Solution to coverage issues created by large hangars

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ABSTRACT

The airport of St Nazaire is equipped with a 13-element dual frequency localizer operated in Cat 1.
The addition of 2 large hangars (200x27m and 145x24m or 656x89 feet and 476x79 feet) has created an out of tolerance coverage DDM which has not been detected at the first flight inspection. Pilots reported false capture when flying some approach trajectories.
A new flight inspection detected the issue and a solution had to be found.
This coverage issue was in fact coming from the reflected clearance signal by the hangars interacting with the clearance signal on the opposite side of the runway. Reducing a clearance/clearance disturbance is quite challenging.
This presentation is going to show how this issue has been solved by using asymmetric clearance radiation patterns. This asymmetric radiation patterns are obtained by using the standard antenna distribution unit (ADU) and can be applied to any existing antenna systems. Just the CSB and SBO feedings to the ADU have been modified.

INTRODUCTION

The airport of St Nazaire is equipped with a 13-element dual frequency localizer operated in Cat 1.
The construction of 2 large hangars (POLARIS: 195x27m and WPC: 145x23m or 656x89 feet and 476x79 feet) created reflection of the ILS signal which lead to disturbances in the coverage area on the opposite of the buildings.

Picture 1: front view

Picture 2: view from localizer

The 2 hangars are parallel to the runway and at a distance to runway center line of 540m (1772ft) for POLARYS and 525m (1723ft) for WPC.

To reduce the flight time, the ATC can allow the aircraft to fly a shorter approach path as illustrated below.

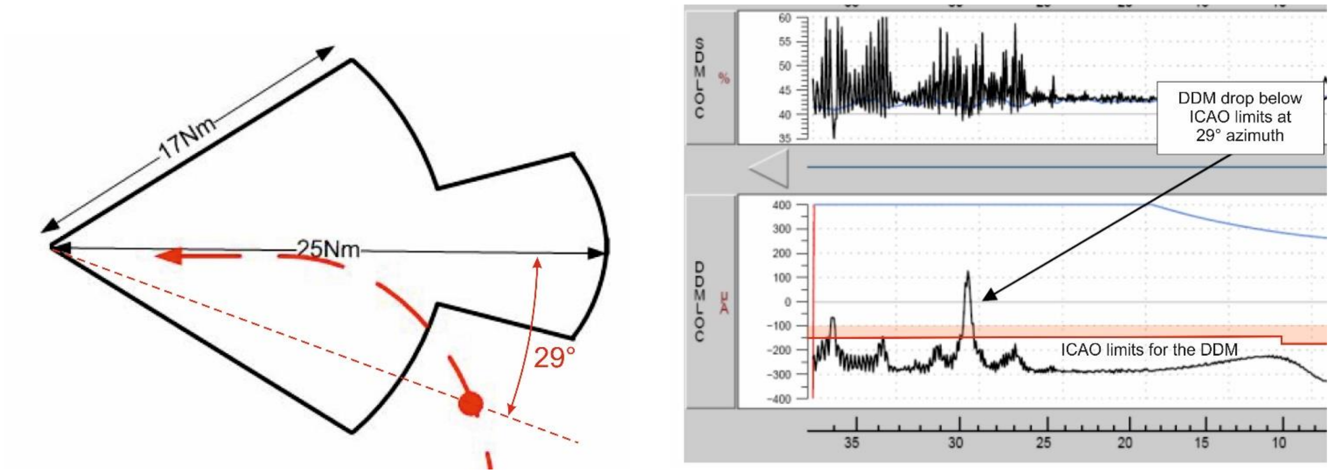


Figure 1

When flying this route, the aircraft is at 22NM when passing the 29° azimuth angle.
So even if the aircraft is flying outside the ICAO specified coverage area of 17NM, pilots are reporting false capture.

The flight inspection aircraft confirms that at this location the DDM is dropping below 150µA.

A previous flight inspection at 10 NM and 1500 feet showed the disturbance created by the hangars. But as one can see on the graph below the localizer was inside the ICAO specifications even with the clearance SBO level set to the lower monitor alarm limit.

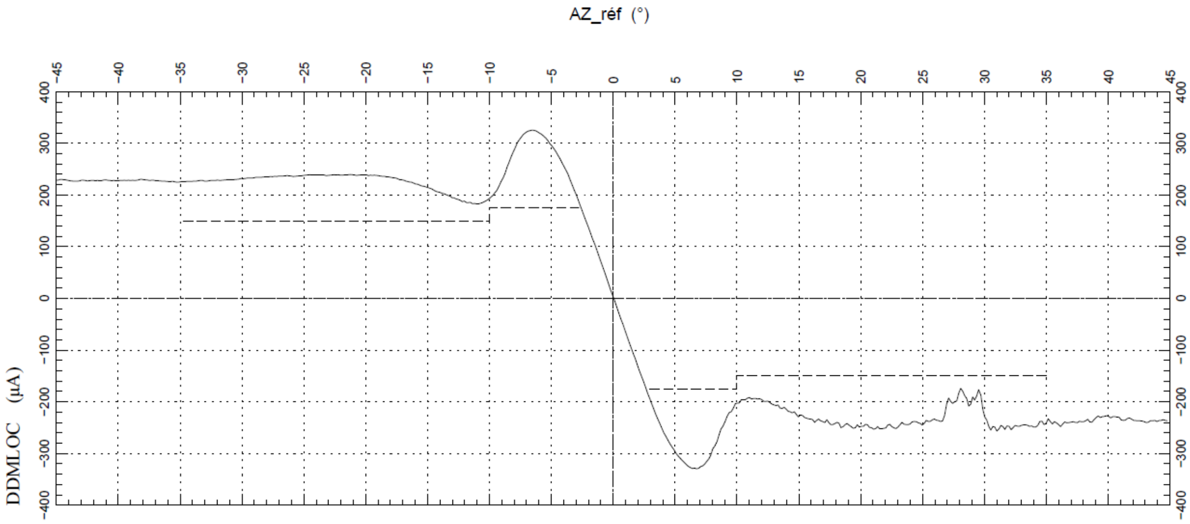


Figure 2

After some pilots reported false capture when not flying the conventional approach path, a follow-up flight inspection showed that even at the coverage limits at 17 NM and 2000 feet the coverage is jeopardized.

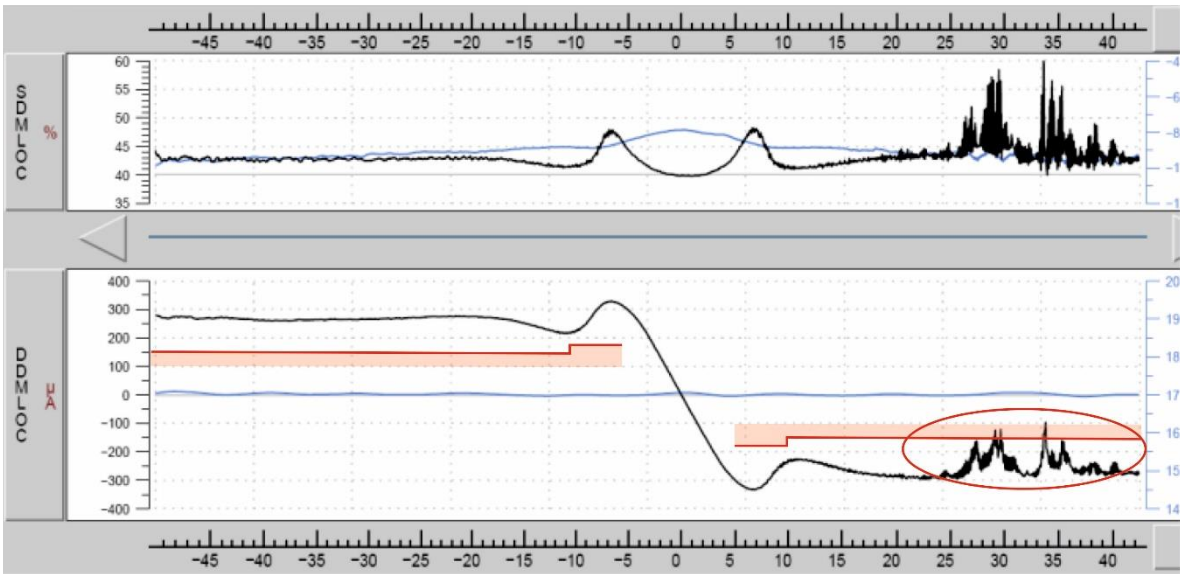


Figure 3

The Localizer simulation software ATOLL developed by the French Civil Aviation University (ENAC) has been used to simulate this localizer with the 2 hangars. The results shown below give a similar result as the one measured by the flight inspection. The DDM is dropping to approximately -100 µA.

