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Evaluation, Commissioning and Certification of the First Super Wide Aperture Localizer Array: an Efficient Solution to Course Multipath Interference

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ABSTRACT

In order to provide horizontal guidance to landing aircraft, two-frequency Instrument Landing System (2F-ILS) localizers radiate information on two carriers; 1) the course signal for the linear guidance around the runway centerline within the azimuth sector +/- 4°, 2) and the clearance signal for the required coverage within the localizer service volume (+/- 35° typically).
In case of course signal reflections from obstacles placed within its sector, the guidance structure along centerline can be seriously affected by course/course interference and the Category III structure roughness criteria can not be guaranteed anymore.
In order to substantially reduce course multipath problems in Geneva, Skyguide, in cooperation with Watts Antenna Company and after significant study, decided to install the Watts Model 201 Super Wide Aperture Slotted-Cable Localizer Array, on Runway 23 in 2005. For the clearance signal, the course array has been associated to the Normarc NM 3525 from the supplier Park Air Systems.
In order to solve course / course interference, course incident signal towards the reflector must be reduced with a more directive array. In order to achieve the required directivity with a narrow beam, the aperture of the array has to be drastically increased. A wide-aperture, such as 83 meters, is required to produce the beam. At the time, the widest aperture arrays commercially available were 47 meters or smaller.
This paper describes the different phases of the installation, commissioning and certification project in Geneva and the practical results achieved. After diagnosing the problem as course / course interference, the theoretical analysis showed the capability of the Model 201 to reduce the influence by 50 percent or more. This paper also describes the tuning phase and highlights the flight check results. As the practical results were very encouraging and solved the signal in space problems, Skyguide decided to assess the stability of the equipment. After having met long-term stability testing and achieving the 4000 hours continuity of service required in the International Civil Aviation Organization (ICAO) publication Annex 10[1], the wide-aperture localizer achieved certification for Category III operations.
As a result of a directive antenna providing a very narrow course beam, the array demonstrates the smallest critical and sensitive areas of any Instrument Landing System (ILS) localizer available today. Computer modeling conducted by the Ohio University Avionics Engineering Center, under contract by Watts Antenna Company, confirms these results[2-6]. The directive beam allows for development of airport real estate and taxiing of large and super jumbo aircraft, such as the Airbus A-380 with a substantial reduction in the influence to the ILS guidance signal.

INTRODUCTION

The earliest ILS localizer arrays were designed for 360 degrees of coverage[7]. Over the years, necessity has dictated an increase in the array aperture resulting in narrower beams and an incremental reduction in coverage. As problems in the front course became evident, wire reflectors were added behind the array to reduce the energy incident on multipath sources behind the array that reflected into the front course. The wires, in many cases, resulted in degrading of the guidance quality and signal level in the back course rendering it unusable. A natural reduction in the localizer coverage area resulted.
As the localizer aperture grew and efforts to reduce multipath using simple non-directive antenna elements in the array became a challenge, directive elements such as the log-periodic dipole were used in their place to reduce lateral radiation. As the level of radiation in any direction is determined by the array factor multiplied by the element factor, directive elements help to obtain larger aperture performance from the smaller aperture arrays. As the array becomes very large, the element used in the array becomes of little consequence except for broadband characteristics, mutual coupling, and front-to-back ratio.
When these arrays were challenged, a further reduction in the coverage, or service volume, of the localizer was accepted allowing new tailored radiation patterns designed to reduce multipath. When the airport environment became increasingly difficult, the two-frequency ILS was developed that allowed course centerline signals to be radiated on a much narrower beam while clearance signals were transmitted on a separate carrier and with a broader radiation pattern. This division, creating two distinct antenna patterns, allowed development of the course array in much larger apertures while maintaining the general characteristics of the clearance pattern.
It is interesting to note that the aperture size of the ILS localizer has not increased linearly over the years. ILS engineers have long known the need for the largest practical course aperture possible but struggled to produce a broadband, cost effective and easily maintained system. Little known to many was the period around 1951 where a slotted waveguide localizer aperture of 200 feet (61 meters) were developed with substantial success but some design and maintenance difficulties. Clearance signals were provided by an 8 loop clearance array. The waveguide of that time had course patterns narrower than some "modern wide aperture" localizer systems today. These arrays were few in number and were inevitably removed in order to simplify or standardize existing systems. In some cases their replacement resulted in a reduction in the guidance signal quality when compared to the modern antennas.
The waveguide system was successful in producing narrow beam radiation but was difficult to tune for broadband operation. The waveguide used a type of slot cavity with an excitation probe that had to be tuned for different operating frequencies. The significant problem, however, was that not only did the electrical spacing of the slots vary with frequency but the physical dimensions of the waveguide itself resulted in a change in the velocity-of-propagation thereby limiting the frequency of operation even further. In the Watts slotted cable system a coaxial distribution system is used. The transverse electromagnetic mode (TEM) of a coaxial system is constant with regard to the velocity-of-propagation so one significant difficulty in producing a wide aperture broadband system was overcome. In short, the Watts Model 201 Super Wide Aperture Localizer is a continuation of an effort to obtain broadband super wide aperture localizer antennas with a simplified distribution system[8].

BACKGROUND

Since 1995, Runway 23 at Geneva Airport has been equipped with a THALES ILS system from the "SEL 4000" generation. The localizer antenna system was comprised of the dual frequency array "SEL 20+5": 20 dipoles for the course and clearance signals and 5 V-dipoles exclusively for the clearance signal. In 1995, this equipment passed Category III certification with a good quality of course structure roughness. (See Figures 1 and 2).

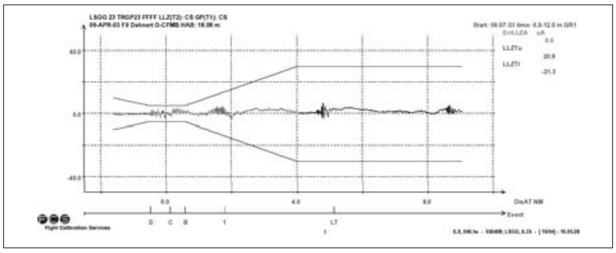

Figure 1. Course Structure in April 2003

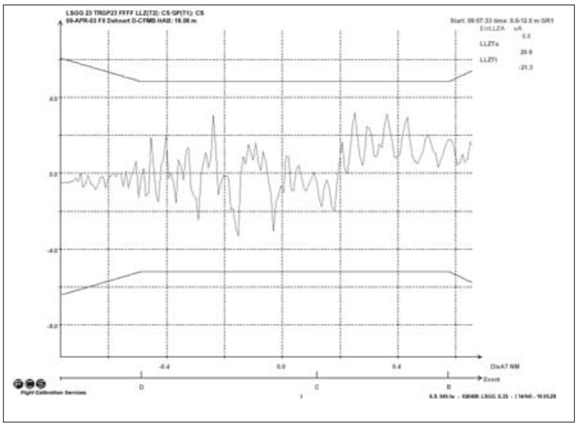

Figure 2. Course Structure in April 2003 (Zoom in of Short Final Segment)

Since October 2003, a slow, but continuous, degradation of the signal-in-space along the centerline was observed, due to on-going work on the airport. (See Figures 3 and 4).

