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Research on Height and Diameter of Doppler VHF Omnidirectional Beacon in Complex Environment

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Abstract. With the development of community around Doppler VHF omnidirectional beacon(DVOR), more and more DVORs are restricted, and even severely disabled. The DVOR's counterpoise can be elevated to improve the coverage. But raising counterpoise will cause some problems such as null and worse bearing error. The paper research the lateral multipath, longitudinal multipath, height and diameter of counterpoise from the null, the first Fresnel zone, signal coverage, bearing error combing surrounding buildings and terrain, providing some technical means for improve or eliminate nulls and bearing error in construction of DVOR, and pre-evaluating whether it can pass the flight inspection after the completion of construction.

1 Introduction

VHF omnidirectional beacon(VOR) is a navigational aid that operates in the very high frequency(VHF) band of the radio spectrum and that radiated uniformly in azimuth. Specifically, this facility operates between 108MHz and 118MHz and provides azimuth guidance to the pilot in the form of a visual display. There two general types of VOR systems being using by ICAO, namely, the conventional VOR(CVOR) and the Doppler VOR(DVOR). Because CVOR is more susceptible to multipath interference than DVOR, DVOR is used mainly by CAAC.

With the development of Chinese cities, more and more tall buildings block and reflect DVOR signals, making them limited or even unavailable. Some DVOR around the airport are particularly serious. For example Lianshenwei DVOR of Zhuhai, most angles are restricted including 98°~113°, 330°~010°, 135°~158°etc. A similar situation occurred in Guanlan, Pingzhou, Ruian, Xiaoshan DVOR navigation aid. Except reselecting the site of DVOR, the only thing we can do is raise the height of counterpoise while increasing the diameter of counterpoise.

2 Multipath effect

Multipath[1] include mainly longitudinal multipath and lateral multipath. Lateral multipath can, in certain of the navigation aids, cause rays emitted from DVOR at different azimuth angles to meet and combine at the airborne equipment. The combination of two different modulation signals yields a resultant generally containing false bearing information.

Longitudinal multipath cannot ordinarily cause errors in the modulating intelligence except, as mentioned, when it causes the serious weakening of the total signal. Similarly, lateral multipath cannot cause nulls in the vertical radiation pattern. Figure 1 illustrates the two different categories of multipath.



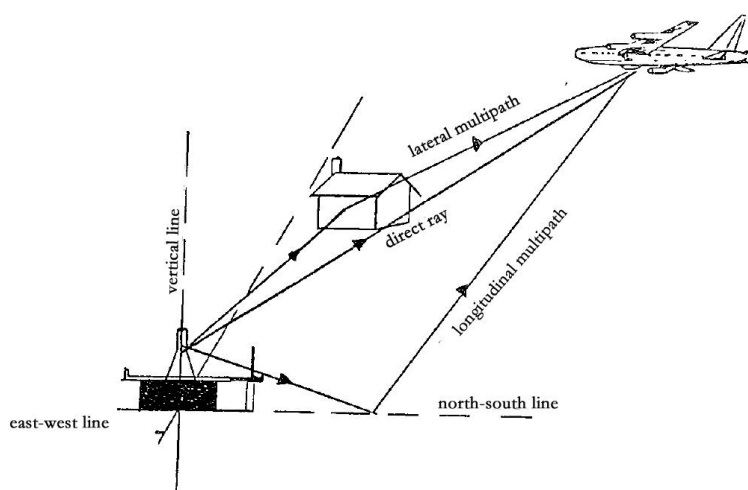


Figure 1. longitudinal multipath and lateral multipath

2.1 Longitudinal multipath

The longitudinal multipath can result from reflection from the counterpoise and from the earth, causing nulls in the vertical pattern of radiation and this in turn causes loss of signal in the airborne receiver. Hence, it is important in analysis to identify those features that may lead to excessive multipath problems.

Usually, the height of counterpoise is less 10 meter, longitudinal multipath is not obvious and vertical pattern of radiation does not divide severely. However, when tall buildings appear around DVOR, raising the height of counterpoise will result in dramatic longitudinal multipath, and the vertical lobe pattern will have multiple nulls at low elevation angles.