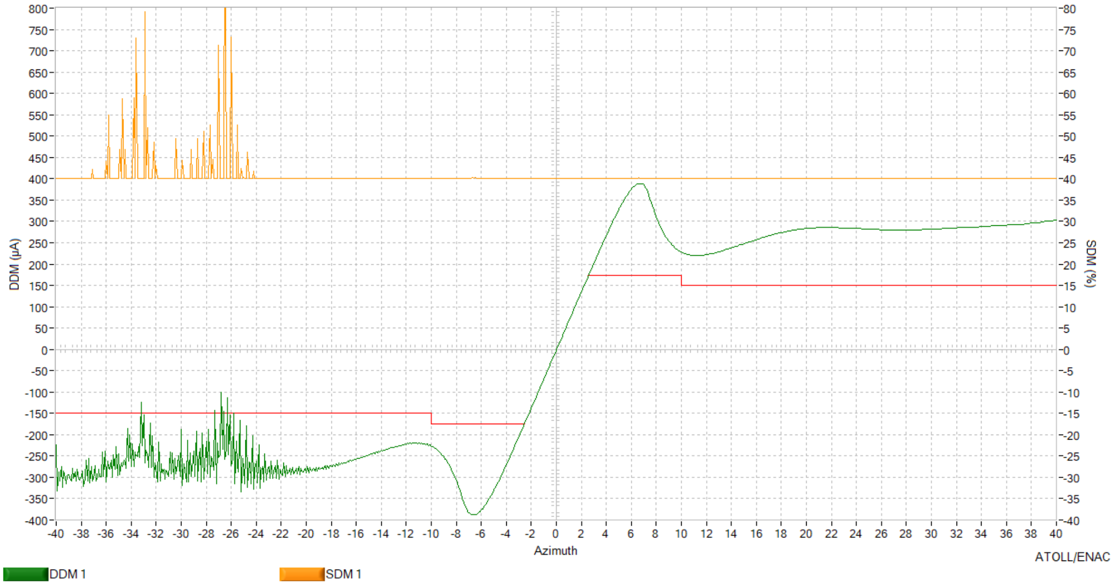


Figure 4

One could consider increasing the CLR SBO level to move the -100µA pick above the limit. But this would have 2 side effects. It would also increase the reflected DDM and therefore increase the disturbance. And it would also increase the SDM in the disturbed region leading to values above the 60% limit specified in Annex 10.

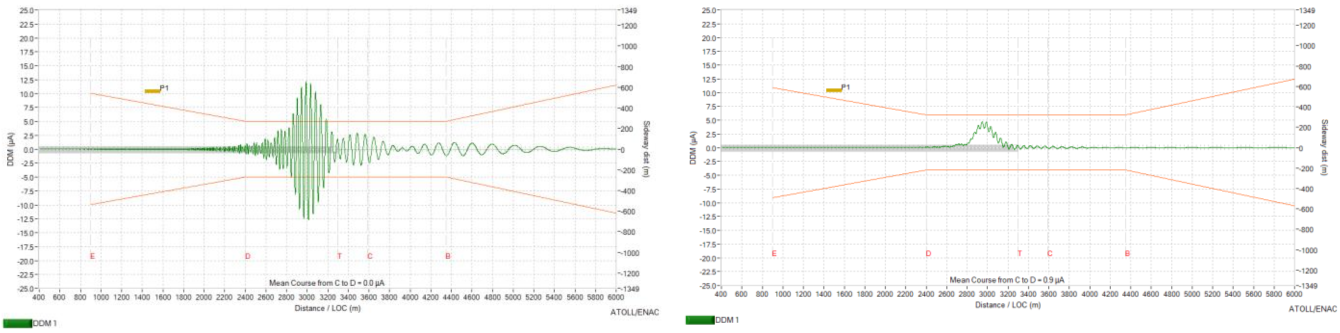
BASIC TYPES OF DISTURBANCES ON A DUAL FREQUENCY ILS

There are 2 types of disturbances on a dual frequency Localizer (see figure 5):

- Course to course or clearance to clearance disturbances, single frequency behavior
- Clearance to course disturbance, dual frequency behavior

The former generates large pseudo periodic bends
The later results in a small offset of the DDM

On an approach on center line the 2 behaviors are depicted below:
Simulations

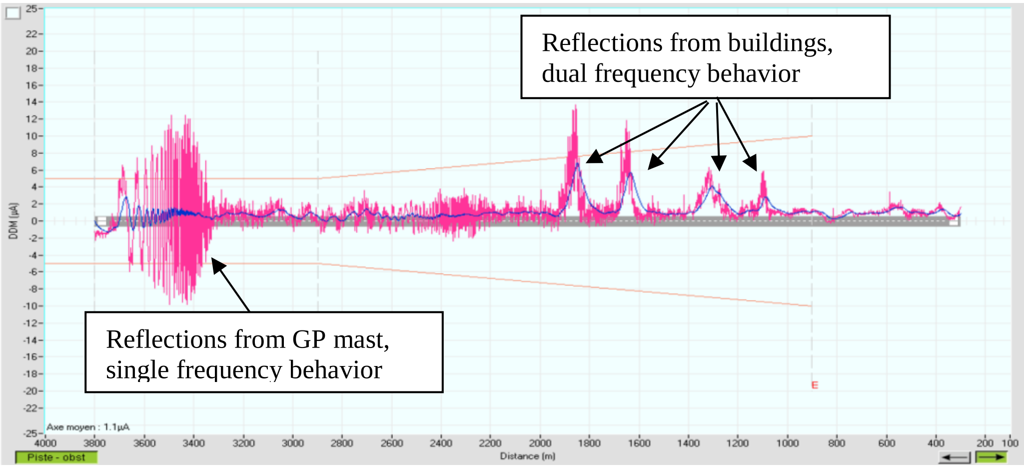


Single frequency behavior
Reflected course signal disturbs the direct course signal

Dual frequency behavior
Reflected clearance signal disturbs the direct course signal

Figure 5

Measurement



Pink = raw data, blue = filtered data
Figure 6

The case covered by this paper is a Clearance to Clearance disturbance and therefore a single frequency behavior. The reflected signal is therefore going to create huge bends in the coverage area. There is no capture effect even if the localizer is a dual frequency system.

There is also a DDM disturbance cause by the reflection when flying along the runway center line as one can see below. But given that this ILS is operated in Cat I, we don’t have to take care about it.