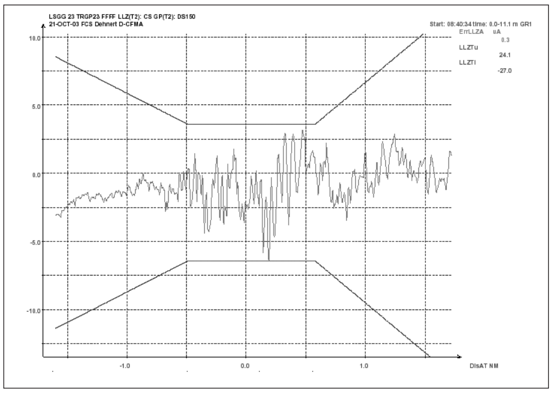

Figure 3. Course Structure in October 2003 (Zoom in of Short Final Segment)

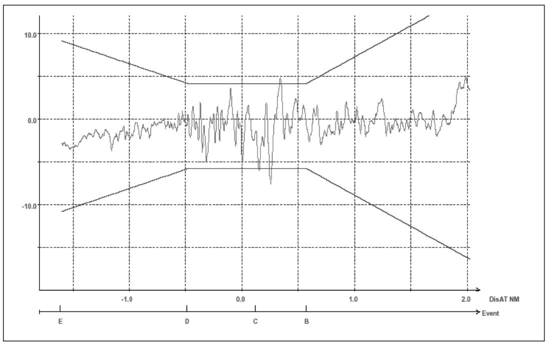

Figure 4. Course Structure in March 2004 (Zoom in of the Short Final Segment)

In September 2004, routine flight check measurements indicated that the structure roughness criteria were not respected any more: it was outside the 95 % maximum amplitude specification. (See Figure 5).

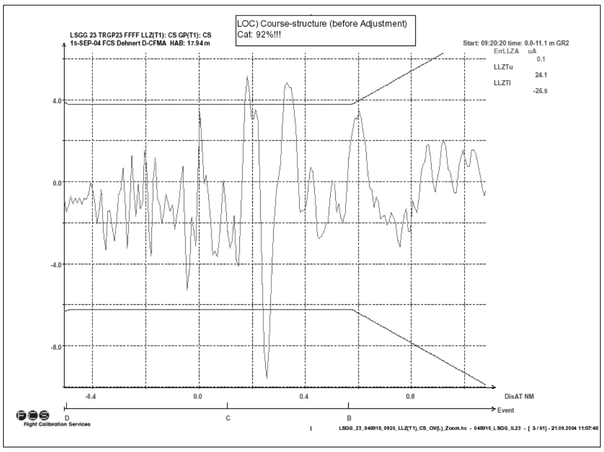

Figure 5. Course Structure on 15th September 2004 (Zoom in of Short Final Segment)

After having lost temporarily the Category III certification, technical compromises and tunings were found and the localizer was flight-checked and assessed again within the Category III criteria, but with nearly no margin. (See Figure 6).

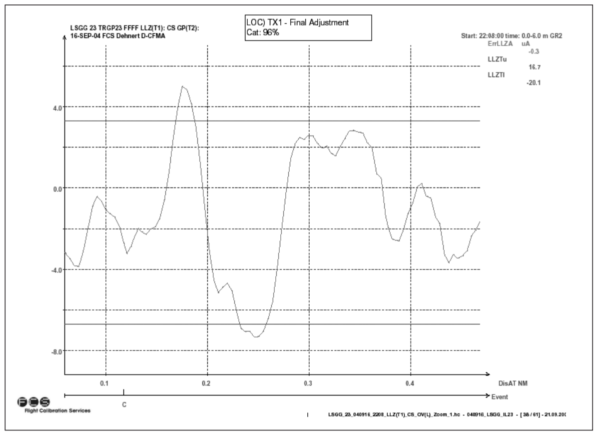

Figure 6. Course Structure on 16th September 2004 (Zoom in of Short Final Segment)

In such a delicate situation, it was decided in October 2005 to launch a localizer replacement project. After having passed the critical period of Fall 2005 and Winter 2005-2006, the THALES 20+5 localizer had to be replaced by a much more efficient antenna system that was insensitive to multipath interference. This system had to be found and ready for operation in October 2006.

PROJECT DESCRIPTION

Special flight checks (without clearance signals) showed that the perturbation between ILS points B and C was caused by a reflection of the course signal on obstacle(s) within the course sector, typically within the azimuth sector +/- 4° around the centerline. After having been reflected, this erroneous course signal interferes with the direct course signal on centerline, producing course / course interference.

Study Description

Software simulations confirmed course / course interference. Correlation analysis showed that the reflector was positioned at an azimuth angle of 3°, well within the course sector. For this type of interference, the unique improvement consists in reducing the incident course signal on the obstacle. Radiating less signal at 3° means indeed having a narrower course beam, which also entails installing a wider antenna array. In order to solve course / course interference, course incident signal towards the reflector has to be reduced with a more directive array. In order to achieve the required directivity with a narrow beam, the aperture of the array has to be increased. That's why only two localizers with a wider aperture (wider than 44.5 meters) and with a narrower course beam were considered in the study: the Normarc Model NM 3525 comprised of 24 log-periodic antennas from the supplier Park Air Systems with an aperture of 47 meters and the Model 201 Slotted Cable Localizer from the supplier Watts Antenna Company with an aperture of 83 meters. In order to characterize their sensitivity to course / course interference, Beam Bend Potential (BBP) calculations were performed. They represent the course SBO radiation pattern, normalized according to the same sector width. Indeed, this theoretical tool enables comparisons between antenna networks and assessment of the potential course bend reduction. (See Figure 7).

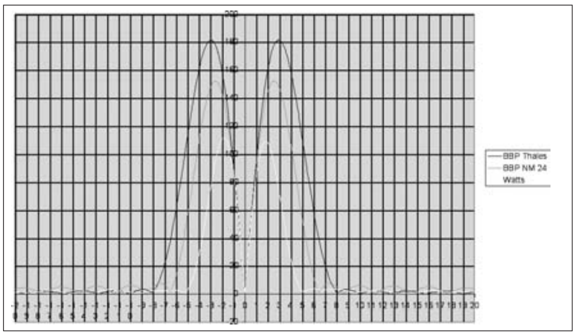

Figure 7. Beam Bend Potential Versus Azimuth Angle (Thales 20+5 in Blue, Normarc 3525 in Pink, Watts 201 in Yellow)

Figure 7 clearly shows that the Normarc 3525 is less sensitive to course / course interference than the Thales 20+5, and that the Watts Model 201 is much less sensitive than the two others. The Watts model is only sensitive to scattering objects placed in the azimuth sector of +/-5° around the centerline, whereas the sensitive regions for the Normarc 3525 and the Thales 20+5 are respectively +/- 6.5° and +/- 8°. Figure 8 characterizes the course bend potential reduction, referenced to the Thales 20+5. It enables to assess the reduction factor from the current situation: how much the amplitude of the perturbations will be decreased? At the azimuth angle of 3°, the relative voltage reduction of the Normarc 3525 is 0.8, producing a reduction factor of 20%, whereas the relative voltage reduction of the Watts 201 is 0.4, producing a reduction factor of 60%. This means that, if the amplitude of the perturbations with the Thales 20+5 was approximately 6 uA, one could expect an amplitude of 4.8 uA with the Normarc 3525 and 2.4 uA with the Watts Model 201.

