

Evaluation, Design, Commissioning and Certification of a $\pm 15^\circ$ Reduced Coverage Localizer

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ABSTRACT

In order to provide horizontal guidance to landing aircraft, two-frequency Instrument Landing System localizers are radiating information on two carriers;

1. The course signal for the linear guidance around the centerline within the azimuth sector of approx. $\pm 4^\circ$
2. The clearance signal for the required ICAO coverage within the service volume of $\pm 10^\circ$ at a range of 25 NM and $\pm 35^\circ$ at a range of 17 NM.

In case of clearance signal reflections from obstacles, the DDM coverage can be seriously affected by clearance / clearance interference and the ICAO requirements cannot be guaranteed anymore, with for example false courses and/or low clearance.

In order to substantially reduce clearance multipath problems in Zurich, Skyguide, in cooperation with Park Air Systems and Eurocontrol and after significant study, decided to install the NORMARC 7220B localizer with a $\pm 15^\circ$ reduced clearance coverage in 2007.

This paper describes the different phases of the evaluation, design, commissioning and certification and the practical results achieved. It also presents the technical and operational validations and the documentation effort for the ICAO NSP meetings in November 2007 and April 2008. Global harmonization is being pursued to encourage further implementation of such localizer designs, because such systems are more capable to improve signal quality than conventional ILS while supporting operational requirements.

DESIGN OF A REDUCED/RAISED COVERAGE LOCALIZER ANTENNA ARRAY.

In the last 20-25 years, the issue of the coverage volume of the ILS Localizer has been raised several times, and different solutions have been proposed/presented. However, so far the proposed systems had some weaknesses:

- Necessary to change or complement avionics; or
- False courses/low clearance between the reduced lateral coverage and $\pm 35^\circ$

The Design Goals

- The new antenna system must be 100% compatible with existing airborne equipment.
- The main lateral coverage region, $\pm 15^\circ$ shall be 100% compliant with existing ICAO Annex 10 specifications. (e.g. 25NM within $\pm 10^\circ$ 2000' and 17NM from $\pm 10^\circ$ to $\pm 15^\circ$ 2000').
- Outside the main lateral coverage region and out to $\pm 35^\circ$ there must be no false courses or low clearance (where there exist receivable ILS Localizer signal).
- The Clearance CSB field strength shall have a large negative gradient from $\pm 10^\circ$ to $\pm 15^\circ$ (reduction of field strength by approx. 8dB)
- From $\pm 15^\circ$ to $\pm 35^\circ$ the Clearance field strength shall be reduced further, but shall be sufficient to suppress the effect of CSB course side lobes.

The Design

A proprietary antenna array design tool, developed within Park Air Systems AS was used for the synthesis phase of the design. Antenna radiation patterns were initially computed using relatively simple computer tools that did not take mutual coupling between antenna elements into account. The design was finally tested by modeling the

complete array (20 Log-periodic dipole antennas) with the Method of Moments. The NEC 4.1 program from Lawrence Livermore National Laboratory was used for this purpose.

The resulting radiation patterns of the design, computed without the effect of mutual coupling are shown in Figure 1 for CSB pattern and in Figure 3 for SBO pattern.

The corresponding radiation patterns computed with mutual coupling are shown in Figure 2 for CSB pattern and Figure 4 for SBO pattern.

With the exception of the innermost side-lobes of the Course CSB patterns and slightly higher Clearance signal from $\pm 20^\circ$ and out, the two set of calculated radiation patterns are identical within the region of interest.

The effect of production tolerances in the antenna distribution unit is shown in Figure 5 and Figure 6 (Nominal antenna feeds, and measured values on the distribution unit for Zurich Localizer 16).