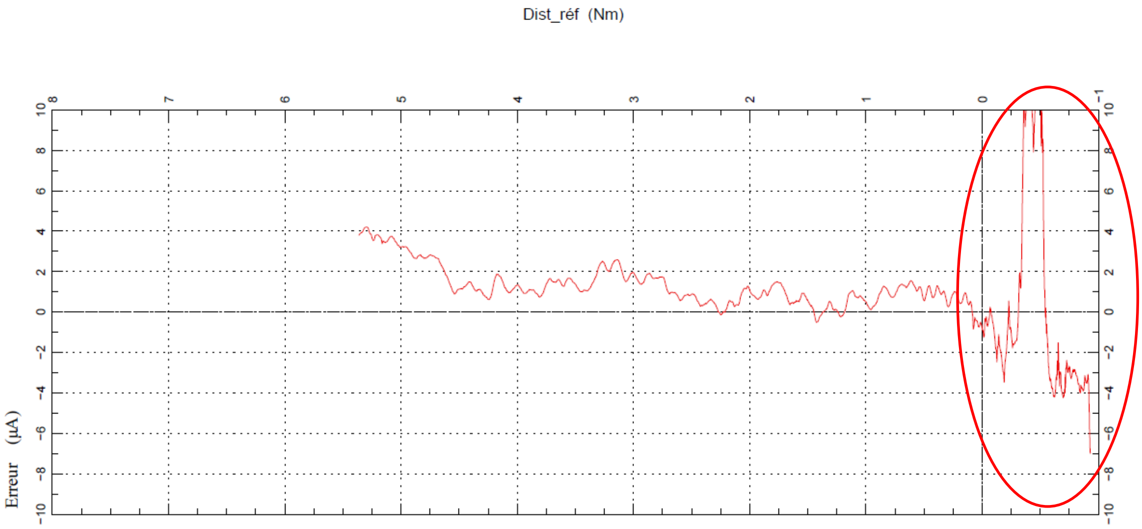


Figure 7: Measured DDM on approach on center line

CALCULATION OF THE AMPLITUDE OF THE REFLECTED SIGNAL

The equation giving the bend amplitude coming from a reflected signal can be written as follows:

$$DDM = \frac{1}{1+R} DDM_{direct} + \frac{R}{1+R} DDM_{reflect}$$

R is the amplitude ratio between the reflected and the direct signal
DDM_{direct} is the DDM of the direct signal
$DDM_{reflect}$ is the DDM of the reflected signal

In our case

$$DDM = \text{-}100\mu A = \text{measured minimum DDM at } 35°$$
$$DDM_{direct} = \text{-}300\mu A \text{ and } DDM_{reflect} = +300\mu A$$

From these numbers, we can evaluate the ratio between the reflected and the direct signal.

$$R = \frac{DDM - DDM_{direct}}{DDM_{reflect} - DDM} = \frac{-100+300}{300+100} = \frac{200}{400} = 0.5$$

So, the reflected signal at the receiver is approximately half amplitude of the direct signal one.

SOLUTION FOR REDUCING THE DISTURBANCE

To reduce the amplitude of the disturbance we can try to decrease the ratio R previously calculated.

This can be done by generating an unsymmetrical radiation pattern. We need to reduce the amplitude in the direction of the object and increase it in the direction of the receiver getting the disturbed DDM.

What ratio R should we target?

The minimum DDM should be less than -150µA. So, let's target a DDM = -200µA.

This leads to a ratio R' of:

$$R' = \frac{DDM - DDM_{direct}}{DDM_{reflect} - DDM} = \frac{-200+300}{300+200} = \frac{100}{500} = 0.2$$

The nominal Clearance (CLR) CSB radiation pattern looks as shown below.

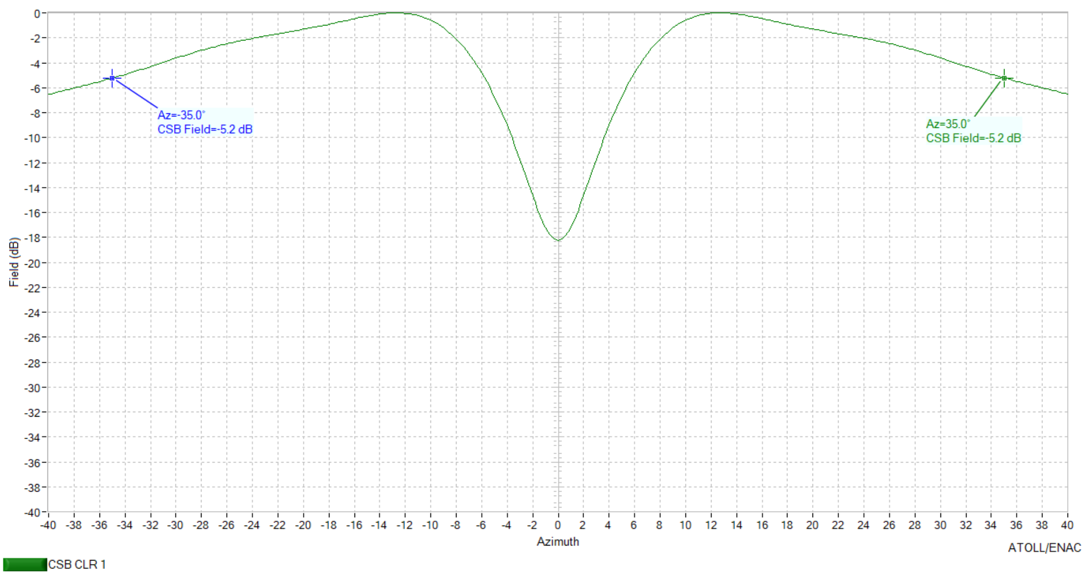


Figure 8: ATOLL simulated clearance CSB radiation pattern

With this radiation pattern, we get an amplitude ratio of 0.5 (-6dB) at the receiver between the reflected and the direct signal. This ratio can be changed by reducing the incident signal on the object and increasing the direct signal to the receiver.

To achieve this change without modifying the Antenna Distribution Unit (ADU) we are going to radiate a small part of CLR CSB into the CLR SBO radiation pattern ($SP_{(\alpha)}$ = SBO Pattern).

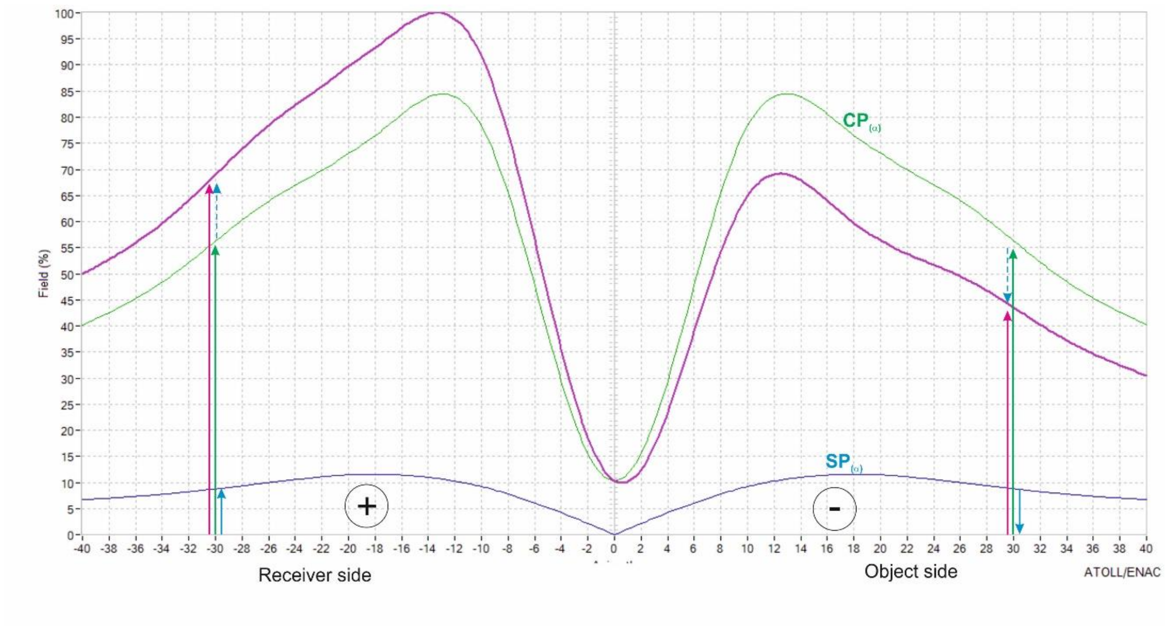


Figure 9: ATOLL simulated clearance CSB radiation pattern modification with linear scale

Because the SBO pattern provides a phase change of 180° when crossing azimuth α=0°, we are now adding a bit of CSB on one side and subtracting the same amount on the other side.
The phase of this additional CSB in $SP_{(\alpha)}$ must be adjusted to be in anti-phase in the direction of the reflecting object and in phase in the direction in which the receiver is disturbed.

