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Test and Simulation of 9960Hz Subcarrier Modulation for DVOR Station of Civil Aviation

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Abstract. In order to solve the problem of 9960Hz subcarrier modulation of DVOR system exceeding the limit, this paper use the test system and three-dimensional modelling and simulation technology to ensure flight calibration passes smoothly. Taking an airport for example, the field test and modeling simulation are carried out in the same situation when the surrounding site and parameters are the same with the flight calibration, ensuring that the results are in good agreement with the flight calibration results. We can get that the substation is the key factor which affects the 9960Hz subcarrier modulation exceeding the limit. After removing the substation, 9960Hz subcarrier modulation meet the requirements, the airport pass the flight calibration one-time finally. This method solves the problem of the 9960Hz subcarrier modulation in a DVOR station and provides the reference basis for the problems encountered in the construction and operation of the navigation station, which ensuring the safety and efficiency of air transportation.

1. Introduction

VOR (Very High Frequency Omnidirectional Range) [1] is a land based direction-finding navigation system for civil aviation, which can provide the relative azimuth information from the aircraft to the omni-directional beacon station. VOR is the standard air navigational system in the world [2][3]. DVOR (Doppler Very-High-Frequency Omnidirectional Range) is a further development of CVOR, which is an omnidirectional beacon system developed by using the principle of Doppler effect that can produces more precise azimuth signals.

The DVOR was commonly used in China at present. In the recent years, with the site of the DVOR station getting worse, more and more station has the problem of 9960Hz subcarrier modulation, which may affect the operation of the airport and lead to the airport shutdown directly. For examples, fault phenomenon of alarm shutdown caused by DVOR 9960Hz subcarrier modulation suddenly dropping to 17-18% in Pu Dong Airport in 2011. Jitter overrun in 80°~115° azimuth and 250°~310° azimuth leading failed pass the flight calibration in Xiang Yang Airport DVOR in 2016. Jitter overrun of 9960Hz subcarrier modulation in a certain azimuth appeared when progressing flight calibration for DVOR station in Qie Mo Airport. The same situation occurred at an airport in Harbin in 2018.

For the problem of 9960Hz subcarrier modulation exceeding the limit, the common method was adjusted the equipment parameters to meet the standard requirements. However, this method can only be considered from the equipment, it cannot solve the problem that the signal of the 9960Hz subcarrier modulation is changed due to the external environment. At the same time, it is necessary to have a flight calibration for synchronous verification during the equipment commissioning, which requires a lot of time, energy and economic cost.
This paper proposed a method which combining field test and modeling simulation to solve the problem of 9960Hz subcarrier modulation overrun. We can use the vehicle navigation online test system to simulate the flight check. At the same time, we can set the equipment parameter and site conditions by modeling and simulation. Finally, we will find the key obstacles to the airport. This method is simple and time-saving.

2. Research methods

2.1 Principle of field test
The field test uses the vehicle navigation online test system, which satisfies the ICAO DOC8071[4] specification request and provides the technical means for the navigation equipment realization ground test. The system includes the antenna module, the antenna control module and the navigation equipment on-line tester module. The test system schematic diagram is shown in Figure 1.

![Figure 1. Navigation test system.](image)

The antenna module includes the test antenna and the GPS antenna, and the test antenna is used to obtain the ILS/VOR space signal of the instrument landing system; GPS antennas is used to receive satellite signals. The antenna control module is used to transmit and control the satellite signal received by the GPS antenna and drive the GPS antenna to the specified position. The navigation equipment on-line test module is used to filter, demodulate and calculate the received signal, which obtains the correlation parameter data and analyzes the received data and graphically display the analysis results.

2.2 Modeling Simulation System
The DVOR system is composed of a central antenna and an edge-band antenna. The central antenna radiates 30Hz of very high frequency amplitude modulation signal to the space and demodulates the 30Hz datum phase signal. Because of the Doppler principle, the edge-band antenna modulates the VHF FM signal modulated by 30Hz in space and demodulates the 30Hz variable phase signal. If the magnetic azimuth of the 30Hz variable phase signal and the 30Hz reference phase signal is the same at design and installation time, then the receiver on the plane can realize the directional function by comparing the different phase between them.

In the DVOR, the 9960Hz signal is called the subcarrier. According to the theory of antenna
propagation, 9960Hz subcarrier cannot be radiated alone, it must be selected on the carrier \( f_0 \). In the DVOR, the 30Hz and audio amplitude modulation carrier were radiated from the central antenna, and the \( f_0 + 9960\text{Hz} \) top frequency and the \( f_0 + 9960\text{Hz} \) bottom frequency are radiated from the edge band antenna. According to the principle of space modulation and the theory of Doppler effect, a complex FM and AM modulation wave can be obtained in space or in the receiving point, and 30Hz to 9960Hz subcarrier FM (Doppler effect), the wave on the carrier is amplitude modulation, at the same time, the audio such as 30Hz and 1020Hz on the carrier is amplitude modulation. The full DVOR spectrum \([5]\) is shown in Figure 2.

