

Analysis of Aircraft Navigation Control Performance Improvement Based on Antenna Sideband DVOR Model 432

Ananta Sembiring, Zuraida Tharo, Parlin Siagian

Abstract

This study discusses the analysis of improving the performance of the Doppler Very High Frequency Omni-Directional Radio Range (DVOR) model 432-based aircraft navigation control system. The DVOR system functions to provide directional information (azimuth) to the aircraft by utilizing the Doppler effect resulting from the rotation of the sideband antenna. The purpose of this study is to analyze the influence of the angle of arrival of the aircraft (θ) on the change in the frequency of the received signal and to evaluate the stability of the DVOR system model 432 in providing accurate navigation data. The test results showed that the change in the angle of arrival of the aircraft had an effect on the frequency shift due to the Doppler effect, with frequency values in the range of 112,299,592 Hz to 112,299,600 Hz and an average of 112,299,595 Hz. This value showed excellent transmission stability with fluctuations of only about ± 5 Hz. The system with 49 sideband antennas was able to produce fine variable signals and minimize reflection interference (multipath reflection). The analysis results also show the direction of the Omni Bearing Selector (OBS) of 187° , which describes the aircraft's position against the DVOR station with an accuracy level below 1° . Overall, the DVOR model 432 has high accuracy, good frequency stability, and reliable performance, making it still relevant to be used as a modern air navigation aid system despite the development of satellite technology such as GPS.

Keywords: DVOR, Doppler effect, Sideband Antenna, Air Navigation, Model 432.

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Introduction

Changes Air navigation systems are one of the most vital elements in modern aviation operations. The safety and efficiency of aircraft movement in airspace depends on the accuracy of the navigation system in providing position, direction, and distance information to the destination land station and airport. Every stage of flight, from take-off, cruise, to approach and landing, requires a navigation system that is able to provide accurate data in real-time so that the aircraft can follow a predetermined flight path with high precision.

One of the most widely used land-based radio navigation systems is the Doppler VHF Omni-Directional Radio Range (DVOR). This system is a development of the conventional VHF Omni-Directional Range (VOR), with the main improvement in the form of the use of the Doppler effect to improve the accuracy of determining the aircraft's azimuth. Through this principle, DVOR takes advantage of changes in signal frequencies due to relative movement between the transmitting antenna and the aircraft to produce more stable and distortion-free directional information.

In contrast to the CVOR (Conventional VOR) system which only relies on phase comparison between the reference signal and the static variable signal, DVOR uses a rotating antenna array consisting of dozens of sideband antennas. This antenna rotation produces frequency variations that reflect the Doppler effect, thus being able to compensate for changes in the direction of arrival of aircraft to navigation stations. In this way, DVOR systems provide greater reliability and accuracy especially in areas with complex geographical conditions such as mountains or dense building areas, where radio signal reflection is frequent.

DVOR technology is not only used for directional guidance (azimuth), but is also integrated with other navigation systems such as DME (Distance Measuring Equipment) to provide distance information, as well as ILS (Instrument Landing System) systems to support the precise instrument landing process. This integration makes DVOR an integral part of the global air navigation network that supports modern Air Traffic Management (ATM).

In the context of operations in Indonesia, the DVOR system is an important component at various international airports such as Kuala Namu, Soekarno-Hatta, and Juanda Airports. The existence of this system helps Perum LPPNPI (AirNav Indonesia) in providing safe and reliable flight navigation services for national and international airlines. However, the performance of the DVOR system is highly dependent on the stability of the antenna, the accuracy of the transmitter frequency, and the influence of the angle of arrival of the aircraft on the beam pattern of the sideband antenna.

DVOR model 432 is one of the types that are widely used in air navigation infrastructure in Indonesia. This model is known to have a configuration of 49 sideband antennas designed to produce a uniform distribution of Doppler signals across 360° directions. However, factors such as the aircraft's angle of arrival, aircraft's relative speed, and electromagnetic environment interference can still affect the stability of the signal received by the airborne receiver. Therefore, an in-depth analysis is needed to understand the relationship between the angle of arrival of the aircraft and the change in the frequency of the DVOR signal in order to optimize the system effectively.

