetrically placed to the middle of the runway. Thus, the ddm is a direct measure for the different influence both objects would have in such a scattering scenario.

Fig. 13 shows such a setup for investigating individual scatterers of an A380, where a fully metallized model is compared with a model the fuselage of which is not metallized.

Fig. 13 Comparative measurement setup with a full and half metallized A380

In this setup the ILS is covered with blinds. The waveguides are twisted with an offset angle of 20°, so that their main lobes are ± 10° to the middle of the runway. Both aircraft are placed in a distance of r_1=15 m at angles of 10° to the middle of the runway. Fig. 14 shows results of these comparative measurements. It shows also differences between a fully metallized A380 and a B747. Additionally, the reference curve for the ddm is displayed without any scattering object as it is varying with the distance due to the vertical arrangement of the slotted waveguides. The receiving antenna was at a constant height of 50 cm.

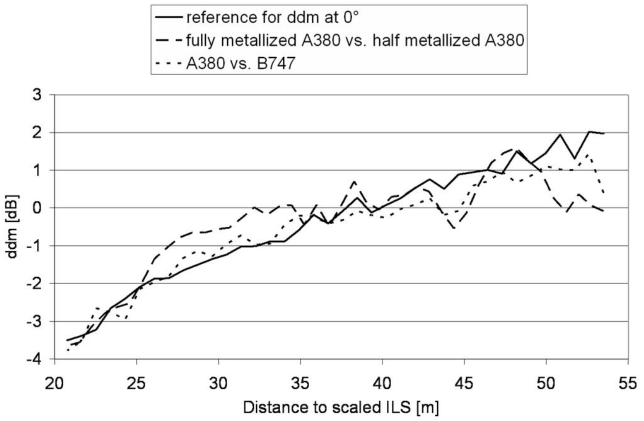

Fig. 14 Results for comparative measurements

It has to be stated that the direct propagation path is still existent, thus deviations from the reference ddm are not the direct ratio for their radar cross sections (cp. equation 2).

Though, some qualitative observations can be made. Comparing the A380 and the B747 no large deviations from the reference ddm can be observed. Thus, in this configuration they have very similar influence on ILS disturbance scenarios. This is basically an interesting investigation since there are already experienced data concerning the influence of a B747 on ILS disturbance scenarios. So, if further measurements prove that the impacts of both aircraft are almost the same, the A380 is no new threat for safe ILS operation.

Considering the scattering influence of an A380's fuselage a constant difference of about 1 dB between 25 m and 35 m is obvious. Even larger differences can be found at 45 m and for distances above 50 m. Consequently, it can be concluded that the fuselage has obviously influence on the total scattering characteristic. Such conclusion on individual scatterers are important, if an aircraft model is implemented in a numerical simulation tool where parts without significant scattering behaviour can be omitted for a simplification of the model.

Conclusions

This paper presents a slotted waveguide antenna setup based on the function principle of the Instrument-Landing-System. This allows bistatic scattering measurements of large objects where numerical solutions are hardly feasible as they are facing the problem of very large structures and non-plane-wave incidence due to boundary conditions of the ground plane. The slotted waveguide antennas offer the possibility to mimic individual antenna patterns, so they can be used not only for different ILS-categories but also for other radar or navigation system. Measurements with a large sphere and the aircraft A380 and B747 demonstrate that their scattering influence on ILS disturbance scenarios can well be determined in the scaled setup. Additionally, it is shown that the scaled ILS function principle offers the possibility to perform comparative scattering measurements of two objects. Such measurements can be used to investigate the influence of individual scatterers on the overall scattering behaviour of an object.

As the design of the slotted waveguide antennas is very well scalable its application is not limited to ILS-applications but can be used in a much wider frequency range at different scaling factors for other radar applications.

For example, the scattering influence of moving rotors of wind generators and their impact on a primary radar system can be investigated in a scaled setup using a waveguide in a higher operating band.

Acknowledgment

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