2.2 Lateral multipath

Lateral multipath involves the mutual interference between signals radiated at two different azimuth bearings. One is direct ray. The second, the interfering ray, contains different navigational information than does the direct ray. The mix of the two modulations in the airborne receiver results in incorrect information being presented to the pilot. Lateral multipath will causes bearing error and 9960 Hz modulation beyond standard of CAAC.

The requirement for lateral multipath to exist is that there be obstacles in the radiation field that accept radiation at one azimuth angle and reflect it off in a different direction either in a specular or diffuse fashion. Obstacles will exist in the radiation field and may consist of building that cannot be removed, power line, and antenna for other equipment.

The lateral multipath has little relation with the height of counterpoise. Regardless of whether the counterpoise is high or low, as long as there are obstacles around DVOR, the influence of lateral multipath effect should be considered. However, increasing the radius of the counterpoise can improve the lateral multipath caused by the obstacles.

3 Null and coverage

There are two kinds of DVOR navigation aids. The first is responsible for approach and departure, which the required coverage distance is no more than 70 nautical miles. The second is the route navigation aids, which required coverage about 150 nautical miles.

Some obstacles exist around DVOR, which is characterized by a short coverage distance and the counterpoise that needs to be elevated. The conflict of coverage and null must be solved combing the flight procedure in actual operation.

3.1 Required coverage distance

DVOR coverage[2-3] as specified Annex 10 of International Civil Aviation Convention is “The VOR shall provide signals such as to permit satisfactory operation of a typical aircraft installation at the levels and distances required for operational reasons, and up to an elevation angle of 40 degrees. The field strength or power density in space of VOR signals required to permit satisfactory operation of a typical aircraft installation at the minimum service level at the maximum specified service radius should be 90 microvolts per meter or minus 107dBW/m².”

Every airport has its own flight procedures, each airport has its own DVOR flight procedure, and the DVOR is responsible for guiding distances that may be long or short. DVOR is responsible for the approach and departure flight procedures shown in Figure 2

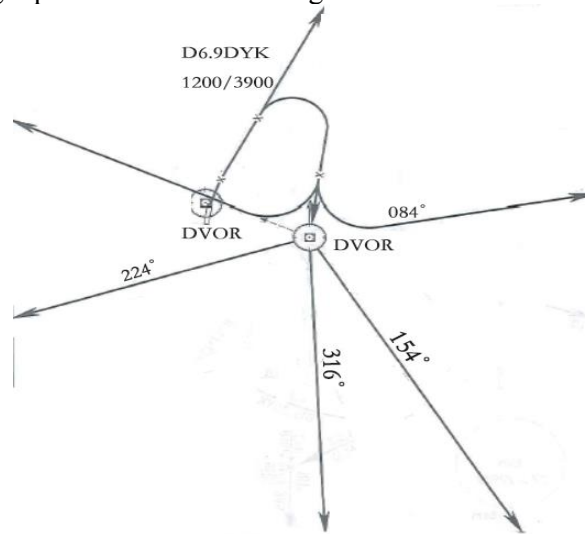


Figure 2 departure and approach based on DVOR

3.2 Vertical pattern synthesis

The vertical lobes of DVOR are composed of the lobes reflected by counterpoise and the lobes reflected by the ground. The lobes reflected by counterpoise are responsible for the coverage of the high elevation angle, while the lobes reflected by the ground are responsible for the low elevation angle, show as Figure 3.

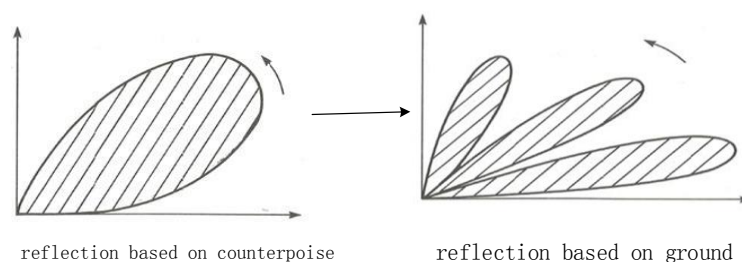


Figure 3. vertical lobe through counterpoise and ground

When the counterpoise is 10 meters high and counterpoise diameter is 30 meters, the spatial lobes of the DVOR are as shown in Figure 4.