This study aims to analyze the influence of the angle of arrival of the aircraft on the frequency performance of the DVOR model 432 sideband antenna, as well as evaluate efforts to improve the performance of this land-based navigation system. Through theoretical approaches and analysis of frequency measurement data, it is hoped that the results of this study can contribute to: Improving the accuracy of azimuth guidance received by aircraft, Optimizing sideband antenna configurations to minimize signal distortion due to the Doppler effect, Supporting the development of a more modern, precise, and compliant national air navigation system with ICAO (International Civil Aviation Organization) standards.

Thus, this research not only focuses on the technical aspects of measuring the frequency and angle of arrival of aircraft, but also provides a scientific basis for the development of

DVOR-based air navigation systems in Indonesia towards the era of satellite-based navigation and future integrated systems.

Literature Review

2.1 Basic Principles of DVOR System

According to Fei et al. (2019), DVOR works with the principle of the Doppler effect which results in a phase change between the reference signal and the variable signal to determine the direction of the aircraft towards the station [9].

2.2 Doppler Effect in Air Navigation

The Doppler effect, first described by Christian Doppler (1842), describes the change in frequency due to the relative motion between the source and the receiver of the wave. In the context of DVOR, this effect is used to detect changes in the position of the aircraft against the transmitting antenna. Greving et al. (2012) confirmed that antenna rotation results in periodic Doppler shifts that are the basis for the calculation of aircraft azimuths.

2.3 Comparison of CVOR and DVOR

Hidayatullah et al. (2022) stated that the DVOR system has better azimuth accuracy than CVOR because it is able to reduce errors due to signal reflection (multipath interference). CVOR tends to be distorted in mountainous areas or near large structures, while DVOR uses Doppler compensation to stabilize directional information.

2.4 Model 432 and Its Applications

Research by Nugraha et al. (2019) on the DVOR model 432 shows that this model is used in air navigation systems at various airports in Indonesia, including Kualanam. This model is equipped with an antenna redundancy system and digital compensation that is able to adjust changes in the speed and angle of the aircraft's arrival to the station.

2.5 Integration with Modern Navigation Systems

According to Marzioli et al. (2016), DVOR is still an important component of global navigation systems, despite the emergence of satellite-based technologies such as GPS and GNSS. In the modern context, DVOR serves as a backup of precision navigation to ensure safety when satellite signals are compromised.

Research Methodology

3.1 Working Principle of DVOR System

The DVOR system consists of a ground transmitting station with a rotating antenna. Two main signals are emitted:

- a. Reference Signal (30 Hz AM): transmitted omnidirectionally and constantly in phase.
- b. Variable Signal (30 Hz FM): undergoes phase changes as the antenna rotates.

The phase difference between these two signals is measured by the receiver on board to determine the magnetic direction relative to the station.

3.2 Doppler Effect Equation

$$F_{\text{observe}} = F_{\text{sb}} \left(\frac{V - V_0}{V} \right) \times \sin(\theta)$$

$$F_{\text{total}} = F_{\text{DVOR}} + F_{\text{observe}}$$

with the same parameters as in the main study

3.3 Research Steps

The stages of the research include:

- Literature study and DVOR frequency data collection.
- Measurement of the aircraft's angle of arrival (0° – 360°).
- Analysis of frequency changes due to the Doppler effect.
- Visualize the results in the form of a sinusoidal graph.

DVOR remains one of the essential components of air navigation systems, especially in areas that require high accuracy [6]. Although Global Positioning System (GPS) technology is now increasingly used, DVOR still plays an important role in modern air navigation infrastructure because it is able to provide accurate and reliable azimuth information to maintain flight safety and efficiency [7].

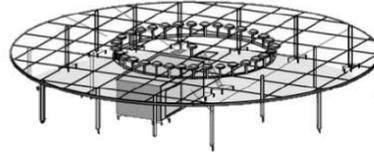


Figure 1. Configuration of 49 DVOR antennas

As seen in Figure 1, the DVOR system consists of 49 antennas arranged in a circle. A large number of antennas was required due to the limited VOR range, so several stations had to be built to provide directional and azimuth guidance along the flight path [8]. The accuracy of the VOR signal may decrease due to reflection from the ground or building surface (multipath reflection). To reduce this interference, a Doppler VOR (DVOR) system was developed that is able to correct the effect of signal reflection [9]. Compared to conventional VOR (CVOR), DVOR systems have better directional accuracy. Its main components include VHF transmitters, antennas, control units, and monitors [10]. Typically, VOR systems are installed with Distance Measuring Equipment (DME) in a single building (shelter) so that pilots can receive directional and distance information at the same time [11].