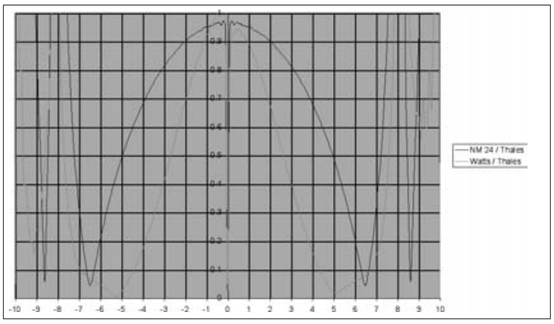

Figure 8. Bend Potential Reduction Referenced to the Thales 20+5 Versus Azimuth Angle (Normarc 3525 / Thales 20+5 in Blue, Watts 201 / Thales 20+5 in Pink)

Thus, the theoretical analysis shows that the solution Watts 201 is much more efficient than the Normarc 3525 and the Thales 20+5. However, in Fall 2004, it also presented three drawbacks; 1) the slotted cable antenna only radiates course signal, 2) a clearance antenna had to be combined in order to respect the required +/-35° service volume, 3) it had never been operationally used and certified.

The Replacement Strategy

The initial goal of the replacement project was to commission a localizer, which delivers good quality course structure and a good margin with regard to Category III roughness criteria. The theoretical study shows, that only the Watts Model 201 can achieve this performance. The Normarc NM 3525 may pass the Category III criteria, but with no significant margin. However, as the Watts Model 201 had never been commissioned, it has been decided to apply the following strategy with two alternatives; 1) the preferential one is to commission the Watts Model 201 for the course signal combined to the Normarc 3525 for the clearance signal and assess the system stability; 2) the backup alternative is to commission the Normarc 3525 radiating both course and clearance signals, as a conventional system. In case of instability of the preferential alternative, the backup one could have been commissioned and put into operation, on condition that it passed the Category III roughness criteria. Thus, the strategy consisted in installing, tuning and flight checking the two antenna systems and then assess the stability of the preferential alternative. Figures 9 and 10 present the layouts of the designed systems. It should also be noted that only eight log-periodic antennas radiate clearance signal in the Normarc 3525. However, the whole system was installed, in order to have a back up alternative available.

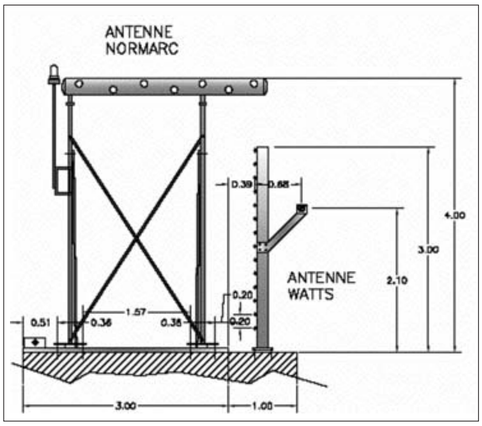

Figure 9. Vertical Layout of the Combined System: Watts 201 for the Course Signal and Normarc 3525 for the Clearance Signal

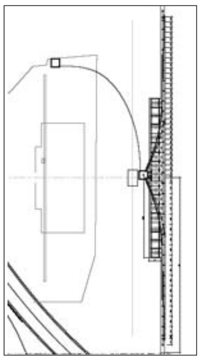

Figure 10. Horizontal Layout of the Combined System: Watts 201 for the Course Signal and Normarc 3525 for the Clearance Signal

Realization Description

In March and April 2005, the combined system was installed, tuned and flight checked. Figure 11 illustrates the tuning phase of the course signal of the Watts Model 201. Close observation of the figure shows maintenance staff in front of the slotted-cable measuring slot distributions.

Figure 11. Combined System Watts 201 + Normarc 3525 During Slot Measurements

According to the theoretical study, the flight check results of the combined system were very encouraging. As illustrated by Figure 12, its course structure roughness of less than +/- 2 uA passed with a big margin the Category III criteria.

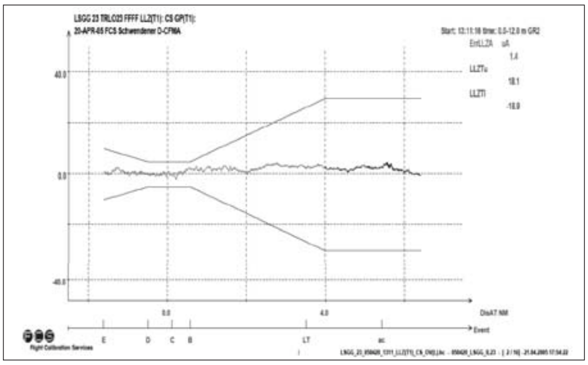

Figure 12. Flight Check Results of the Combined System Watts 201 + Normarc 3525: Course Structure

The azimuth transverse structure profiles measured by flight check present also a high degree of correlation with the theoretical study and the simulations. These flight profiles, illustrated by Figure 13, also respect the Category III criteria: 1) a perfect linear behavior of the DDM within the course domain of +/- 4°; 2) a stable behavior of the SDM at 40% without any over modulation problem; 3) enough field strength ensuring the typical ICAO service volume of +/- 10° at 25 NM and +/- 35° at 17 NM.

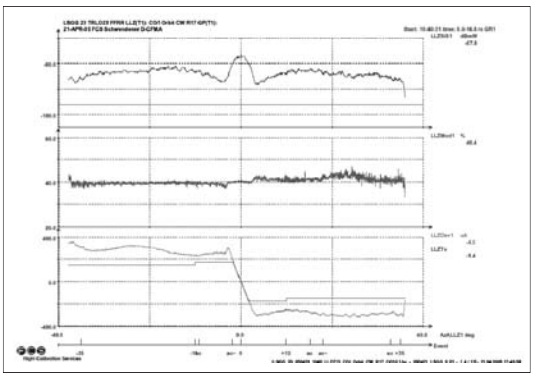

Figure 13. Flight Check Results of the Combined System Watts 201 + Normarc 3525: Azimuth Transverse Structure (Field Strength in Green, SDM in Blue, DDM in Pink)

According to the strategy, the backup alternative, Normarc 3525 radiating course and clearance signals, was also flight checked. Figure 14 illustrates its course structure roughness of +/- 4.5 uA to +/- 5 uA, which meant that it passed the Category III roughness criteria, with nearly no margin and that the second alternative was really a backup one.