The level ratio that must be provided by the radiation pattern can be calculated as follows:

$$R' = R \cdot R_P$$

R' is the ratio we need at the receiver to reduce the level of the disturbance
R is the ratio between the reflected and the direct signal we currently have which is depending on the size and the reflection factor of the object reflecting the signal
R_P is the additional ratio which must be provided by the modified radiation pattern

So,

$$R_P = \frac{R'}{R} = \frac{0.2}{0.5} = 0.4 \Rightarrow \approx -8dB$$

This value looks a bit too large and we may have the risk of losing the coverage field strength amplitude at 17 NM on the right side of the runway center line.
We set therefore R_P = -6dB. This should reduce the DDM maximum disturbance only 80 µA instead of the targeted 100 µA, but should be enough to bring the localizer into the ICAO limits.

CALCULATION OF THE FEEDING RATIO FOR THE CSB SIGNAL.

The simulated radiation patterns $CP_{(\alpha)}$ and $SP_{(\alpha)}$ when feeding both with the same input power are shown below.

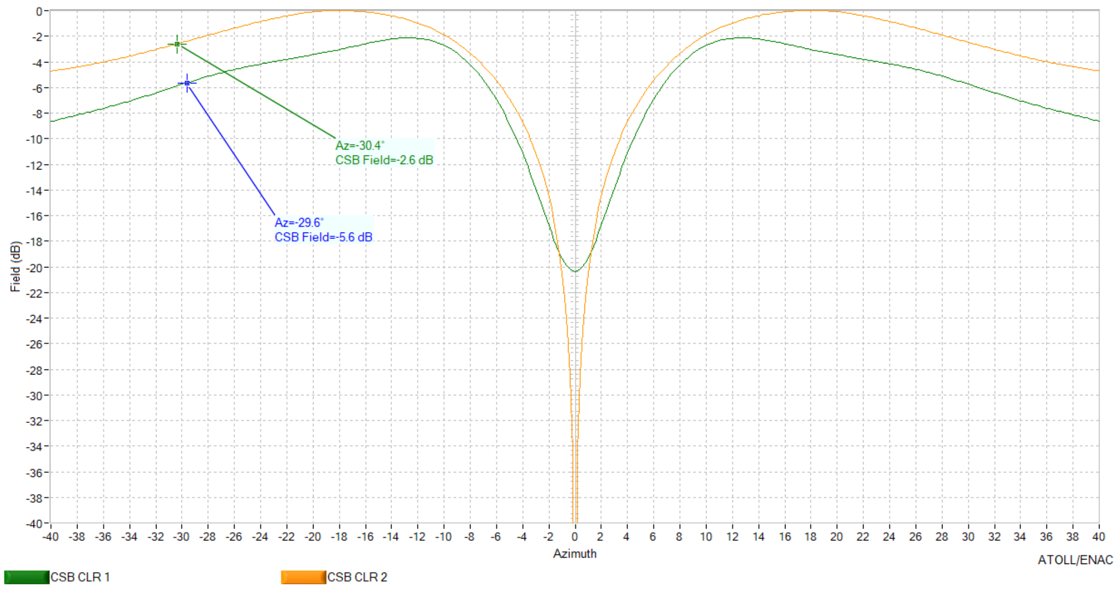


Figure 10: Relative field strength in logarithmic scale

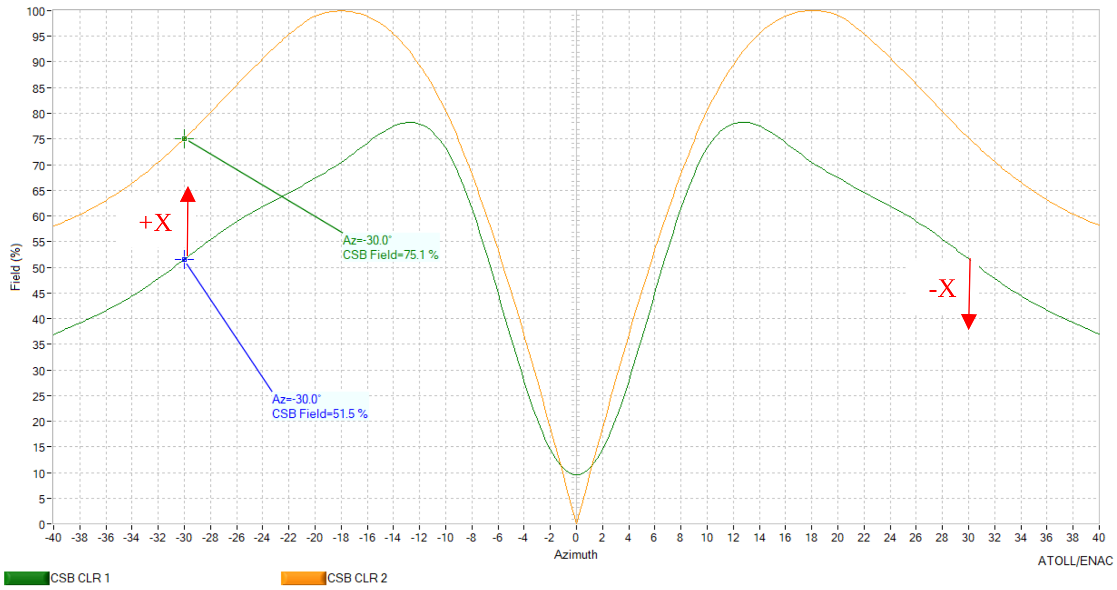


Figure 11: Relative field strength in linear scale

In the azimuth 30° the relative amplitudes of the CSB and SBO radiation patterns are respectively $CP_{(30)} = 0.515$ and $SP_{(30)} = 0.751$.

The amplitude of the signal to be added on one side and subtracted on the other can be calculated as follows:

$$\frac{CP_{(30)} - X}{CP_{(30)} + X} = 0.5 \Leftrightarrow (-6dB)$$

$$X = CP_{(30)} \frac{0.5}{1.5} = 0.515 \times \frac{0.5}{1.5} = 0.172$$

The relative feeding level of CSB in $SP_{(\alpha)}$ will be:

$$CSB_{SP} = \frac{0.172}{0.751} = 0.229 \Rightarrow -12.8dB$$

Applying this feeding level leads to the following radiation pattern.