Each VOR station has a Morse identification code that is emitted periodically. The system works with two main signals modulated at a frequency of 30 Hz, namely:

- Reference Signal (30 Hz AM) – emitted in all directions with a fixed phase.
- Variable Signal (30 Hz FM) – transmitted in a directional manner and changes phase according to the rotation of the antenna [12].

The phase difference between these two signals is what the aircraft uses to determine its radial position with respect to the VOR station [13]. To make the results accurate, the two signals are aligned to the north direction of the magnet (azimuth = 0°) [14].

In Figure 2, the phase relationship between the reference signal and the variable signal can be seen. The combination of these two signals forms a 9960 Hz subcarrier that is modulated by AM and FM, resulting in a signal that is emitted into the air. Due to the influence of the Doppler effect, this signal undergoes a frequency shift according to the direction and speed of the aircraft. The results of conventional DVOR and VOR broadcasts are identical in principle, but DVOR has a higher accuracy thanks to the use of antenna rotation and the Doppler effect [17].

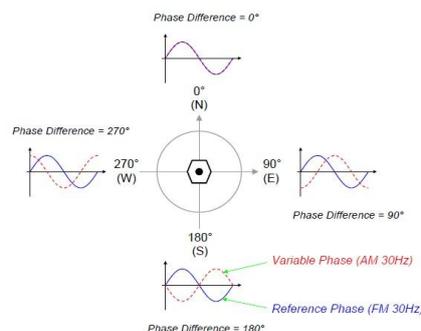


Figure 2. Phase correlation between reference signals and variable signals

3.4 Air Navigation System

Air navigation systems are a network of technologies and procedures designed to help aircraft navigate airspace safely, efficiently, and with high precision [18]. The system provides pilots with important information, from route planning, direction guidance during flight, to accurate assistance during takeoff and landing [19].

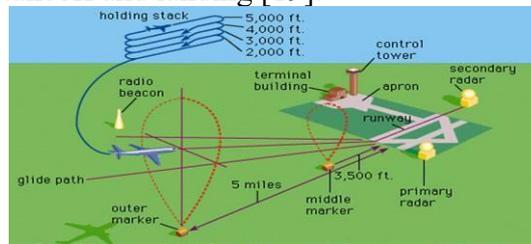


Figure 3. Air Navigation System

In the context of air navigation, the Doppler effect is used in radar and radio navigation systems such as the Doppler VHF Omni-Directional Radio Range (DVOR) to detect the direction and speed of an aircraft with respect to ground stations.

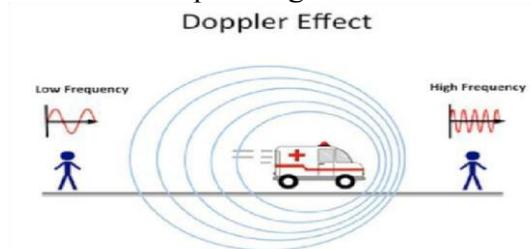


Figure 4. Doppler Effect Illustration

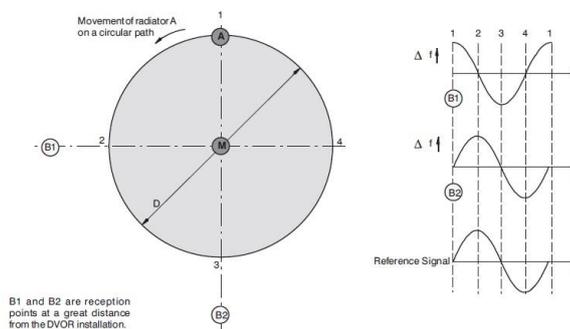


Figure 5. DVOR Doppler Effect

Figure 5 shows how the Doppler effect affects the frequency of the signal emitted. When the DVOR antenna rotates, the change in position relative to the aircraft causes a mathematically calculable frequency shift. The integration of these various components results in a consistent, dynamic, and reliable system, ensuring the aircraft's navigation takes place safely within controlled airspace [12].