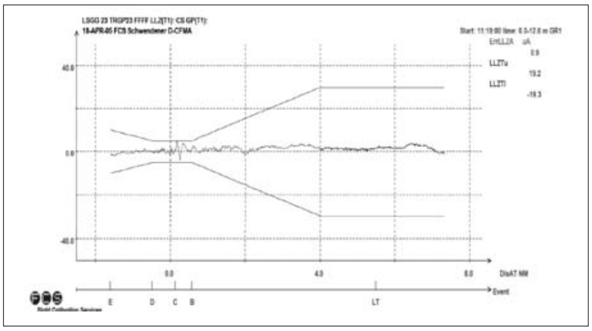

Figure 14. Flight Check Results of the Normarc 3525 (Course and Clearance): Course Structure

Critical area tests of the Watts 201 and the Normarc 3525 were also performed with fire trucks in the vicinity of the localizer. No perturbations were observed by the flight checks. Figure 15 illustrates this special test.

Figure 15. Critical Area Test

After these very encouraging flight check results and stability data, the decision was made to begin the stability test phase with the combined system Watts 201 + Normarc 3525.

SYSTEM DESCRIPTION

The Model 201 Localizer System[9] is a modification of a standard two-frequency, capture-effect (CE) localizer system affected by replacing the existing course array with the Super Wide Aperture Model 201 antenna and associated distribution and monitor recombiner circuits. The system is designed to interface with any manufactured transmitting and monitor equipment. The course antenna can be used with numerous clearance antenna arrays, however, optimum performance and compatibility must be evaluated on a case by case basis. The system is designed to provide the highest quality course signals at runways where reflections from structures, aircraft, trees or power lines close to the centerline would otherwise cause excessive course bends. Outside the narrow course beam the broader beam of the clearance array provide guidance to +/- 35 degrees azimuth. The Model 201 course array is the result of an effort by Watts to overcome sitting difficulties encountered with smaller aperture arrays and to produce wide and super wide aperture localizer antennas with a simplified distribution.

Where course in-beam multi-path prevents the use of smaller wide aperture arrays or where an increase in airport efficiency is desired, the Model 201 Super Wide Aperture Localizer Antenna replaces the course array and cabling, course distribution unit and course monitor recombiner unit installed with a conventional two-frequency localizer system. In the event that the course and clearance distribution and monitor distributions are combined, all course inputs and outputs are dummy loaded and the transmitter output signals are fed directly to the distribution unit of the Model 201 antenna. This modified system provides the final approach azimuth guidance information to a landing aircraft, enabling the pilot, or autopilot, to maintain the proper alignment with the runway centerline during an approach and landing. The system is largely unaffected by multipath reflections at any site meeting obstruction safety standards for landing.

The Model 201 antenna produces the narrowest course beam available today from a simplified distribution scheme while insuring that the design objectives for sidelobe suppression are not degraded by the process of "cutting antenna pair nulls" in a multipath environment. The narrow beam radiated from the course array is intended to essentially eliminate course in beam signal reflections and allows the construction of buildings closer to runways and taxiways without degrading the ILS. The narrow beam permits the movement of aircraft close to the antenna array and results in the smallest critical and sensitive areas of any ILS localizer. The physically smaller critical and sensitive areas maximize the efficiency of airport operations with regard to the ILS by permitting the possibility of more take-off and landings in a given period. The antenna is engineered to provide Category III signal quality for the most complex airport environments in the world and represents research and development (R&D) in ILS antenna design well ahead of today's standards.

The Model 201 Super Wide Aperture Localizer Antenna System comprises course antenna, course antenna support and reflector, course antenna RF distribution and monitor recombiner unit, course antenna aperture monitor antennas, course antenna test probe, obstruction light kit, dry line dehydrator, system cable and connectors, two-frequency transmit and monitor electronics, clearance array, clearance RF distribution unit and clearance monitor recombiner unit. The antenna is typically located on the extended runway centerline beyond the stop end of the runway. The course antenna is supported by frangible aluminum supports in order to prevent serious damage to an aircraft that might overrun the runway and pass through the antenna system. The antennas of the clearance array are mounted discretely on aluminum supports at a height that allows the clearance antennas to look over the course antenna reflector. The course antenna and clearance array interface unit boxes are located behind and in the center of the antenna structure containing all the components necessary to interface with the transmitting antennas and to provide monitor signals to the electronics rack of the standard two-frequency localizer station.

Hardware Presentation

As illustrated by Figure 16, the overall structure is comprised of two different sub-systems; 1) the clearance array comprised of 8 log-periodic antennas of the NM 3525 from the manufacturer Park Air Systems (4 meters high, 14 meters aperture) see Figure 17, 2) the course antenna, which is the slotted cable from the manufacturer Watts Antenna Company. (64 radiating slots, 2.1 meters high, supported by a 3 meters high reflector), see Figure 18.

Figure 16. The Combined System

Figure 17. The Clearance Array

The course antenna, which is not a conventional parallel fed array, is comprised of 16 antenna sections connected to each other through joiners. Each section is 4.5 meters long and has 4 radiating slots, which gives a total of 64 radiating slots with a total aperture of 83 meters.

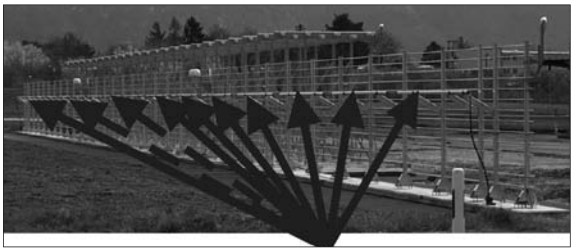

Figure 18. The Course Antenna Comprised of 16 Slotted Cable Sections

Course CSB and SBO are fed through two 7/8 inch pressurized cables into a hybrid (6_/4) in the interface unit. The two outputs of this hybrid are the two course feeding cables: Feed Right and Feed Left at both ends of the slotted cable. (see Figure 19). These cables are also 7/8 inch pressurized cables, for a better phase stability. They must be identical (type, length) and symmetrical for stability reasons.

Figure 19. The Two Feeding Cables Feed Right and Feed Left

With only two cables (course CSB and SBO), one hybrid and two feeding cables (Feed Left and Feed Right), the transmitting part is very simple. The key of the system is in the slotted cable design. The antenna is fed symmetrically at both ends, which implies waves traveling in opposite directions simultaneously, producing a standing wave. As illustrated by Figure 20, the transmission line is comprised of a 7/8 inch diameter rigid copper for the outer conductor and a 3/8 inch diameter inner conductor, Teflon pin supported. Each antenna section has four radiating slots. The brass probe screws project through a Teflon sleeve, into the eyelet, soldered in the inner conductor. Each probe screw forms a cylindrical coupling capacitor.