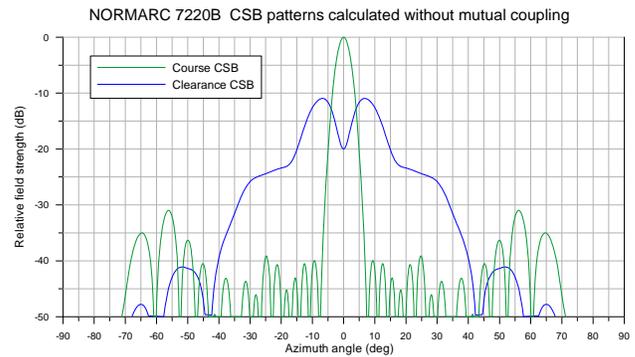


Figure 1

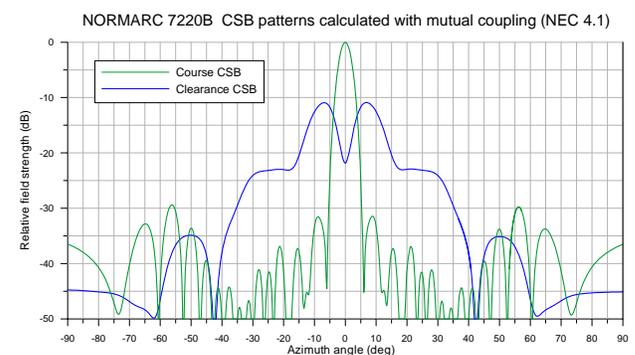


Figure 2

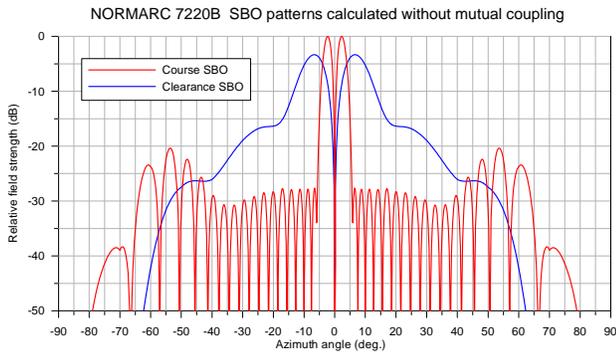


Figure 3

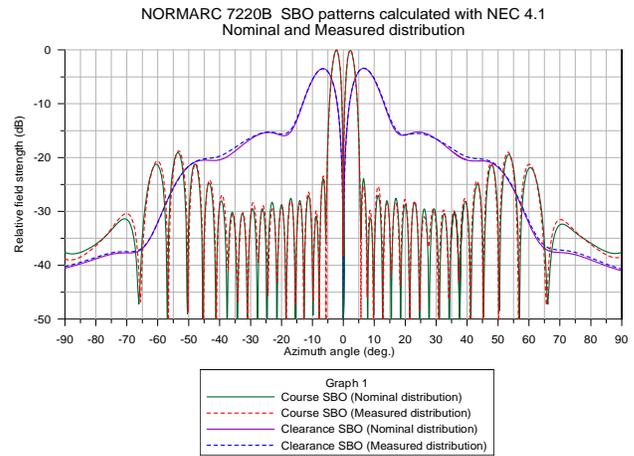


Figure 6

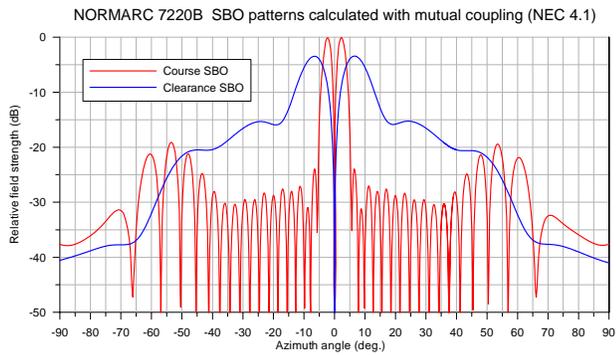


Figure 4

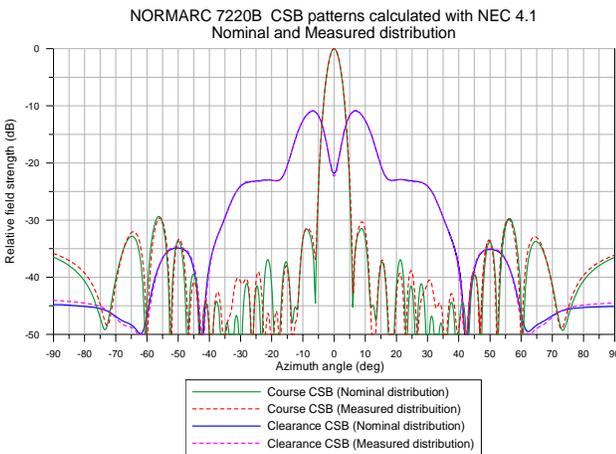


Figure 5

OPERATIONAL ASPECTS AND ICAO STANDARDS

When reviewing the available means to optimize ILS signal quality, a variety of excellent and well-established methods exist. This includes, for example, super-wide aperture arrays to significantly focus the course signal of the localizer. On the clearance side however, significant challenges remain with respect to both clearance-clearance and course-clearance multipath. One reason is that the ILS localizer requirements in the far out and low corners of coverage represent a significant design driver for the course array. This limits the options to reduce the illumination of airport obstacles with clearance energy. While a number of systems with reduced coverage have been declared over the years, the indications outside the declared reduced coverage remain erratic as these systems are normally not designed for the specific local installation challenge. Furthermore, site specific systems not meeting the Annex 10 SARPs requirements by design are not supportable by the mature ILS market. Actually, not meeting ILS coverage requirements is the most common state-filed difference to Volume I of ICAO Annex 10. Since it was felt by a number of members of the nav aids community that ILS coverage requirements were excessive, a review of those requirements was initiated. The goal of the review was to identify possible changes to ILS coverage requirements that meet the operational need while improving the means available to service providers to restore multipath margins in challenging airport environments.

Review of Localizer Coverage Requirements and Operational Need

The signal components provided by the localizer can be split up into four components: linear guidance near the centerline, full-scale fly-left or fly-right needle

indications, validity flag and IDENT. From an operational point of view, in particular the full-scale indications have lost significance. This is especially true for aircraft with FMS-driven navigation displays, but also more generally in vectoring environments. A thorough review of operational factors including pilot procedures, intercept guidance, procedure design, vectoring standards, etc. lead to design requirements that would require coverage to ± 15 degrees. This is sufficient to support pilot arming of the Auto Flight Control System for localizer intercept, even in worst-case scenarios. Outside of 15 degrees, however, aircraft operators still expect the ILS signal to be free from low clearance or false course indications – out to the conventional 35 degree limits. Consequently, a “reduced coverage localizer” would need to maintain a clearance signal strong enough to cover any course sidelobes. This requirement had the secondary effect that IDENT coverage would also be ensured in line with operator’s expectations. In fact, the IDENT turned out to be the most constraining function in relation to coverage requirements, as pilots have become used to completing the IDENT check as part of the check for approach, around flight level 100 – typically significantly outside of conventional coverage. Despite this diverging operational reality, it was demonstrated through a task-load study that pilots would still be in a position to complete the IDENT check during a worst-case, high-workload intercept of a reduced coverage system [1].