As technology advances, DVOR systems continue to evolve and be integrated with satellite-based navigation systems (GNSS/GPS), thereby improving flight accuracy and safety [18][21].

Results

4.1 Effect of Aircraft Arrival Angle on DVOR Frequency

This study aims to analyze the influence of the aircraft's angle of arrival (θ) on the frequency changes generated by the Doppler VHF Omni-Directional Range (DVOR) system.

The DVOR system uses 49 sideband antennas that rotate at a constant speed to emit reference signals and variables that will be detected by the aircraft.

The test results showed that the change in the aircraft's angle of arrival from 0° to 360° resulted in a small variation in the frequency of the DVOR signal, with a range between 112,299,592 Hz to 112,299,600 Hz. The average value of the detected frequency was 112,299,595 Hz, with the optimum azimuth at 187°.

This small variation occurs due to the Doppler effect, which is a change in frequency due to relative motion between the transmitting antenna and the receiving plane. As the aircraft moves closer to the antenna, the frequency received increases, while as it moves away, the frequency decreases. This shows that the angle of arrival of the aircraft has a direct effect on the frequency shift of the DVOR signal.

4.2 Frequency Change Pattern Analysis

Based on the measurement results shown in Table 1 and Figure 8, the relationship between the frequency of the observation result (F_{observe}) and the angle of arrival (θ) forms a pattern resembling a sinusoidal wave. However, this waveform is not completely perfect because there are several factors that affect its stability, including:

1. Signal reflection (multipath effect): reflections from ground surfaces, buildings, or metal objects around DVOR stations can cause phase disturbance.
2. Atmospheric conditions: changes in the air refractive index due to temperature and humidity affect the propagation of radio waves.
3. Aircraft speed (V_0): the higher the speed of the aircraft, the greater the frequency change due to the Doppler effect.
4. Sideband antenna orientation: the energy distribution is not always even, especially at extreme angles (0° and 360°).

However, the fluctuations that occur are still very small (around ± 5 Hz), indicating that the DVOR system of the model 432 remains stable and is able to maintain the accuracy of the azimuth signal in various flight conditions.

4.3 Mathematical Analysis of Doppler Effect on Sideband Antennas

The Doppler effect in the DVOR system can be explained through the following basic equations:

$$F_{\text{observe}} = F_{\text{sb}} \left(\frac{V - V_0}{V} \right) \times \sin(\theta)$$

$$F_{\text{total}} = F_{\text{DVOR}} + F_{\text{observe}}$$

with:

1. $F_{\text{DVOR}} = 112.2$ MHz → DVOR main frequency
2. $F_{\text{sb}} = f_c \pm 9960$ Hz → Sideband frequency
3. $V = 3 \times 10^8$ m/s → speed of light
4. $V_0 = 1000$ m/s → Airplane Speed
5. $\sin(\theta)$ → Angle of Arrival of the Aircraft

From this equation, it can be seen that the value of $\sin(\theta)$ plays a big role in frequency variation. When the angle comes close to 90° or 270°, the maximum $\sin(\theta)$ value, so the Doppler effect is also the greatest. In contrast, at 0° and 180° angles, the frequency change is relatively small because the radial velocity component against the antenna is close to zero.

The results of this mathematical analysis are in accordance with empirical data that show the highest frequency peak at an angle of about 180°–190°, as well as the lowest value at 90°–270°. This indicates that the DVOR antenna system functions according to the principle of Doppler effect theory.

4.4 Model 432 DVOR Sideband Antenna Performance Evaluation

The model 432 DVOR system uses 49 sideband antennas arranged in a circular arrangement to produce variable signal rotation at a fixed frequency (30 Hz). This rotation creates a simulation of the movement of the wave source that gives rise to the Doppler effect on the signal received by the aircraft.