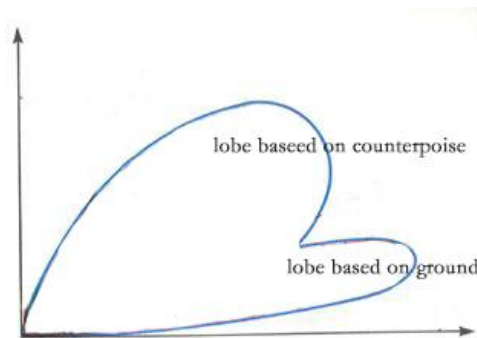


Figure 4 DVOR synthetic lobe

There is an obvious drop in the local signal of the two lobe. The upper lobes are responsible for approach and departure, and the lower lobes are responsible for routing.

3.3 Nulls change accompanying counter's height increase

3.3.1 Null's position calculating. DVOR is a horizontally polarized antenna[4], the nulls of DVOR[3] can be calculated from equation (1). The higher the counterpoise height, the lower the first null, then the second to the Nth null will appear at a lower elevation angle.

$$\gamma = \sin^{-1}[(n\lambda)/(2h)] \quad (1)$$

The DVOR frequency is 108.1MHz, counterpoise is 60 meters, and antenna's height is 1.2 meters from counterpoise, the first, second and third null is 1.32°, 2.64°, 3.96°. if the counterpoise diameter is still the regular 30 meters, the flight altitude is 3000 feet, the nulls will appear in 22nm, 11nm and 7nm, show as Figure 5.

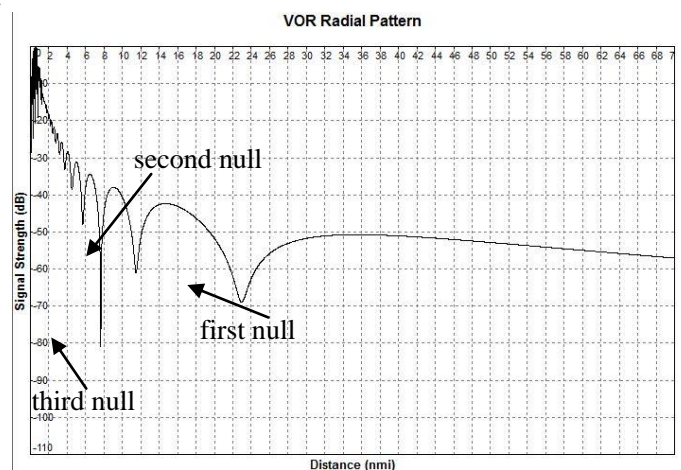


Figure 5 first three nulls when counterpoise is 60m

The first, second and third null is 1.13°, 2.27°, 3.40° when the counterpoise height is 70m, the nulls will appear in 24nm, 12nm and 8nm, show as Figure 6.

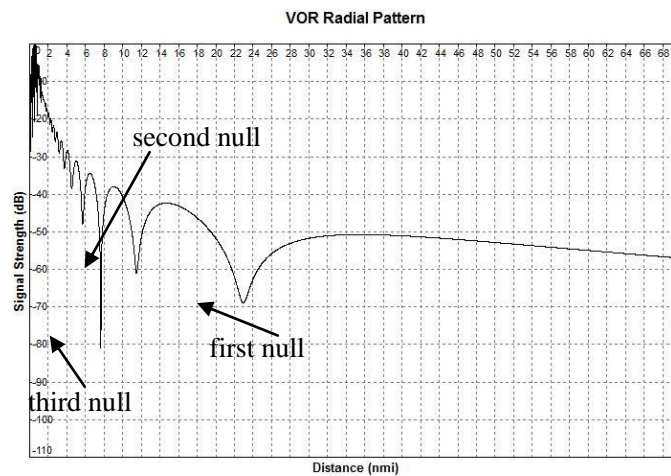


Figure 6 first three nulls when counterpoise is 70m

3.3.2 Eliminating nulls. We can calculate the suitable counterpoise according to the null. When the counterpoise is 60 meters, antenna is 1.2 meters from counterpoise, we can eliminate the third null while the counterpoise may be expanded to 18 meter. The second is 26 meter and the first is 52 meter, show as Figure 7. In practical operation, the diameter of counterpoise is usually 30 meter, so if necessary we mainly eliminate the first few nulls.