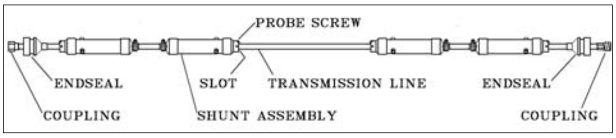

Figure 20. Course Antenna Section

Equivalent Circuit

The slotted cable is equivalent to an RF transmission line bridged periodically by shunt impedances Zi and Z'i, representing the slot assemblies. (see Figure 21). There is an even number of slots (64) and no slot in the middle.

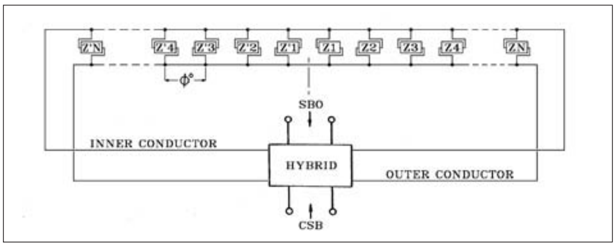

Figure 21. Equivalent Circuit of the Antenna

As illustrated by Figure 22, each slot assembly can be represented by the following equivalent circuit, comprised of, 1) a reactance Xp, produced by the probe screw forming a cylindrical coupling capacitor, 2) an admittance Ys of the slot itself, which has a capacitive and a resistive part and, 3) a susceptance Bs of the slot shunt assembly, which is a piece of transmission line terminated in a short circuit.

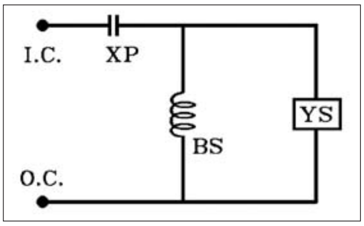

Figure 22. Equivalent Circuit of Slot Assembly

The reactance Xp is the only component that varies from slot to slot throughout the antenna. At any given slot, the length of the probe screw controls the amount of energy which is transferred out of the transmission line.

SBO and CSB Modes

Course SBO and CSB signals are fed respectively in phase and out-of-phase at both ends of the slotted cable, as illustrated by Figures 23 and 24.

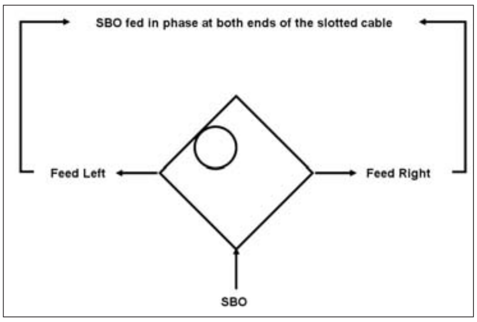

Figure 23. Course SBO Feeding Mode

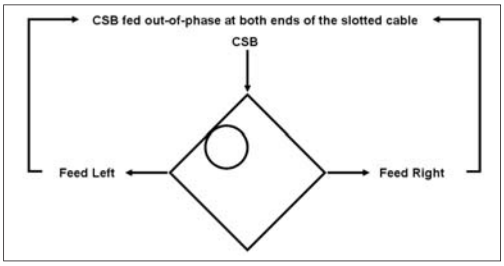

Figure 24. Course CSB Feeding Mode

Course CSB signal is comprised of equal but opposite waves that cancel each other at the center of the antenna and course SBO is comprised of equal and in-phase waves that produce a maximum at the center of the antenna, as illustrated by Figure 25.

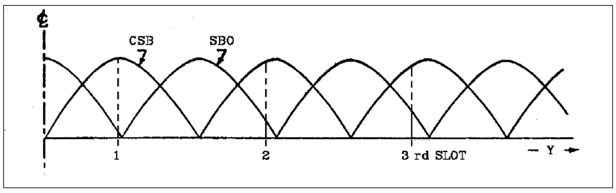

Figure 25. SBO and CSB Standing Waves Modes in the Middle of the Antenna

Measured Slot Distributions

As the slotted cable is fed symmetrical at both ends, it is possible to measure each of the slots in amplitude and phase, with only one feed cable or with both. As the CSB mode is produced by equal but opposite waves, the CSB distribution can be deduced from the vectorial difference of the two distributions (Feed Left and Feed Right). Figure 26 for the CSB amplitude and Figure 27 for the CSB phase show good correlation between actual measurements (light blue) and the computation of the vectorial difference (orange).

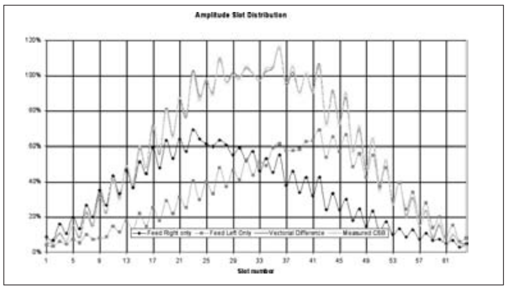

Figure 26. CSB Amplitude Distribution

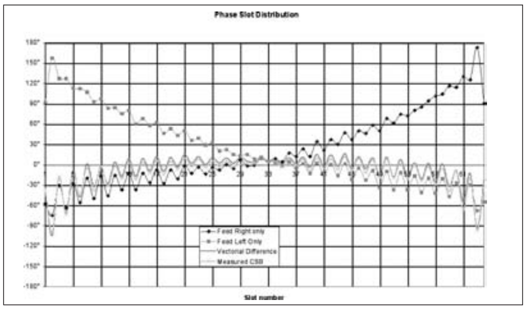

Figure 27. CSB Phase Distribution

As the SBO mode is produced by equal and in-phase waves, the SBO distribution can be deduced from the vectorial sum of the two distributions (Feed Left and Feed Right). Figure 28 for the SBO amplitude and Figure 29 for the SBO phase show good correlation between the actual measurements (light blue) and the computation of the vectorial sum (orange).

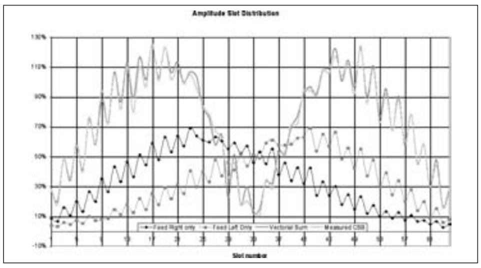

Figure 28. SBO Amplitude Distribution

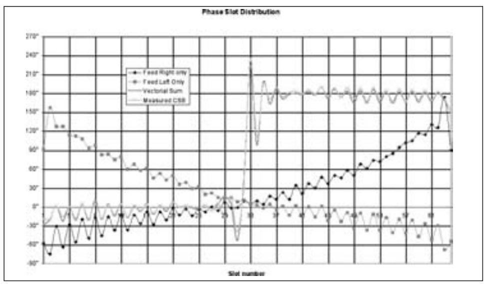

Figure 29. SBO Phase Distribution

The Gaussian Function

The probe screws are cut to produce CSB and SBO antenna current distributions that look approximately like Gaussian shapes: exp(-x2) for CSB and its derivative -2x exp(-x2) for SBO. Figures 30 and 31 respectively illustrate these voltage distributions of CSB and SBO. They also show the correlation between the theoretical Gaussian shapes and the measured distributions.