As a consequence of these operationally derived requirements, a new localizer design, as explained above, was undertaken. Simulations confirmed that a key benefit of the design was to increase signal quality by shifting the clearance peak away from 12 to 15 degrees to 7 to 8 degrees from the centerline. This has been evaluated at a major airport with a building reflector at 12 plus degrees through a dedicated site survey and simulation in order to address the clearance-course interference case. The ability of the new localizer to restore multipath margins in comparison to an existing solution is shown in Figure 7.

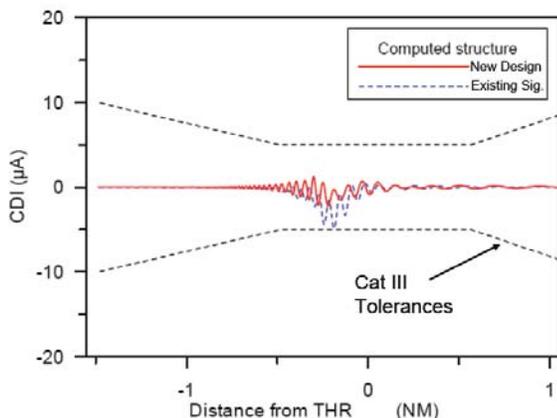


Figure 7: Result of Clearance-Course Benefit Study

ICAO Standardization

The validation work of the implementation in Zurich included a review of operational data. This included feedback from flight crews, flight data analysis, as well as a detailed safety monitoring by the service provider operational staff. This confirmed that the intended goals were fully achieved, e.g., that the change in localizer design was completely unnoticeable by flight crews and ATC. In order to encourage global implementation of this solution which increases the achievable safety margins, the work was presented both to the ICAO Navigations Systems Panel and the Operations Panel [2], [3], [4], [5]. Despite coverage requirements having been successively reduced over the many years of ILS operation (first from omni-directional to ± 90 degrees and then to the current ± 35 degrees), it proved difficult to implement a relaxation of field strength requirements down to ± 15 degrees. This was primarily due to concerns over FM broadcast compatibility and possible further building development. Consequently, an alternate requirements formulation was pursued [6]. The proposal currently being discussed foresees to raise the lower boundary of coverage in line with operational requirements, up to a maximum lower boundary. Thus, where operationally compatible, coverage could be raised at the limits of coverage (17NM), starting from 15 degrees and 2000ft HAT (Height Above Threshold), up to 4500ft HAT at 35 degrees, as illustrated by Figure 8.

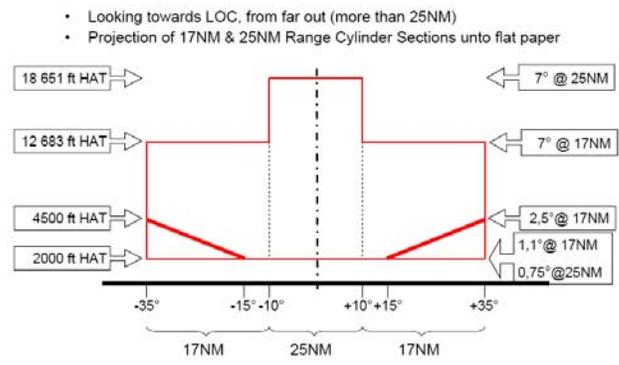


Figure 8

SUPPORTING TECHNICAL VALIDATION

The site of the localizer 16 in Zurich has been identified as a potential site, where the coverage reduction may solve the signal in space problems. This section presents the realization of this replacement project and its technical outcome. This specific case Zurich 16 represents also a detailed supporting technical validation.

Zurich Localizer 16: an Initial Problematic Situation

Since the fifth building phase of Zurich airport, the signal in space of the localizer 16 has suffered from serious signal reflections from new buildings, especially the parking garage number 3. These signal reflections have produced the so-called "Clearance / Clearance Interference": the clearance signal towards the parking garage number 3 (which carries the information "full scale deflection right"), after a reflection on its facade, interferes with the direct and correct clearance signal which carries the information "full scale deflection left". The result of such an interference has produced in Zurich a very serious degradation of the signal in space: in the "150 Hz Dominant" domain, where the signal normally carries the information "full scale deflection left", the DDM (Difference in Depth of Modulation) is so affected that the information "full scale deflection left" was not guaranteed any more. As illustrated below by Figure 9, some false courses (where the DDM is equal to zero and where the Course Deviation Indicator is really centred) have been measured by the flight check for azimuth angles between 10° and 20° from the centreline. In parallel with the building of the parking, the quality of the signal has been continuously degraded between 2001 and 2003. Finally, in November 2003, the operational coverage of the localizer has been restricted to a beam of $\pm 5^\circ$ around the centreline.