![Figure 2. The full DVOR spectrum figure](image)

Take the 9960Hz subcarrier as an example, in the ideal condition, the equipment send the standard signal and the terrain is the ideal level, assuming that the signal propagation process without any obstacles. If there is no obstacle in the process of signal propagation, the received signal is the complete standard signal. But in fact it is impossible to have the ideal site, because of the terrain and obstacles, the transmission of signals in the process produce the reflection and diffraction, so the signal changes, resulting in the final demodulation 9960Hz subcarrier signal changes, which leading to the emergence of a modulation system overrun.

So how to analyze the signal changes. It is difficult to achieve by artificial hands and can only simulate by professional software simulation. In this paper, we will use IDS Company's three-dimensional electromagnetic environment simulation software and progress an accurate modeling in the equipment, topography, buildings and flight procedures and so on. Through the simulation system, we have successfully completed the simulation analysis service of more than 80 airports in the country, all stations are checked by flight and the simulation system is shown in Figure 3.

![Figure 3. The simulation System](image)

### 2.3 Analysis Process

For the DVOR, the following process is used to analyze the problem, as shown in Figure 4.
First of all, in order to ensure the validity of the test data and the feasibility of modeling and simulation, the result of the field test and modeling simulation are compared with the results of flight calibration. Secondly, the key obstacles are found by modeling and simulation, and the optimal treatment scheme is given by using different analysis schemes. Thirdly, the airport is processed according to the best scheme provided. Finally, we began to test 9960Hz subcarrier modulation.

3. Analysis of 9960Hz subcarrier modulation

3.1 Compared to the flight calibration
Flight calibration is a method to detect the performance of terrestrial radio facilities and navigational lighting facilities by using airborne special equipment. The 9960Hz subcarrier modulation is one of the necessary items for verifying DVOR. According to the AC-86-TM-2016-01《Specification for flight calibration of land-based navigation equipment for civil aviation》，the standard value and tolerance requirements of 9960Hz subcarrier system is $(30\pm2)\%$ [6]. If the result exceeding the tolerance, the flight calibration will be disqualified.

3.1.1. Test. Testing the 9960Hz subcarrier modulation in the position of the jitter exceeding limit, the field test schematic diagram is shown in Figure 5.
The test data is recorded in the direction given in the diagram by the vehicle which was installed in navigation online test system. The test situation on the highway is shown in Figure 6.

The 9960Hz subcarrier modulation is tested in the location of the substation, and the curve of the test data is shown in Figure 7.

Note: The straight line is located above a freeway, it is unable to test.

The 9960Hz subcarrier modulation in the result of flight calibration jitter overrun in the 80°~115° azimuth, which is shown in Figure 8.
Figure 8. The result of flight calibration

The comparison between the test results and the flight calibration are shown in Figure 9.

Figure 9. Comparison between test results and flight calibration results

Comparing the test results and flight calibration results, in the location of the substation coverage (74.6°~116.6°), the two curves are basically the same.

3.1.2. Modeling and simulation. Model is shown in the figure 10.

Figure 10. Simulation model

Comparing the simulation results and flight calibration results, in the location of the substation coverage (74.6°~116.6°), the curves are basically the same. The 9960Hz subcarrier modulation is over 32% and don’t meet the requirements of the standard.

3.2 Modeling and Simulation analysis

3.2.1. Methods and solutions. There are three methods which was used to handle the obstructions around the DVOR station: one is lay profiled metal reflective network from the top of the substation to the edge of the reflective network, one is increase the radius of the reflection from 14m to 27m, the other is delete the existing substations.

The scenario is shown in table 1.
Table 1. Scenario List

| Case   | Method                                      |
|--------|---------------------------------------------|
| Case 1 | Lay profilled metal reflective network      |
| Case 2 | Increase the radius of the reflection to 27 m |
| Case 3 | Delete the substations                      |

3.2.2. Modeling simulation results. The simulation results are shown in table 2.

Table 2. Whether the results meet the standard requirements

| Case   | The Result   |
|--------|--------------|
| Case 1 | Not satisfied |
| Case 2 | Satisfied    |
| Case 3 | Satisfied    |

Considering the economy and practicality, it is recommended to choose the case 3.

3.3 Test

Test the 9960Hz subcarrier modulation in the substation coverage area after deleting the substation, the result is shown in figure 11:

![Figure 11. The result](image)

The test result shows that the 9960Hz subcarrier modulation meets the standard requirements in the 80°–117° range of the original substation after deleting the substation.

4. Conclusion

In this paper, the method of field test and modeling simulation is used to solve the problem of exceeding the limit of 9960Hz subcarrier modulation in an airport DVOR station. Through the research and analysis, it is found that the traditional method of combination of debugging equipment parameter and flight calibration cannot solve the problems caused by terrain and obstacle. The combination of field test and modeling simulation is convenient, feasible, time-saving and accurate, which can solve the practical problems and provide the analysis reference and basis for the problems encountered in the construction and operation of the navigation station. The method is very practical and can be applied to the analysis of other navigation sites.

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