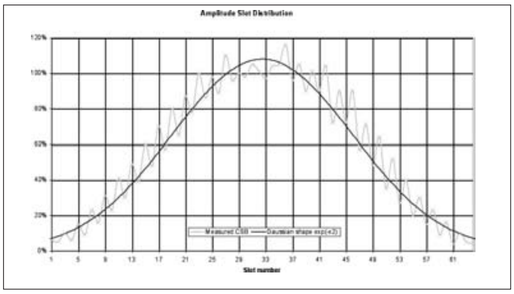

Figure 30. Gaussian Voltage Distribution for CSB (Theoretical and Measured)

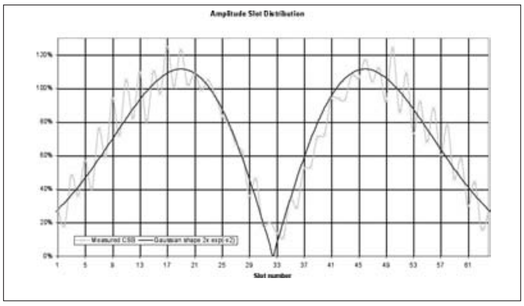

Figure 31. Gaussian Derivative Voltage Distribution for SBO (Theoretical and Measured)

When the number of elements becomes very large, the Gaussian distribution approaches the binomial distribution, which is known to produce theoretically a single beam with no sidelobes. The Gaussian function exp(-x2) and its derivative -2x exp(-x2) have the property of being their own Fourier transform. According to the theory of the linear arrays, this means that the radiation patterns produced by such current distributions will have the same shapes, with no sidelobes. The method employed in the design of the course antenna current amplitude distribution uses a truncated Gaussian shape. The extreme ends are then clipped until measurable minor lobes begin to appear. Allowing reasonable sidelobe levels enables to obtain a much better beam width, with the same aperture. Figures 32 and 33 respectively illustrate the expected antenna diagrams of CSB and SBO. They also show the good correlation between the theoretical Gaussian shapes and the antenna diagrams, computed from the slot measurements.

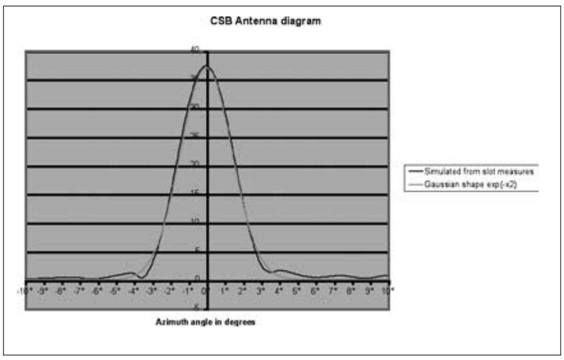

Figure 32. Gaussian Antenna Diagram for CSB. Theoretical (Pink) and Computed from Slot Measurements (Blue)

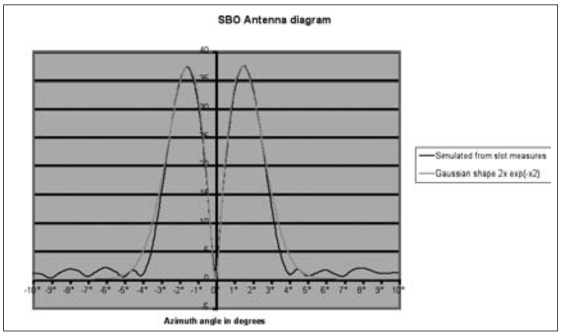

Figure 33. Gaussian Antenna Diagram for SBO. Theoretical (Pink) and Computed from Slot Measurements (Blue)

Flight Check Correlation

In order to validate this Gaussian theory, the SBO antenna diagram was measured during the commissioning flight check. The promising SBO sidelobe rejection, better than -25 dB, computed from the slot measurements, has been confirmed by the flight check results. In addition, the shapes of the main SBO lobes also showed good correlation, with a peak angle of 1.8° from centerline and a 3 dB beam width of 2.9° (azimuth angle from centerline). Figure 34 illustrates this correlation.

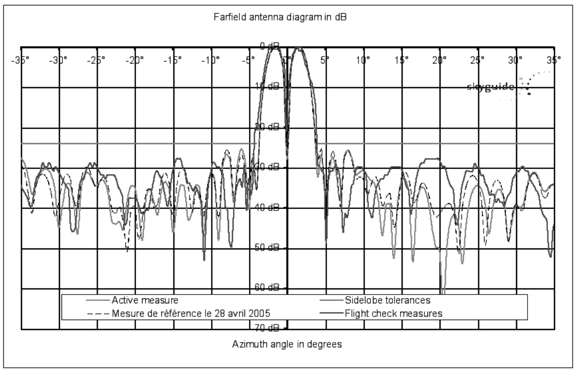

Figure 34. SBO Antenna Diagrams: Measured by Flight Check (Blue) and Simulated from Slot Measurements (Pink)

The computations of the CSB antenna diagram (from the slot measurements) also demonstrate a very good directivity: 1) a sidelobe rejection better than 29 dB, and 2) a total 3 dB beam width of 2.94° (+/- 1.47° around the centerline). Figure 35 illustrates the narrow beam computed.

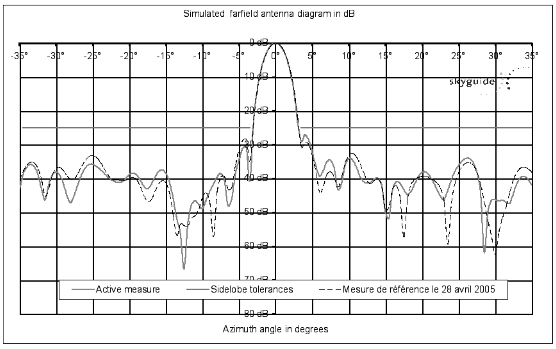

Figure 35. CSB Antenna Diagrams: Simulated from Slot Measurements (Pink)

As illustrated by Figures 36 and 37, good correlations for the total RF level and the azimuth DDM profiles (course and clearance signals) between the simulated and flight check data were observed.