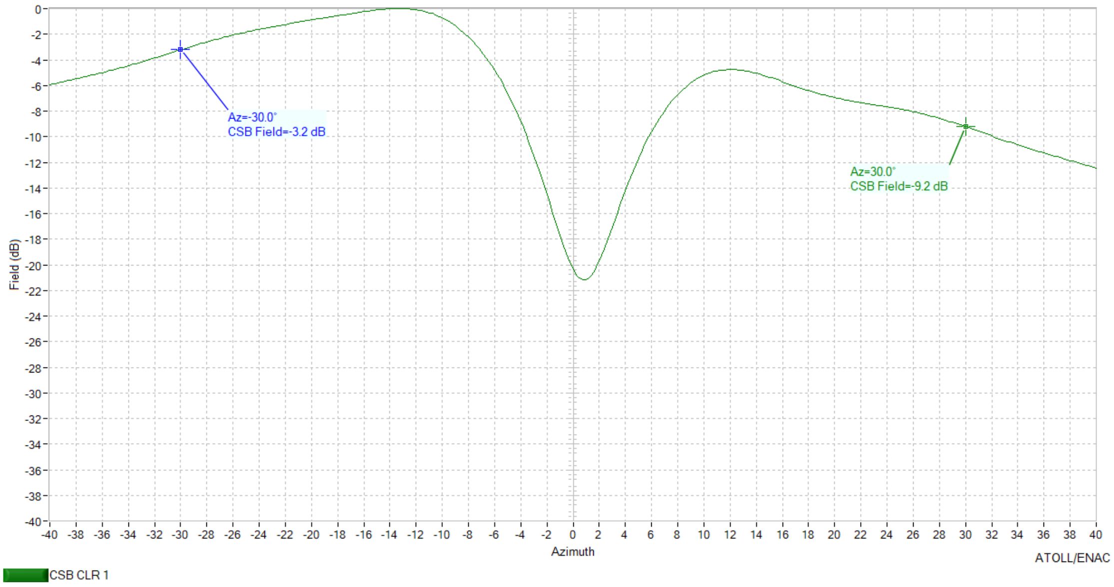


Figure 12: Feeding CSB in the SBO radiation pattern with -12.8dB gives a ratio of -6 dB in the 30° azimuth angles

The real measured radiation patterns using the same feeding power are shown below.

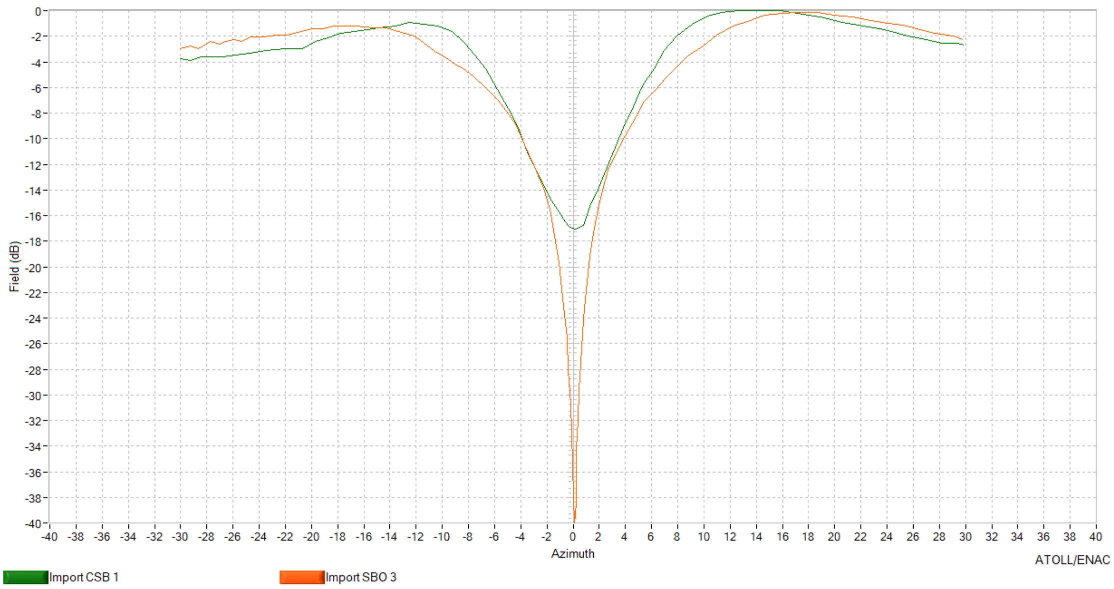


Figure 13: Ground measurements imported in the ATOLL software

One may note that the amplitudes of both radiation patterns are close to the same but for the simulation (see figure 10) the SBO level is 2 dB above the CSB amplitude. This means that the SBO distribution circuit gives an additional attenuation of approximately 2dB with regard to the CSB distribution circuit. This additional attenuation of the SBO signal in relation to the CSB signal is not considered in ATOLL.

Taking this additional attenuation into account leads to increase the CSB signal fed to the SBO radiation pattern of 2dB.

The relative feeding level of CSB in $SP_{(\alpha)}$ becomes therefore:

$$CSB_{SP} = -12.8 + 2 = -10.8dB$$

One may also note that the measured radiation patterns are slightly unsymmetrical. There is a difference of approximately 1dB between right and left side in the opposite direction of what we want to achieve to reduce the DDM disturbance. So, we must add an additional 1 dB feeding to the CSB_{SP} signal giving finally a value of -9.5 dB.

CALCULATION OF THE FEEDING RATIO OF THE SBO SIGNAL

The DDM is related to the ratio between SBO over CSB according to the following equation:

$$DDM = 2\frac{SBO}{CSB}$$

To keep the DDM right in the coverage area, we must also modify the SBO radiation pattern in the same way as what we did with the CSB radiation pattern.

For this matter, we are going to feed a small part of SBO in the CSB radiation pattern $CP_{(\alpha)}$.

$$\frac{SP_{(30)} - X}{SP_{(30)} + X} = 0.5$$

$$X = SP_{(30)}\frac{0.5}{1.5} = 0.751 \cdot \frac{0.5}{1.5} = 0.25$$

$$SBO_{CP} = \frac{0.25}{0.515} = 0.485 \Rightarrow -6.3dB$$

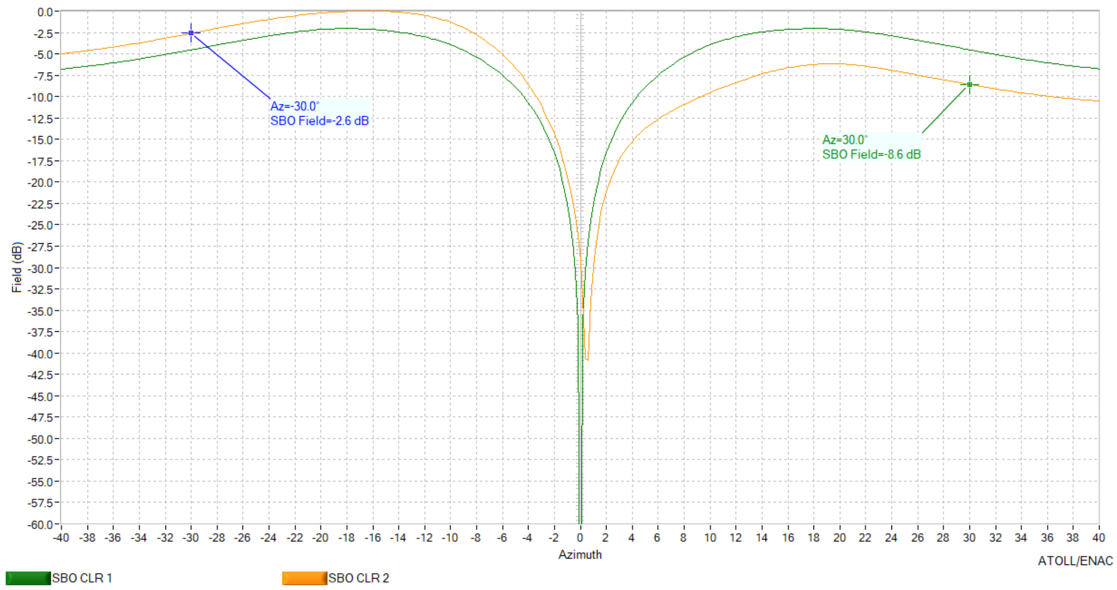


Figure 14: Feeding SBO in the CSB radiation pattern with -6.3dB gives a ratio of -6 dB in the 30° azimuth angles