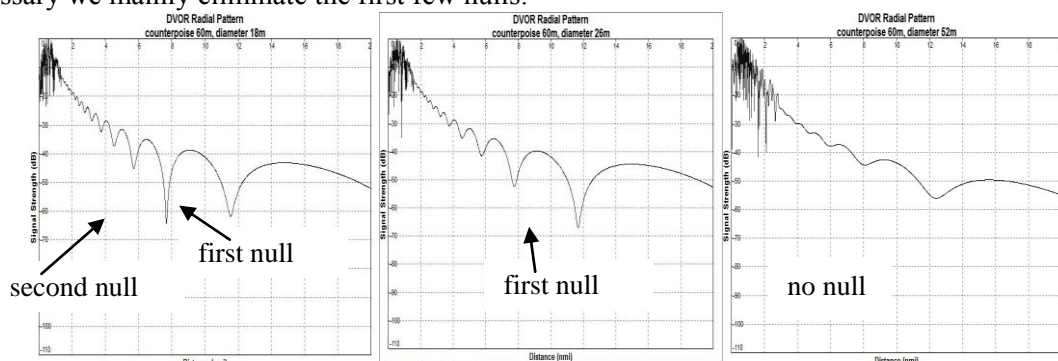


Figure 7 expanding diameter eliminate nulls

Eliminating all nulls will cause diameter of counterpoise to be too large, resulting in poor economic benefit. In practice, the counterpoise diameter can be determined by the DVOR flight procedure of the actual airport to save economic costs.

4 Reflection and bearing error

4.1 Bearing error requirement of CAAC

The duty of DVOR is to guide the bearing of aircraft, so bearing error[4-5] is the most important parameter of DVOR. According to flight inspection centre of CAAC, Bearing error of DVOR include orbit bearing error which average error within $\pm 1^\circ$ and radial error within $\pm 2^\circ$.

Orbit bearing error is checked through a flight inspection method that distance is 20 nautical mile to DVOR centre, and flight orbit is generally performed between 4° and 6° of DVOR elevation angle. Radial bearing error is checked through actual flight procedure of DVOR.

4.2 Reflection effect

Reflection will cause bearing error cannot meet the standard requirements. How to eliminate the effect of reflection of DVOR has always been a topic. After the counterpoise is elevated drastically, this is more and more difficult. Currently there are some measures improving the effect of reflection include

that removing obstacle eliminating the reflection is very rude and effective, changing the exterior material of the building to reduce reflection coefficient, and extending the diameter of diameter to screen reflection. The latter two methods is focused by this article.

5 Eliminating null and error

5.1 Expanding diameter of counterpoise

The counterpoise can not only reflect useful signals, but also shield obstacles from signal effects. We can improve the bearing error through expanding diameter of counterpoise.

5.2 Changing the exterior material of the buildings

The reflection coefficient of the obstacle determines the strength of the reflected signal, metal obstacle will cause the signal to be completed reflected, and the bearing error will be deteriorated. Figure 8 show effect from a radar tower that the exterior material is reinforced concrete. From this figure, the bearing error exceeds the standard requirements in the azimuth of the radar tower is $75^\circ \sim 120^\circ$,

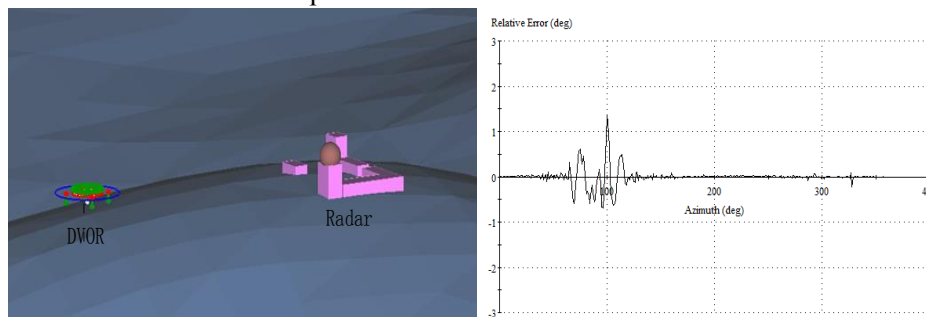


Figure 8 the exterior material of radar tower is reinforced concrete

For improving the bearing error within $75^\circ \sim 120^\circ$, put the brick on the outer wall of the radar tower. The bearing error is improved and meet standard requirement, show as Figure 9.