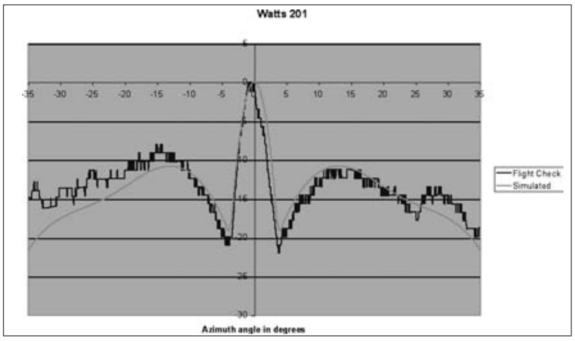

Figure 36. Total RF Level (Course and Clearance). Simulated (Pink) and Measured by the Flight Check (Blue)

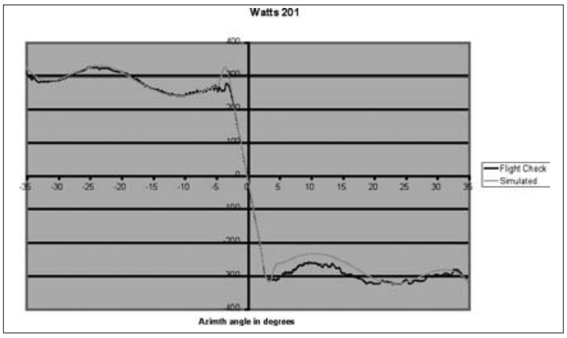

Figure 37. DDM Azimuth Profiles: Simulated (Pink) and Measured by the Flight Check (Blue)

SYSTEM STABILITY

Monitor Stability Data

After the commissioning flight check in April 2005, the stability test phase began for the combined system Watts 201 + Normarc 3525. After four very satisfying weeks, the preliminary data indicated good stability. Consequently, the determination was made to launch a certification process of the system. After more than one year of experience, the following Figures 38 to 41 illustrate the stability of the course monitors.
The integral centerline monitor and the nearfield monitor demonstrate excellent DDM stability. Over a period of one year, a variation of +/- 1uA has been observed, which corresponds to a movement of +/- 0.01° of the radio electrical axis of a 3.0 degree course width. This value is well within the ICAO tolerances. (See Figure 38).

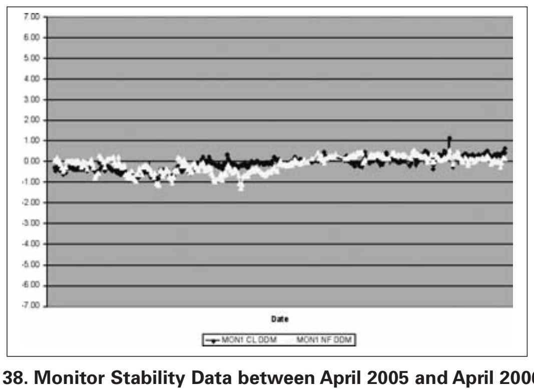

Figure 38. Monitor Stability Data between April 2005 and April 2006: DDM of the Integral Monitor Centerline (CL) in Blue and Nearfield (NF) in Yellow

The displacement sensitivity monitor (DS), which represents the sector width, also demonstrates good stability: between -1 uA and + 6uA, referenced to the 150 uA value, which corresponds to a variation between 149 uA and 155 uA. This maximum + 3.3 % relative variation is also well within the ICAO tolerances. Long term time data storage, with one sample per day over a period of more than one year, is illustrated by Figure 39.

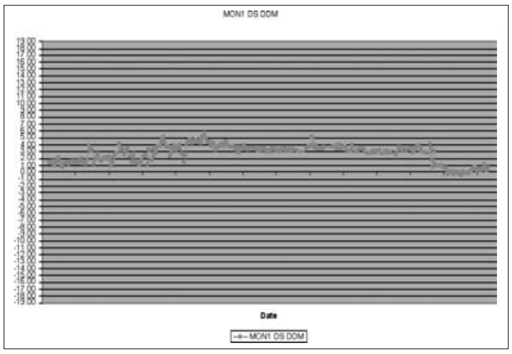

Figure 39. Monitor Stability Data Between April 2005 and April 2006: DDM of the Integral Monitor Displacement Sensitivity (DS), Referenced to 150 uA

As illustrated by Figure 40, the SDM monitors (nearfield, integral centerline and displacement sensitivity) are also very stable: the SDM variations are smaller than 0.2 %.

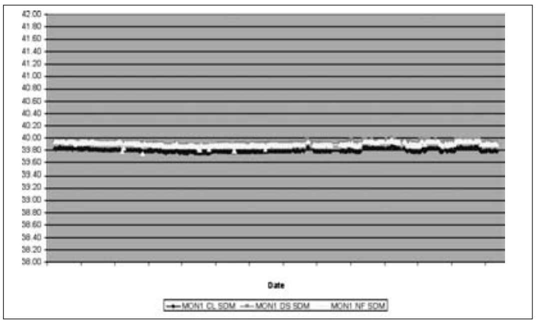

Figure 40. Monitor Stability Data between April 2005 and April 2006: SDM of the Course Integral Monitor Centerline (CL) in Blue, Displacement Sensitivity (DS) in Pink and the Nearfield Monitor (NF) in Yellow

As illustrated by Figure 41, the RF level monitors (nearfield, integral centerline and displacement sensitivity) also demonstrate acceptable stability within the +/- 1 dB ICAO tolerances.

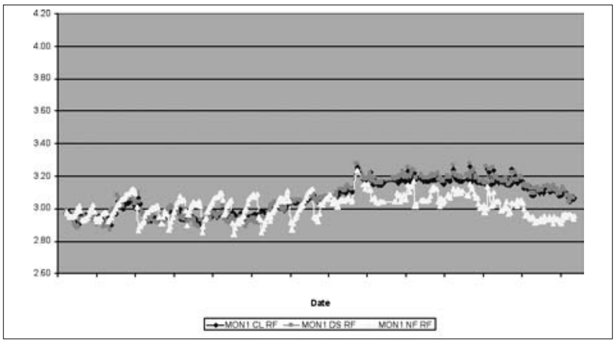

Figure 41. Monitor Stability Data between April 2005 and April 2006: RF Level of the Course Integral Monitor Centerline (CL) in Blue, Displacement Sensitivity (DS) in Pink and the Nearfield Monitor (NF) in Yellow

Ground Measurement Stability

The ground measurements, extracted from the monthly field maintenance, also demonstrate a stable signal-in-space. Figure 42 and 43 respectively illustrate the repeatability and the stability of the course structure and azimuth transverse profile over a period of nearly one year.

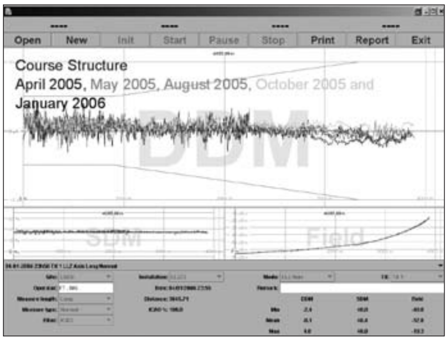

Figure 42. Ground Measurements of the Course Structure in April, May, August, October 2005 and January 2006

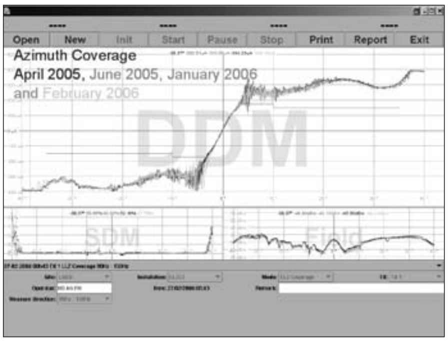

Figure 43. Ground Measurements of the Azimuth Transverse Structure in April, June 2005, January and February 2006

Flight Check Stability

Flight check results also demonstrate a stable signal-in-space. Figure pairs 44, 45 and 46, 47 respectively illustrate the repeatability and the stability of the course structures and azimuth transverse profiles over a period of nearly one year.