The DDM with the new radiation patterns looks as follows

Figure 15: DDM with modified radiation patterns

The DDM is too low around the azimuth of 11°. We must therefore increase the clearance SBO level to get the correct DDM

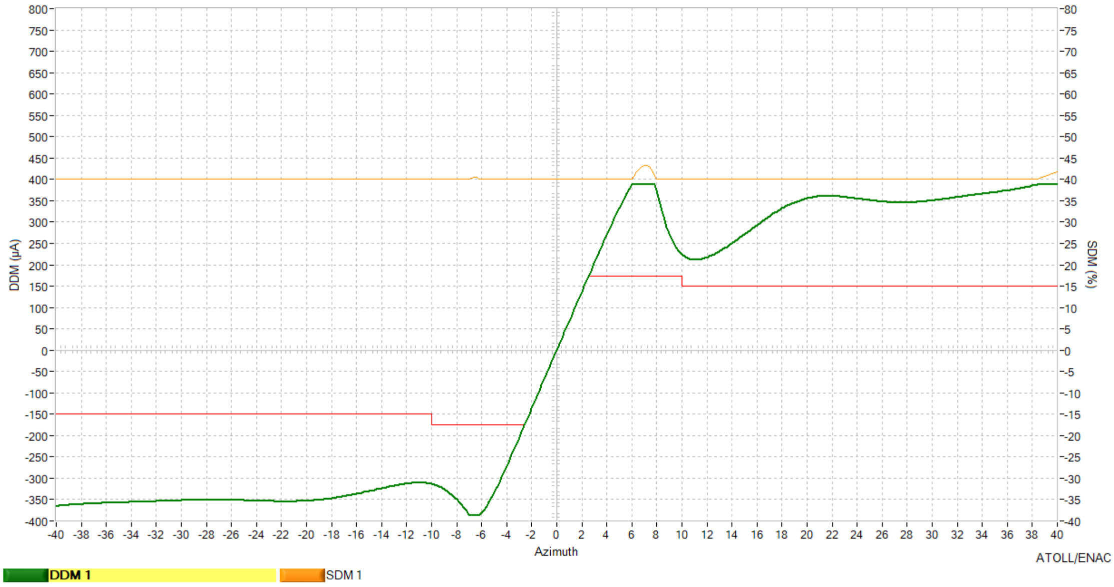


Figure 16: DDM with modified radiation patterns and increased SBO

As we have seen previously the real SBO level is approximately 2 dB less than what we have in the simulation. This means the real SBO signal fed to the CSB radiation pattern must be reduced by 2 dB with regards to the calculation leading therefore to a value of:

$$SBO_{CP} = -6.3 - 2 = -8.3dB$$

Taking also into account the small asymmetry of approximately 1 dB in the radiation patterns gives finally something close to -9.3 dB

Simulating the disturbance coming from the 2 hangars with the modified radiation patterns gives the following results.

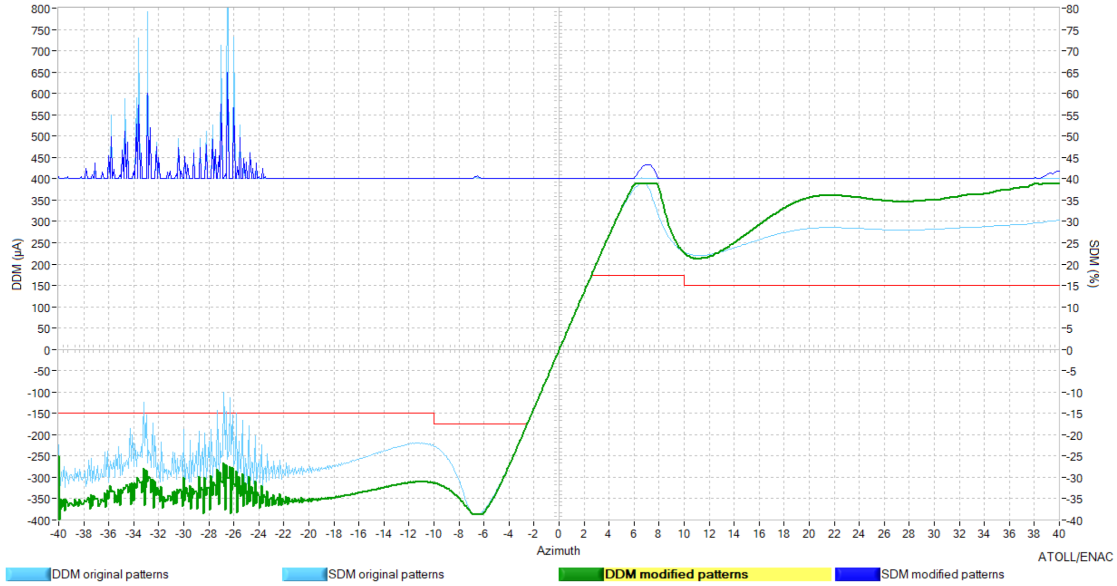


Figure 17: Resulting DDM with modified radiation patterns

One may note that the disturbance is now well below the ICAO limits. We must take care at the DDM at around +11° azimuth as the modified radiation patterns provide a deep at this location.

ADOPTED SOLUTION

To route some CSB in the SBO radiation pattern ($SP_{(\alpha)}$) and some SBO in the CSB radiation pattern ($CP_{(\alpha)}$) we need to split both signals before the ADU connection with the correct ratio and then add them together again in order to feed the ADU.

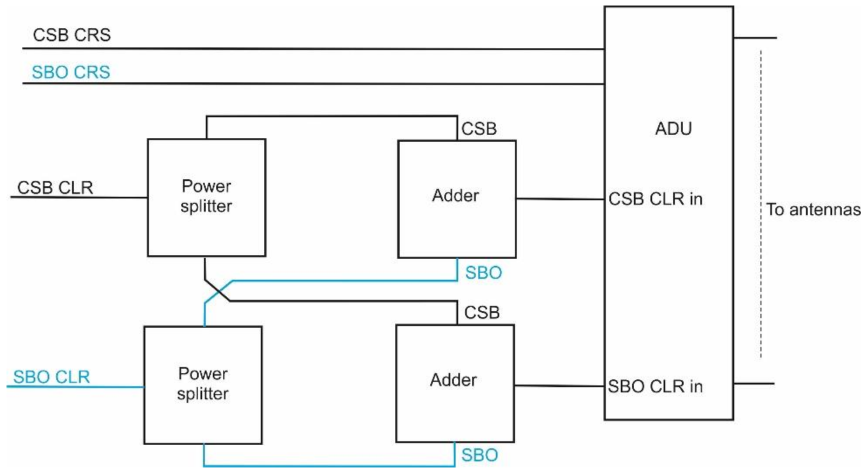


Figure 18

To make the additional circuit as simple as possible and to reduce the insertion loss, the following layout has been used