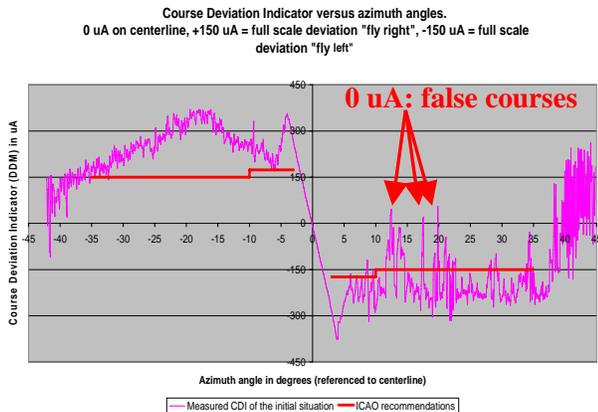


Figure 9: Initial Situation of the Localizer 16 Zurich

Such a restriction of $\pm 5^\circ$ of the coverage, illustrated by Figure 10, has represented a significant deviation from ICAO Annex 10 standards, which are illustrated below by Figure 11. Because of this deviation from ICAO standards, it has been decided to launch the replacement project of the ILS 16 in Zurich.

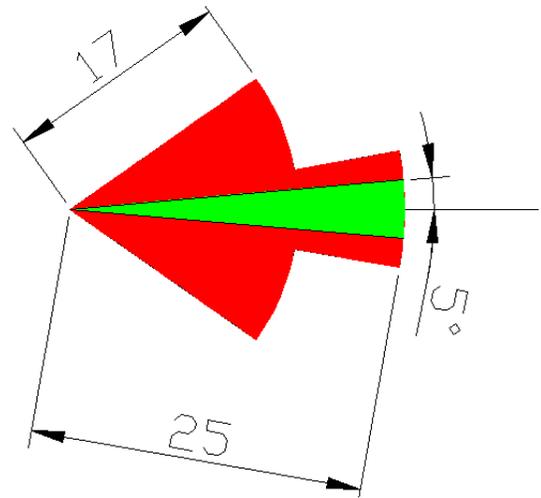


Figure 10: Degraded Situation of the Localizer Coverage: Outside $\pm 5^\circ$, Possible False Courses

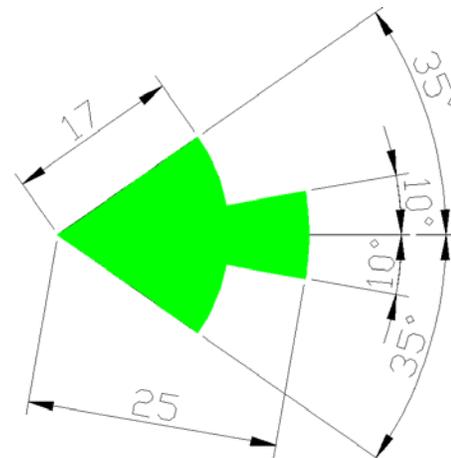


Figure 11: ICAO Annex 10 Volume 1 Chapter 3: Localizer Coverage Requirements

The Replacement Study

The first step of the replacement study has consisted in confirming the source of the interference and the type of interference: a Clearance / Clearance interference. The calculations and simulations have clearly shown and confirmed that the reflector is the parking garage number 3 and that it is located in the Clearance domain. In order to reduce the perturbation, the solution consists in reducing the incident signal on the parking, thus consequently reducing the reflected signal, and finally the amplitude of the Clearance / Clearance interference. Reducing the Clearance incident signal means for the localizer modifying the Clearance radiating antenna

diagram. Radiating less signal in the Clearance domain means also consequently reducing the lateral coverage and the operational service volume.

The New System

The feasibility study has considered a new design of localizer from the ILS supplier Park Air Systems: the model NM 7220 B. This new type of localizer, which is illustrated by Figure 12 below, has integrated the so-called "Reduced Coverage" function.



Figure 12: Reduced Coverage Localizer Installation at Zurich Airport Runway 16

From a mechanical point of view, this equipment is quite similar to the previous ones. Some mechanical improvements have been implemented: frangibility, protection and integration of the cable ducts, antenna distribution unit and monitor combining unit. However, there are no mechanical differences between a full coverage NM 7720 A and the reduced coverage system NM 7720 B.

From a hardware point of view, the main change consists in modifying the Clearance feeds: the distribution (amplitudes / phases) of the Clearance CSB and SBO signals to the antennas has been modified and optimized in order to get the wished and required reduced coverage.

From a monitoring point of view, the philosophy and the theoretical principles remain the same. Thus, the only change in this design deals with the feeds of the Clearance signals.

Based on the described distributions and antenna patterns, the resulting simulated Difference in Depth of Modulation (DDM) in free space (without any reflector), which controls the Course Deviation Indicator (CDI), presents the two "normal" characteristic domains of a localizer:

- The linear region between $\pm 3^\circ$ from the centreline (within the Course domain), where the Course Deviation Indicator (or the DDM) is proportional to the azimuth angle. As the Course signal distributions and its antenna patterns are conventional, this linear region does not represent any change or deviation from the standard situation,

- The "Full Scale Deflection Region" between $+3^\circ$ and $+35^\circ$ and between -3° and -35° where the absolute value of the DDM has to be superior to:
 - $174 \mu A$ (or 0.180 DDM) until $+10^\circ$ (and -10°)
 - $150 \mu A$ (or 0.155 DDM) between $+10^\circ$ and $+35^\circ$ and between -10° and -35° .