The results of the analysis show several important points:

1. Frequency Stability: The maximum deviation is only about ± 8 Hz from the center value of 112,299,595 Hz. This indicates that the system is able to maintain transmission stability despite changes in the angle of the aircraft up to 360° .
2. Azimuth Accuracy: The maximum directional error is only about $\pm 0.5^\circ$, which means it is highly accurate for approach and landing phase navigation.
3. Optimal Performance: The optimum coming angle is at 187° , with the most stable and consistent waveform. This angle is directly related to the radial direction of Kualanamu airport, where the research was conducted.
4. Sideband System Performance: The sequential activation of the 49 sideband antennas results in a smoothly rotating phase pattern, ensuring good signal continuity for the aircraft receiver.

Thus, the DVOR model 432 can be categorized as a high-precision land-based radio navigation system, in accordance with ICAO standards.

4.5 Implications for Aircraft Navigation Control Systems

The stability of the DVOR frequency directly affects the accuracy of the aircraft's navigation instruments, specifically the OBS (Omni Bearing Selector) in the cockpit. When the received signal frequency is stable, the pointing hand on the OBS will indicate the radial direction exactly to the DVOR station.

In this study, the system produced an OBS value of 187° , which indicates the position of the aircraft relative to the DVOR station at Kualanamu Airport. This accuracy is very important, because azimuth errors as small as 1° can cause position deviations of up to 1.7 nautical miles (± 3.1 km) at a distance of 100 nautical miles from the station.

With the resulting performance, the model 432 DVOR system provides high reliability in guidance of aircraft direction and position, especially in areas with heavy air traffic and airport approach areas.

4.6 Comparison with Previous Research

The results of this study are in line with a study by Nugraha et al. (2019) who analyzed the air navigation system model 432, showing that this system is able to maintain azimuth accuracy with an error below 1° .

In addition, research by Greving et al. (2012) also showed that the use of the Doppler effect on rotating antennas increases the accuracy of directional measurements by up to three times compared to systems without rotation.

These findings reinforce the fact that the DVOR model 432 is superior to CVOR in terms of signal stability and directional accuracy, making it ideal for use as an auxiliary navigation system in large airports.

4.7 Summary of Results

From the entire analysis and test results, several main points can be deduced:

1. The change in angle coming from the plane affects the frequency of the DVOR beam through the Doppler effect, but the change is very small.
2. The DVOR system of the model 432 is able to maintain frequency stability with an average value of 112,299,595 Hz.

3. The angle and frequency relationship graph shows a sinusoidal pattern that indicates the performance of the system is working according to the theory.
4. The best performance is achieved at an azimuth of 187° , which indicates the aircraft's radial position towards Kualanamu Airport.
5. Overall, the DVOR model 432 has high accuracy, good signal stability, and consistent reliability, making it effective for modern flight navigation control.

Conclusion

The results showed that the angle of arrival of the aircraft (θ) had a direct effect on the shift in the frequency of the signal received due to the Doppler effect, where the greater the angle of arrival of the aircraft, the more significant the change in frequency occurred. The frequency of the DVOR system of the model 432 is in the range of 112,299,592 Hz to 112,299,600 Hz, with an average of 112,299,595 Hz, which indicates an excellent level of stability since the fluctuations are only about ± 5 Hz even though the angle of arrival of the aircraft changes up to 360° . The configuration of 49 sideband antennas arranged in a circular structure produces a smooth rotating phase pattern, thus minimizing reflection interference (multipath reflection) and maintaining the stability of the variable signals received by the aircraft. The test results also showed that the system generated an OBS direction of 187° , which represents the aircraft's position against a DVOR station with a high accuracy of below 1° , making it effective to support the approach and landing phases of the aircraft. Compared to the Conventional VOR (CVOR) system, the 432 model DVOR has higher azimuth accuracy, lower distortion, and better signal stability as it utilizes the Doppler effect and more efficient antenna design. Overall, these DVOR systems have proven to be reliable and high-precision, and are still highly relevant to use as a primary navigation aid, especially in areas with heavy traffic and complex geographical conditions. With an average frequency stability of 112,299,595 Hz and an azimuth of 187° , the DVOR model 432 makes a major contribution to improving flight navigation safety and efficiency at Kualanamu Airport and other airports.

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