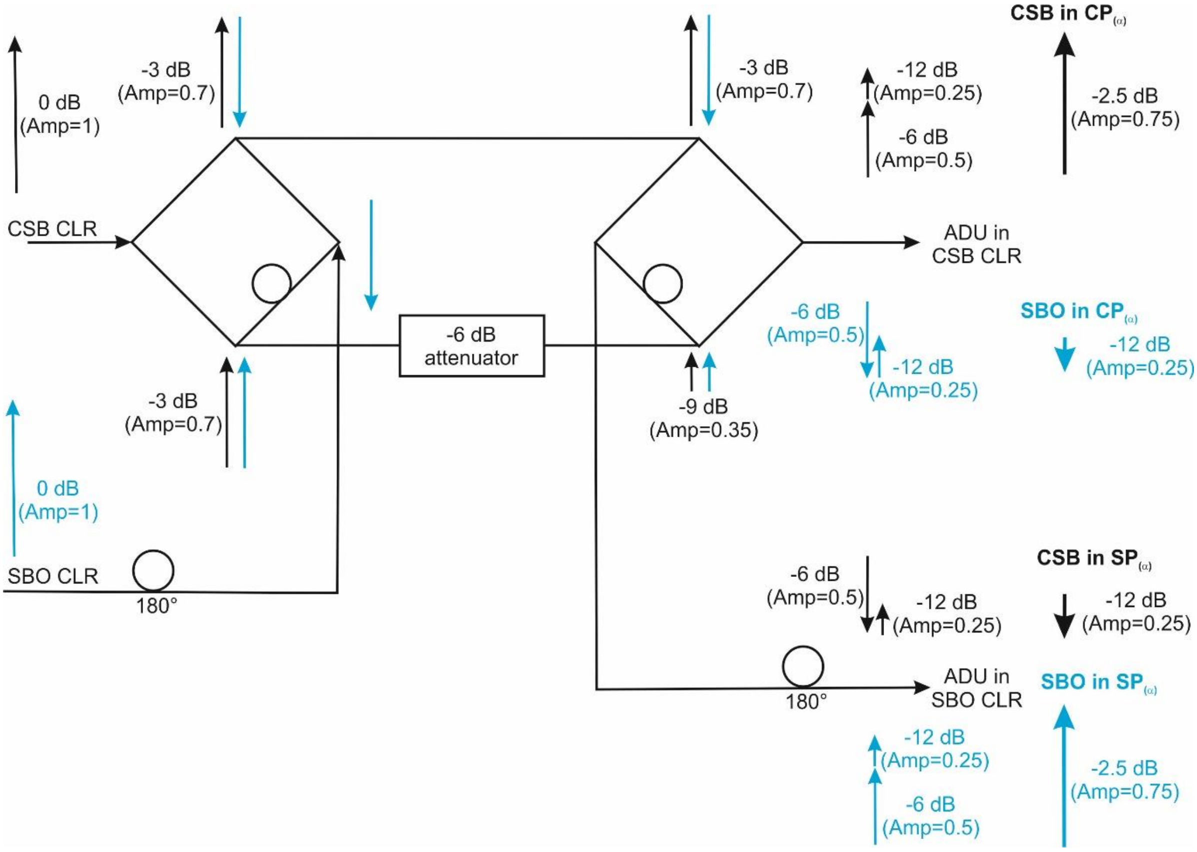
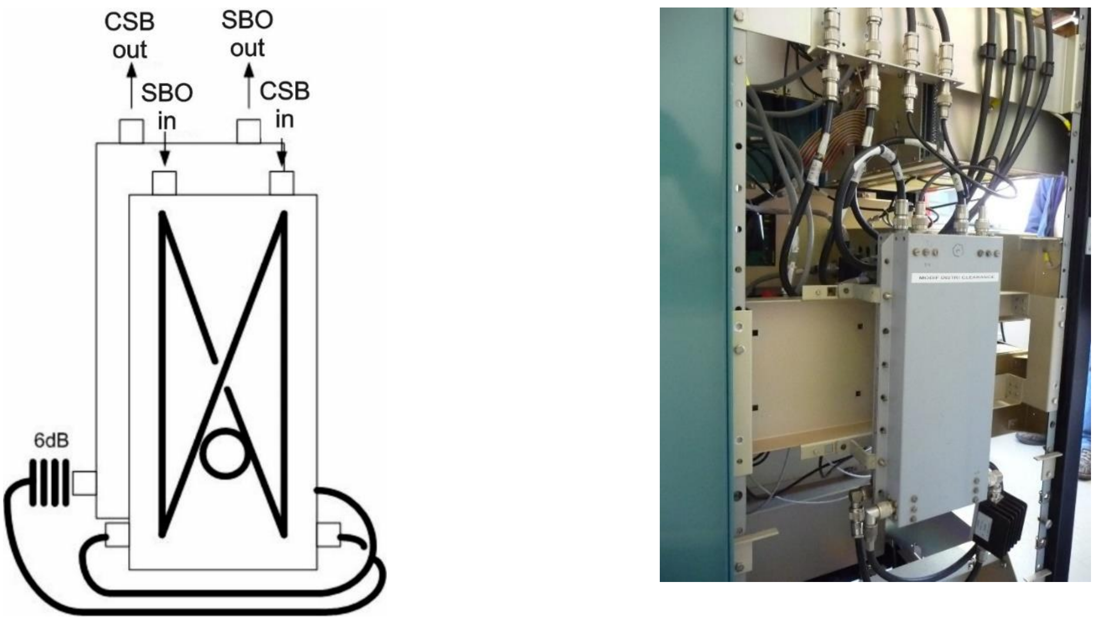


Figure 19

We can see that the insertion loss is -2.5 dB and the ratio of the additional signals is -12 - (-2.5) = -9.5 dB. This value is close to the one calculated in the previous chapter.

The real implementation looks as shown in the pictures below. It uses two 3 dB hybrids and a 6 dB attenuator.



Picture 3

Resulting radiation patterns imported in ATOLL simulation software

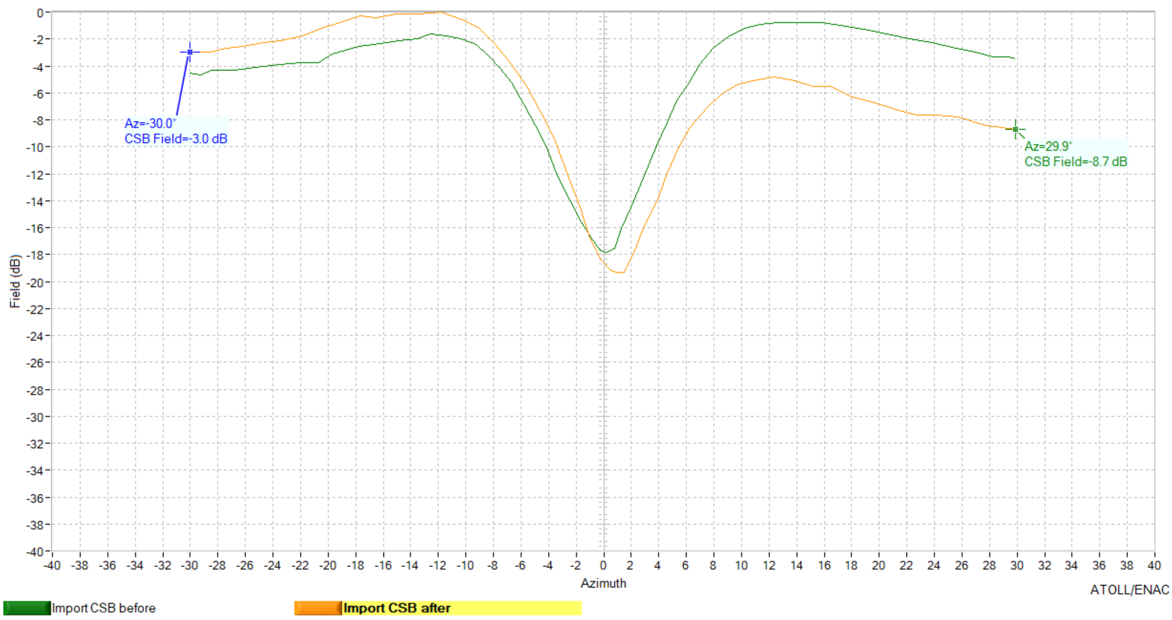


Figure 20: CSB radiation pattern (ratio = -5.7 dB)