These requirements are respected by the simulated Course Deviation Indicator in free space: beyond the linear region, the behaviour of the DDM is quite flat and the "Full Scale Deflection Fly Right" or "Fly Left" indications, which correspond respectively to a DDM of $\pm 150 \mu A$, are fully respected in free space, without any reflector.

The goal of this theoretical design is to guarantee that the RF-Level profile respects the required ICAO recommendations for the field strength within the reduced coverage of $\pm 15^\circ$. Beyond $\pm 15^\circ$ (until $\pm 35^\circ$), it is not guaranteed that these requirements for RF-level are fulfilled. However, if the signal is receivable i.e. if the RF-Level is superior to the receiver sensitivity (no RF-Level flag), then the theoretical design guarantees that the DDM and SDM (the guidance signals) requirements are fulfilled. Figure 13 below illustrates the theoretical principle of the design.

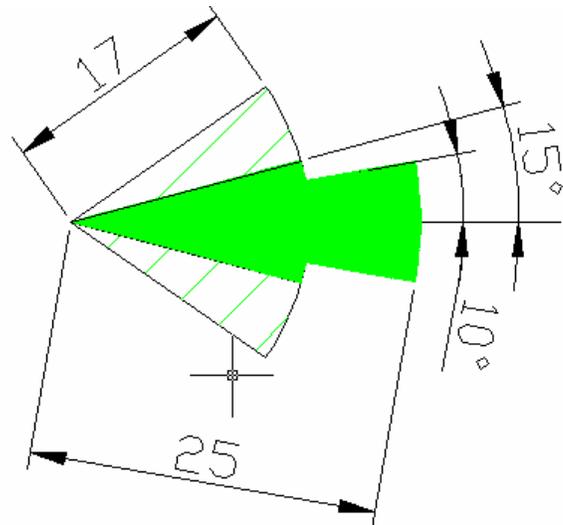


Figure 13: Expected Designed Situation of the Localizer Coverage

Figure 14 below illustrates the simulated DDM behaviour in free space. All the ICAO tolerances for DDM (and SDM) are respected by this theoretical design.

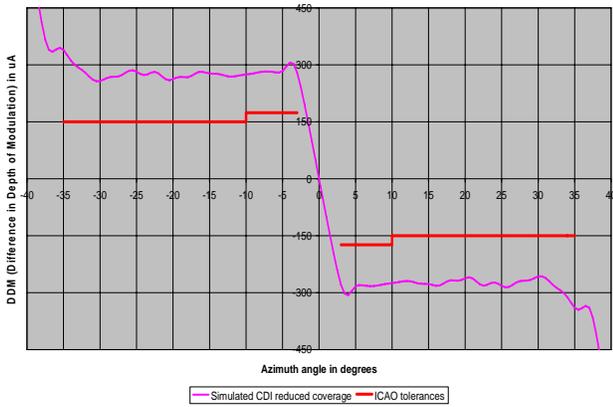


Figure 14: Simulated Course Deviation Indicator (DDM)

Technical Results and Analysis



Figure 15: Picture of the Commissioning Flight Check

The commissioning flight check has been performed by FCS (Flight Calibration Services) in May 2007. As illustrated by the following figures 16 for the CSB, 17 for the SBO antenna diagrams (Course and Clearance) and 18 for the Course Deviation Indicator, the measured signals in space have demonstrated a very high degree of correlation with the expectations and the simulations.