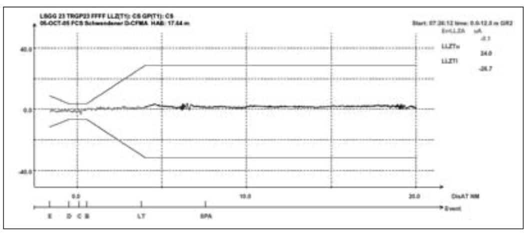

Figure 44. Flight Check of the Course Structure in October 2005

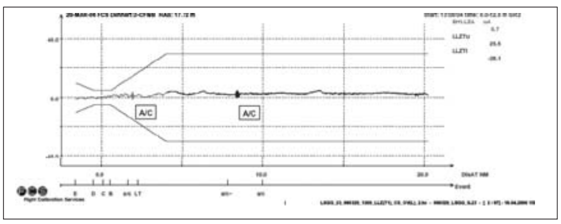

Figure 45. Flight Check of the Course Structure in March 2006

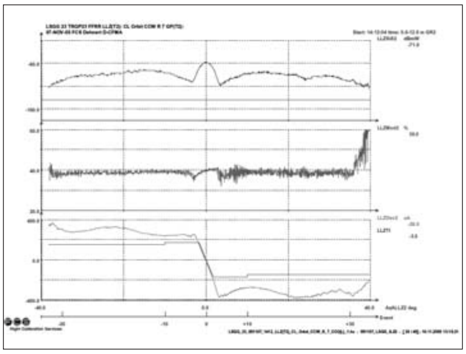

Figure 46. Flight Check of the Azimuth Transverse Structure in November 2005

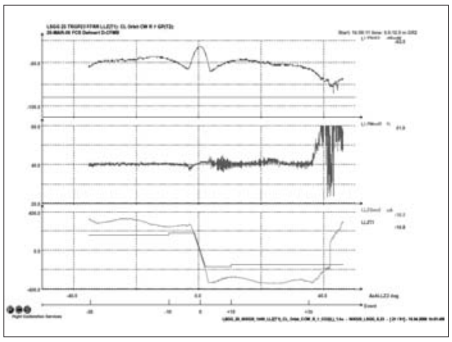

Figure 47. Flight Check of the Azimuth Transverse Structure in March 2006

After having met long-term stability testing and achieving the 4000 hours continuity of service required in the International Civil Aviation Organization (ICAO) publication Annex 10, the Super Wide Aperture Localizer achieved certification for Category III operations.

CONCLUSIONS

1) Wide aperture antennas can be realized for the ILS localizer using slotted-cable technology with a simplified distribution system.
2) The theory of the slotted-cable system represents a science that can be readily computed, verified and understood.
3) The Watts Model 201 Super Wide Aperture course antenna is a stable structure and meets all ICAO Annex 10 requirements for Category III signal-in-space, stability and continuity.
4) The Watts Model 201 Super Wide Aperture course antenna and the Normarc Model NM 3525 clearance array represent a complete ILS localizer system that meets all ICAO requirements for Category III operations.
5) ILS localizer antennas are available with substantial margin to solve the futures problems of course/course interference.
6) When the use of large aircraft, such as Boeing 747 or Airbus A-380, is considered, computer modeling indicate a substantial reduction in the critical and sensitive areas using super-wide aperture arrays.
7) ILS technology will continue to evolve to resolve future problems association with precision landing of aircraft.

REFERENCES

1. ICAO, 24th November 2005, International Standards and Recommended Practices, Annex 10 to the Convention on International Aviation, Volume 1, Radio Navigation Aids, 5th Edition, Amendment 80.

2. Quinet, David A. "Wide Aperture Slotted Cable Localizer Array: Modeling Predictions identifying Benefits of Narrow Course Beam in Presence of Large Structures and Aircraft". Technical Memorandum OU/AEC 99-02TM-H-99-268. Avionics Engineering Center, School of Electrical Engineering and Computer Science, Ohio University, Athens, Ohio, February 1999.

3. Quinet, David A. "Wide Aperture Slotted Cable Localizer Array: Modeling Predictions identifying Benefits of Narrow Course Beam in Presence of Large Structures and Aircraft (Phase 2)".Technical Memorandum OU/AEC 99-05TM-H-99-296-1. Avionics Engineering Center, School of Electrical Engineering and Computer Science, Ohio University, Athens, Ohio, April 1999.

4. Quinet, David A. "Application of the Wide-Aperture, Slotted Cable Localizer Array in Minimizing Critical Areas". Technical Memorandum OU/AEC 99-07TM-H-99-296-2. Avionics Engineering Center, School of Electrical Engineering and Computer Science, Ohio University, Athens, Ohio, April 1999.

5. Quinet, David A. "Evaluation of the Watts Antenna Company 270-Foot Wide-Aperture Slotted-Cable Localizer Antenna and 8-Element LPD Reduced Clearance-Sector Antenna Array". Technical Memorandum OU/AEC 04-16TM-2002-02-03-083. Localizer System Upgrade and Monitor Evaluation. Avionics Engineering Center, School of Electrical Engineering and Computer Science, Ohio University, Athens, Ohio, September 2004.

6. Quinet, David A. "Reduced Localizer Clearance Sector: Modeling Predictions Identifying the Benefits of a Reduction in the Presence of Large Structures and Group VI (A-380) Aircraft". Technical Memorandum OU/AEC 04-03TM-2002-02-03-082. Computer Modeling of Watts 201 Localizer with 8-Element CLR Array. Avionics Engineering Center, School of Electrical Engineering and Computer Science, Ohio University, Athens, Ohio, February 2004.

7. Watts, Chester B., Jr (Watts Antenna Co.) "Instrument Landing Scrapbook or Landing Blind over the years 1940 to 2003", 2005.

8. Watts, Chester B., Jr and Johnson, John H., Sr. (Watts Antenna Co.) "Problem Solving with Advanced Localizer Development" Summary of several problems which can be solved through the use of recent developments in design and manufacture of highly directive runway localizer antennas. November 19, 2004.

9. Watts Antenna Company. "Instruction Book. Highly Directional Instrument Landing System (ILS) Localizer Antenna System. Type Watts Model 201 Super Wide Aperture Localizer Antenna". Herndon, Virginia, April 2005.