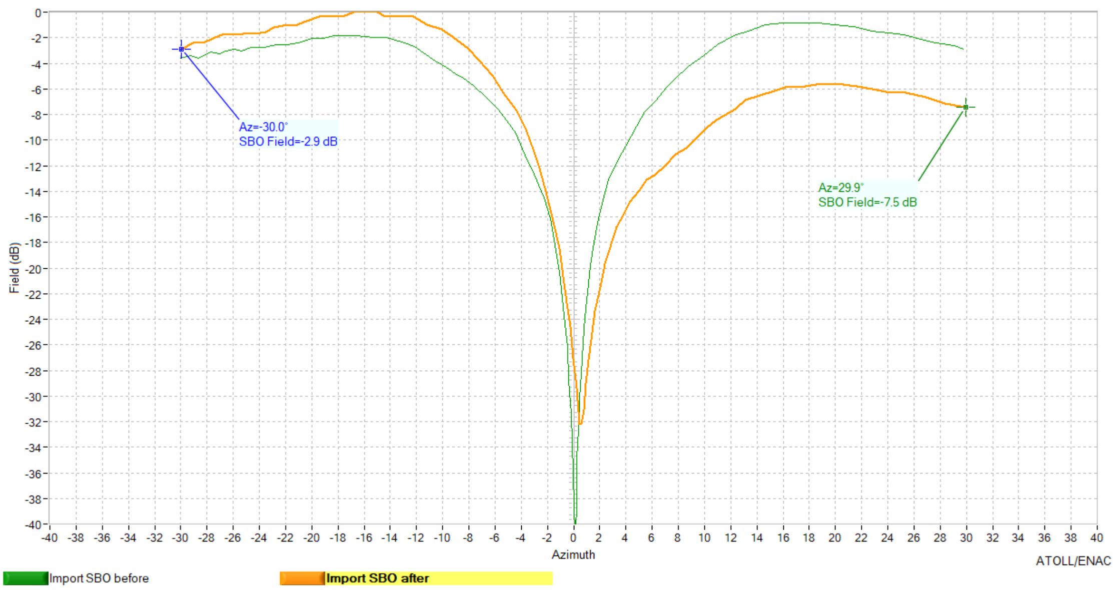


Figure 21: SBO radiation patterns (ratio = -4.5 dB)

FLIGHT INSPECTION

After modification of the radiation patterns the coverage check at 17 NM and 2000 feet gave the following result. This record has been made with the CLR SBO level set to trigger the CLR monitor lower alarm limit.

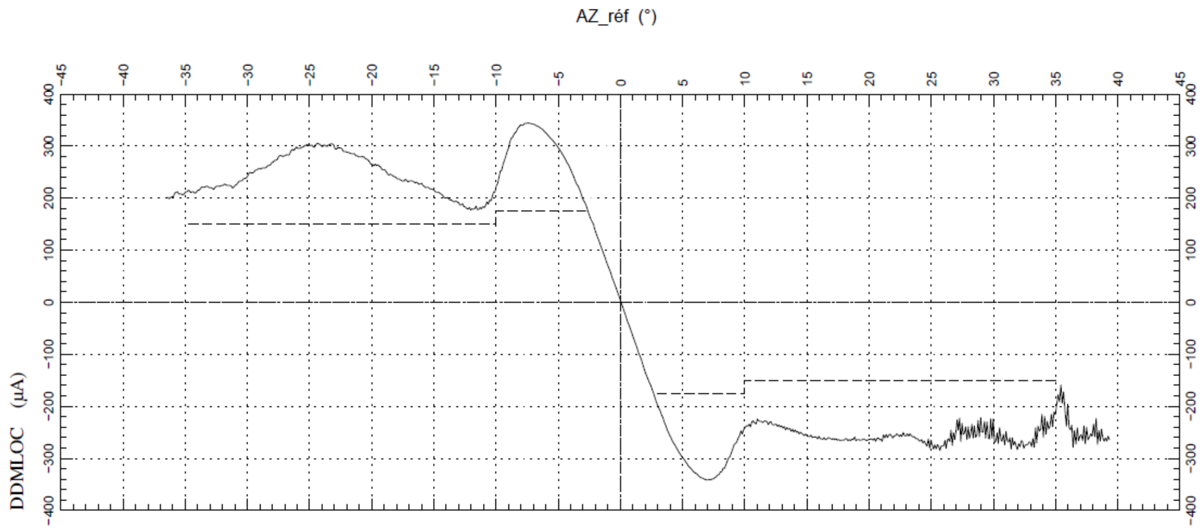


Figure 22: After modification and SBO CLR reduced to trigger CLR alarm low

Compared to the measurement made before the radiation pattern change and in nominal condition, not with the SBO CLR adjusted to trigger the clearance monitor lower alarm limit, we get a significant improvement.

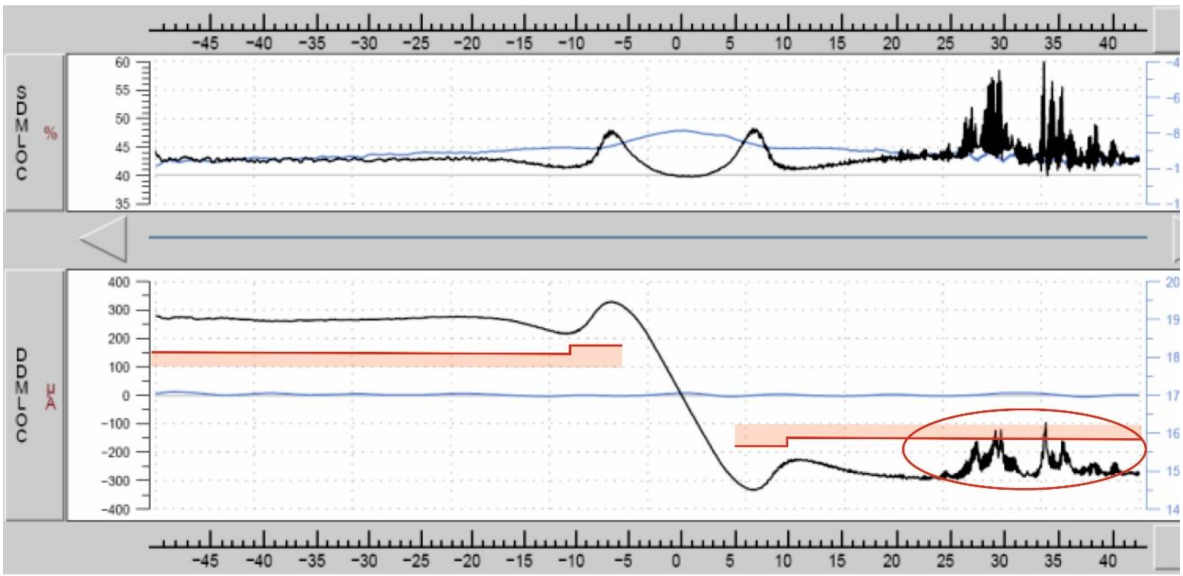


Figure 23: Before modification and SBO CLR nominal

This proves also that after the modifications made to the radiation patterns, the monitoring system is working properly. The recorded DDM was 167 µA at 11° and 212 µA at 10°.

The ILS has been put back in operation after this flight inspection.

CONCLUSION

The example presented in this paper shows that even a Cat 1 localizer can be disturbed by large hangars being build close to the runway. The disturbance created on center line had not to be considered because it came after the threshold. It's the disturbance generated by the reflection in the coverage area that was the issue.

No conventional localizer could bring an improvement in this case because all of them have symmetrical radiation pattern.

The solution presented and implemented proved to work and could be applied to any other type of antenna array from any manufacturer. It is cheap and easy to install.

Other solutions could have been used like changing the façade of the hangar to reduce the amplitude of the reflected signal or adding an additional reflector at the top of the building creating a reflection in anti-phase. These alternative solutions would have been much more expensive and difficult to implement.

ACKNOWLEDGMENTS

Thank you to Vincent Rocchia from the French flight inspection team for providing the flight inspection plots.

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