**NORMARC 7220B RWY 16 Zürich
Measured and calculated CSB patterns**

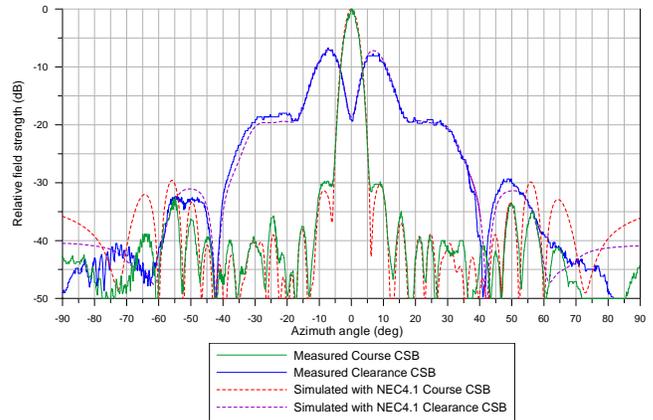


Figure 16: Course and Clearance CSB Antenna Diagrams

in Green: Measured Course CSB / in Dotted Red: Simulated Course CSB

in Blue: Measured Clearance CSB / in Dotted Violet: Simulated Clearance CSB

**NORMARC 7220B RWY 16 Zürich
Measured and calculated SBO patterns**

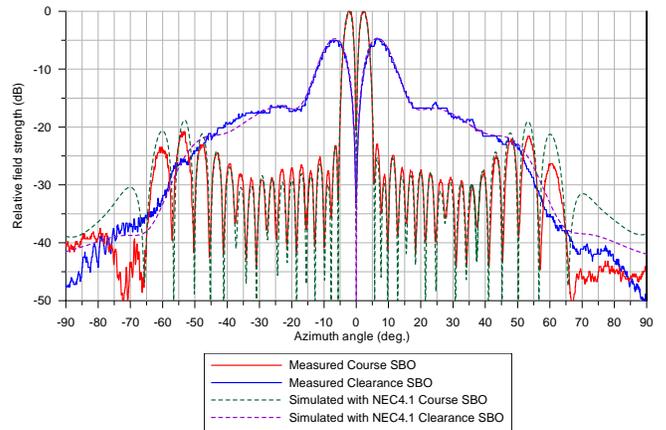


Figure 17: Course and Clearance SBO Antenna Diagrams

in Red: Measured Course SBO / in Dotted Pink: Simulated Course SBO

in Blue: Measured Clearance SBO / in dotted light Blue: Simulated Clearance SBO

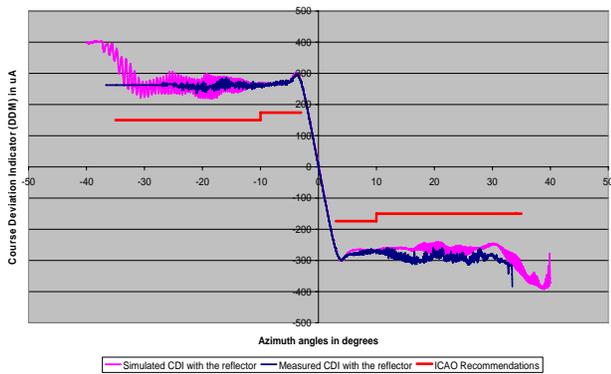


Figure 18: Simulated and Measured Course Deviation Indicator of the Reduced Coverage System at a Range of 17 NM and an Altitude of 3800 ft QNH

The following Figure 19 shows the comparison between the initial disturbed situation and the final undisturbed situation of the Course Deviation Situation. The improvements of the quality of the signal in space are very clear:

- no more false courses are measured
- In the "Full Scale Deflection" regions, the absolute value of the CDI remains so high and stable, that:
 - The margin with the ICAO tolerances (in red) are very comfortable,
 - No interception problems are expected with such stable DDM profiles and smooth transitions between the Course and the Clearance domains.

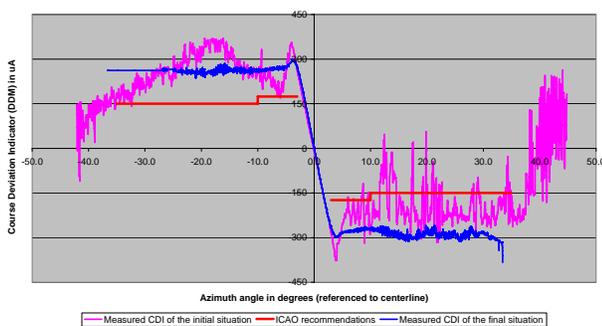


Figure 19: Comparison Between the Initial and Final Situations: Course Deviation Indicator of the Reduced Coverage System at a Range of 17 NM and an Altitude of 3800 ft QNH

The following Figure 20 shows the RF-Level, the Sum of Depth of Modulation (SDM) and the Difference in Depth of Modulation (DDM) profiles of the reduced coverage system measured by the flight check at a range of 17 NM

and an altitude of 3800 ft QNH. The flat profile of the SDM demonstrates also that the ICAO requirements for SDM are also respected, on condition that the RF-Level is sufficient. No over modulation problems, and consequently no erroneous DDM processing for the interception phases are expected with this measured signal in space.

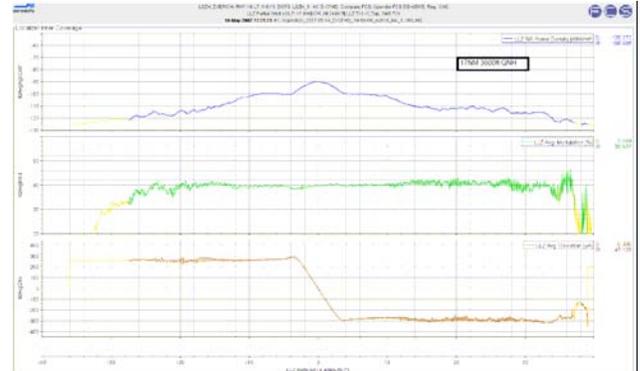


Figure 20: RF-Level (in Blue), SDM (in Green) and DDM (in Auburn) Profiles of the Reduced Coverage System at a Range of 17 NM and an Altitude of 3800 ft QNH

Because of the high terrain, the lateral coverage, where DDM, SDM and IDENT were found useable, has been limited to the following sector: from -25° East to $+30^{\circ}$ West at a range of 17 NM and at an altitude of 3800 ft QNH. The following Figure 21 below illustrates this field strength profile and the minimum of -114 dBW/m^2 required by ICAO (in red).

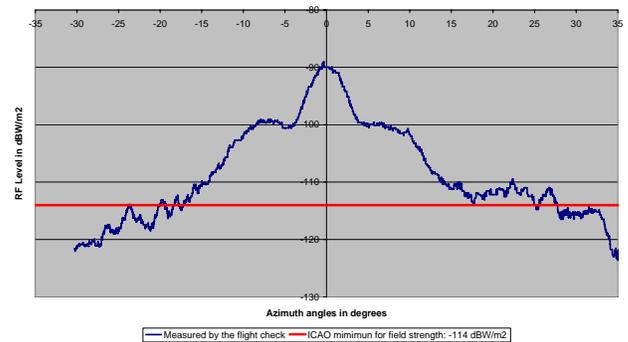


Figure 21: Field Strength Profile of the Reduced Coverage System at a Range of 17 NM and an Altitude of 3800 ft QNH

The effect of the terrain attenuation due the high horizon, especially on the eastern side (for negative azimuth angles), is illustrated by the following Figure 22. On the western side (for positive azimuth angles), the correlation between the simulations, the measurements with and without terrain obstruction is very good. For negative

angles, on the eastern side, the gap between the curves (blue, pink and dark blue) can be explained by the terrain attenuation and the loss of the line of sight conditions.