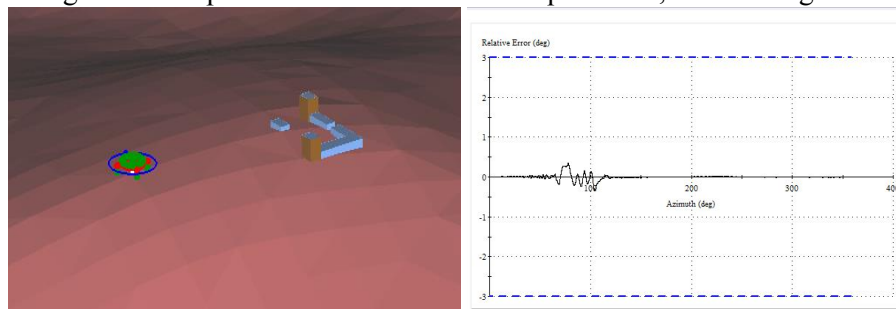


Figure 9 put the brick on the outer wall of the radar tower

5.3 Changing the roughness of external buildings

Another way to improve the bearing error is to increase the roughness of the wall and change the specular reflection to diffuse reflection. According to Rayleigh roughness criterion, As long as the convexity of the reflective surface is greater than formula 2, the bearing error may be improved.

$$h > \lambda / (16 \sin(\gamma)) \quad (2)$$

According to formula 2, Rayleigh roughness criterion figure can draw through incident angle and wave length, show as Figure 10.

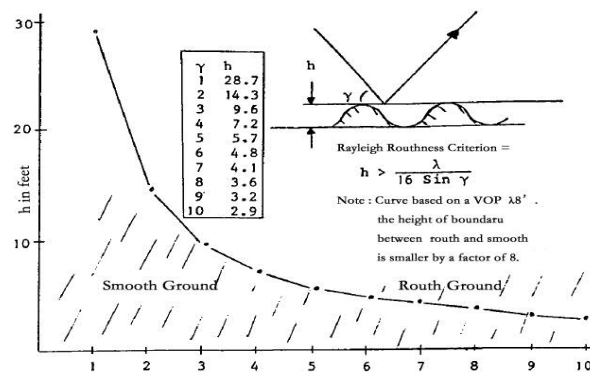


Figure 10 Rayleigh roughness criterion

For improving the bearing error within $75^\circ \sim 120^\circ$ in figure 7, change the convexity of the outer wall of the radar tower. The bearing error is not improved and meet standard requirement, the reason may be convexity is not good, show as Figure 11.

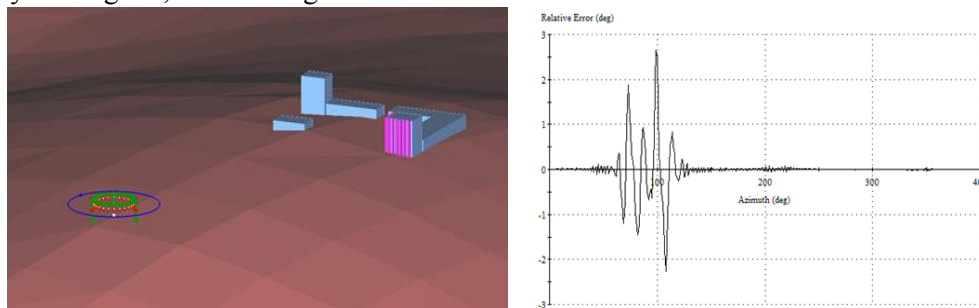


Figure 11 change the convexity of the outer wall of the radar tower

6 Conclusion

As the environment around the DVOR station becomes more and more complex, some navigation stations are surrounded by obstacles. It is impossible to improve the error of some azimuth by expanding the radius of counterpoise and changing the outer wall of the obstacle. In this case, we can only move away from our navigation aids, but this is designed to deal with airspace, land acquisition, route changes and many other issues. Therefore, the best way is to demonstrate the surrounding planning before the construction of the navigation platform, and clearly define the height limit around the DVOR to avoid the deterioration of the signal after the operation.

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