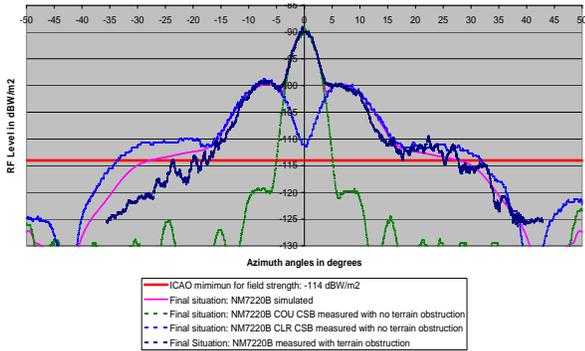


Figure 22: Simulated and Measured (With and Without Terrain Obstruction) Field Strength Profiles of the Reduced Coverage System at a Range of 17 NM and an Altitude of 3800 ft QNH

In order to reduce the interference caused by Clearance reflections on obstacles located at azimuth angles superior to $\pm 15^\circ$, the principle, which consists in reducing the initial field strength of the Clearance signal in these regions, is illustrated by Figure 23. Outside the region of $\pm 15^\circ$, the difference in RF-Level between the final reduced coverage system (in pink) and the two others (the initial disturbed system and a new conventional $\pm 35^\circ$ design, in blue and violet) represents the potential reduction of the interference. The bigger the margin is, the less sensitive to Clearance multipath the new system is.

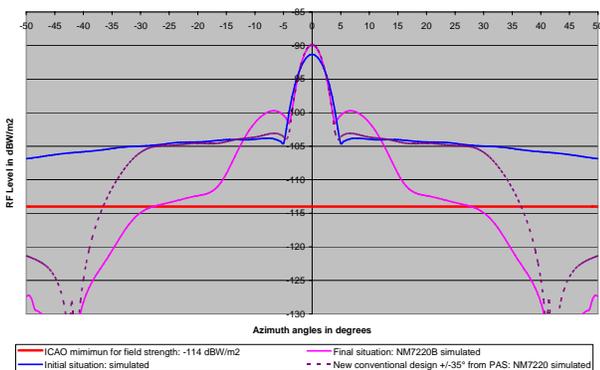


Figure 23: Simulated Field Strength Profiles of the Initial Disturbed System (in Blue), the Final Reduced Coverage System (in Pink) and a Modern Conventional $\pm 35^\circ$ System (in Violet)

Special flight checks have also been organized, in order to check the reception of the IDENT of the localizer. By flying the standard and published IFR approach procedures (documented by the IFR Approach Chart), the "flyability" of the standard interception and the

availability of the IDENT have been assessed. It has been demonstrated that, as with other conventional systems, the IDENT is receivable and useable if the line of sight conditions (i.e. no screening effects due to topographic obstacle) are respected. The following Figure 24 describes the availability of the IDENT, superimposed on the IFR Approach Chart.

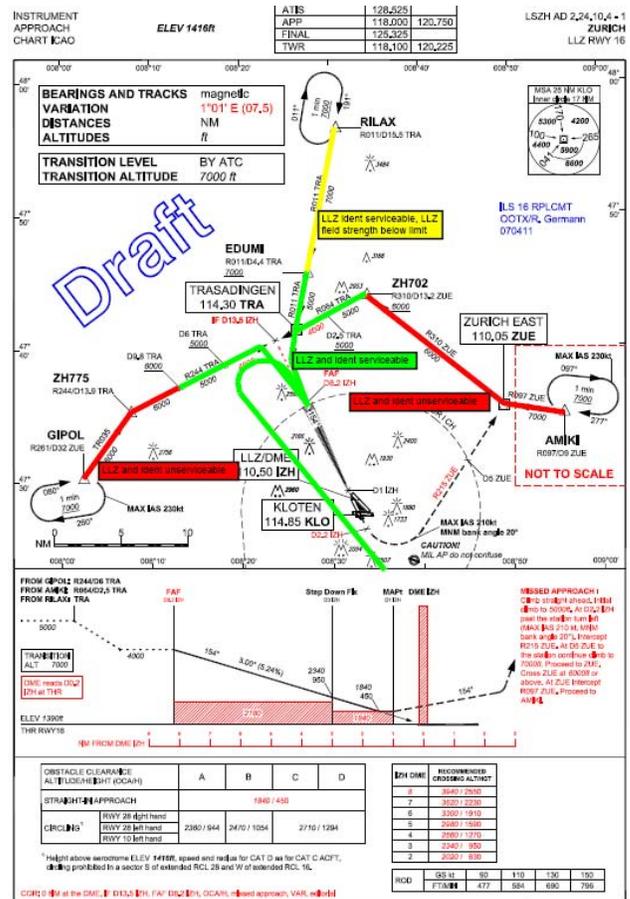


Figure 24: Availability of the IDENT on the IFR Approach Chart Zurich 16

Stability and Operations

The new ILS 16 (and specially the new localizer 16) is CAT III operational since 30th November 2007.

During its stability test phase and since the beginning of its operational service, the localizer has demonstrated a very good technical stability, without any outage. For the integral recombining DDM monitors, the measured stability is the following one:

- $\pm 0.5 \mu A$ for the DDM of the course line monitor,

- $\pm 2 \mu\text{A}$ (referenced to $150 \mu\text{A}$) for the DDM of the displacement sensitivity monitor,
- $\pm 1 \mu\text{A}$ (referenced to $263 \mu\text{A}$) for the DDM of the clearance monitor.

For the nearfield monitor, the measured stability of the DDM is also very good with $\pm 1 \mu\text{A}$. For all the monitors, the stability of the SDM parameters has been assessed to $\pm 0.05 \%$, which is also very satisfying. Finally, for all the monitors, the measured stability of the RF-Level parameters has been assessed to $\pm 0.2 \text{ dB}$, which also respects the recommended ICAO tolerances of $\pm 1 \text{ dB}$ for dual frequency localizers.

A special safety monitoring process within Skyguide is collecting operational data and possible pilot feedbacks. No remark and no pilot complaint has been noted in the Tower-Logbook. Besides, no "Safety Occurrence" or no "Safety Improvement Report" has been generated during this period.

CONCLUSIONS

Based on the described experience of the reduced coverage localizer 16 in Zurich, it has been demonstrated that it is possible to solve the Clearance / Clearance interference on a difficult site, by limiting the incident signal on the reflector. Thanks to the reduction of $\pm 15^\circ$ of the service volume, the improvement of the quality of the signal in space represents a major safety improvement, by solving the false courses problem. Besides, it has been shown that outside this certified reduced coverage of $\pm 15^\circ$, the guidance signals, DDM and SDM, are fully compliant with the ICAO recommendations. This also guarantees the system integrity: if receivable, the signals are correct; if not receivable, they are of course flagged. Moreover, the operational and technical experience accumulated since 24th August 2007 has demonstrated that this localizer has been used and operated like any other conventional system. Thus, this specific case Zurich

16 represents a supporting technical validation of the reduced coverage localizer.

Finally, in case of a bad course structure (along the centreline) caused by Clearance reflections on obstacles located outside the $\pm 15^\circ$ region (or even $\pm 12^\circ$ as discussed earlier), the Course / Clearance interference problem can be reduced or even solved by using a reduced coverage localizer. This solution using a "raised lower coverage limit" localizer represents a major safety improvement compared to conventional ILS with coverage restrictions.

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- Engineering graduate of DESIA (higher educational certificate in business engineering).

Professional experiences :

- Technical Navigation Engineer: ILS troubleshooting, maintenance support, ILS commissioning and optimization:
 - o Conventional ILS
 - o Optimized Glide Path
 - o Optimized Localizer (Clearance modification)
 - o End-Fire Glide Path (factory certification of instructor)
 - o Slotted Cable Localizer
 - o Reduced Coverage Localizer
- Project Leader: Project management for Nav aids replacement and new commissioning.
- Technical speaker / trainer at the ENAC (Ecole Nationale de l'Aviation Civile) Toulouse (university-level college for engineering in aeronautics).

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Job Title: Senior Specialist, Navigation

Topics of Studies:

Bachelor of Science, Avionics Engineering Technology, Embry-Riddle Aeronautical University, 1996 (Magna Cum Laude)

Master of Science, Electrical Engineering, Avionics Engineering Center, Ohio University, 1998

Professional Experiences:

Swiss Federal Aircraft Company (now RUAG), Electrical Systems Group, Emmen, Switzerland:

- Implementation support for fuselage fatigue monitoring systems and small technical upgrades to fighter fleet

Naval Air Systems Command, Satellite Navigation, ATC and Landing Systems Division, Patuxent River MD, USA:

- Validation, testing and standards development for Ground Based Augmentation System (supporting FAA through RTCA SC159, Global Positioning System)

Skyguide, Air Navigation Service Provider, Systems Planning Group, Zurich Airport, Switzerland:

- Development of GBAS (Implementation in Switzerland, international harmonization, siting criteria) and GNSS in general
- Coordination of flight inspection development and test and evaluation capabilities

Eurocontrol, Directorate of ATM Programmes, Airspace, Network Planning and Navigation Division, Brussels, Belgium:

- ILS Sustainment, RNAV Infrastructure and 4D Navigation
- Technical Advisor to ICAO Navigation Systems Panel

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Job Title : Systems Engineer/Product Adv., Navigation

Topics of studies :

- Engineering graduate of Bergen College, Norway (1971)
(Servo systems, digital and analog control systems and automation)

Professional experiences :

- Norwegian Telecommunications Administration and Norwegian Civil Aviation Administration from 1972 to 1996
 - o Field engineer ILS installation
 - o ILS flight inspection
 - o Project management of ILS installations
 - o Mathematical modeling of ILS
 - o Design of ILS antenna systems
 - o Technical speaker/instructor general ILS theory training courses
- Park Air Systems from 1996 -
 - o Head of ILS installation department (1996 – 2000)
 - o Mathematical modeling of ILS
 - o Design of ILS antenna systems
 - o Technical consultant (ILS) for sales department
 - o End-Fire Glide Path (factory certified instructor)