

# 4 VOR and Doppler VOR

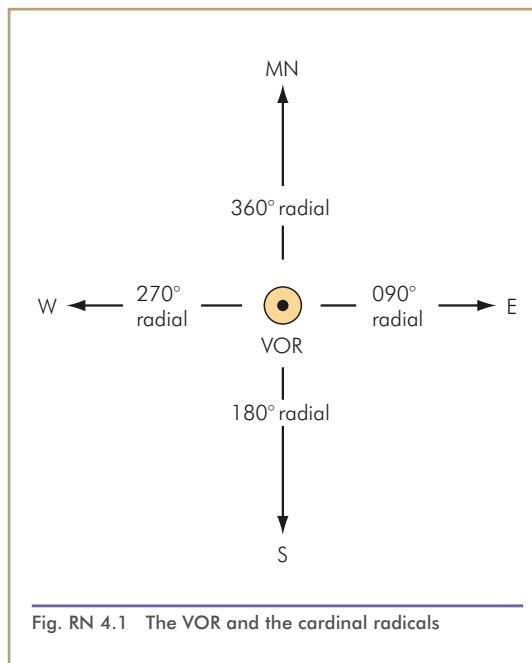
## 4.1 Principle of Operation

VOR is an abbreviation for “VHF Omnidirectional Radio Range”, which implies that it operates in the VHF band. Adopted by ICAO as early as 1960, VOR has been the main short-range navigational aid for several years. Short range infers that ranges up to 200 NM can be expected. It is still the most commonly used short-range aid. As opposed to the NDB, which transmits a non-directional signal, the signal transmitted by the VOR contains directional information.

The principle of operation is bearing measurement by phase comparison. This means that the transmitter on the ground produces and transmits a signal, or actually two separate signals, which make it possible for the receiver to determine its position in relation to the ground station by comparing the phases of these two signals. In theory, the VOR produces a number of tracks all originating at the transmitter. These tracks are called «radials» and are numbered from 1 to 360, expressed in degrees, or  $^{\circ}$ . The  $360^{\circ}$  radial is the track leaving the VOR station towards the Magnetic North, and if you continue with the cardinal points, radial  $090^{\circ}$  points to the East, the  $180^{\circ}$  radial to the South and the  $270^{\circ}$  radial to the West, all in relation to the magnetic North.

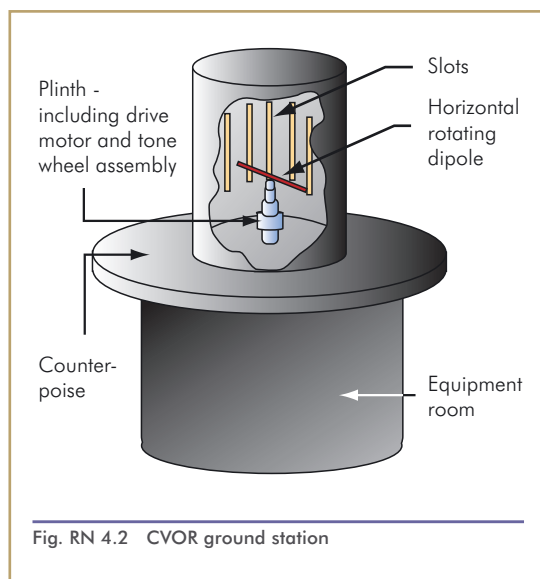
*See fig. RN 4.1*

Before we look in detail at how the system works the following example illustrates the principle and should make it easier to understand.



Think of a lighthouse at sea and imagine the white light rotating at a speed of one revolution per minute (60 seconds). Every time this white narrow beam passes through Magnetic North, a green omnidirectional light flashes. Omnidirectional means that it can be seen from any position around the lighthouse. If we are situated somewhere in the vicinity of the light sources and are able to see them, we can measure the time interval from the green light flash until we see the white light. The elapsed time is directly proportional to our position line in relation to the lighthouse.

The speed of 1 RPM corresponds to  $6^\circ$  per second, so if 30 seconds elapse between the time we see the green flash and the white rotating light, we are on the  $180^\circ$  radial, or directly south of the station ( $30 \text{ sec} \times 6^\circ/\text{sec} = 180^\circ$ ). This calculation can be done from any position and the elapsed time is directly proportional to our angular position (radial). We could name these light signals, calling the green one the Reference (REF) signal and the white beam the Variable (VAR) signal.



## 4.2 Ground Installation

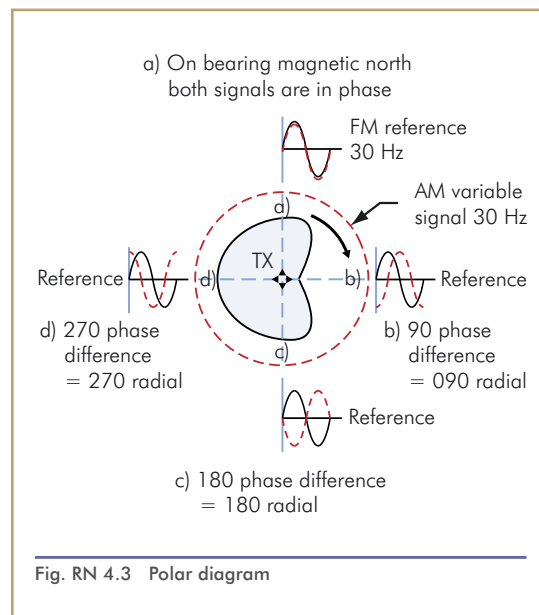
The VOR system operates on frequencies between 108 MHz and 117.95 MHz. Channel separation is 50 kHz and the signals have a horizontal polarisation.

Frequencies between 108 MHz and 111.95 MHz are primarily used for the localiser part of the ILS but can be shared with short range VORs, or so-called terminal VORs. The VOR uses

frequencies having an even decimal as the first digit after the last MHz digit, while localizers use odd decimals. When assigning a VOR to this part of the frequency band, it is an essential requirement that it does not interfere with an adjacent ILS channel. The frequencies from 112.00 to 117.95 MHz are solely used by VOR, both on odd and even frequencies

108.10 Localizer	112.00 VOR
108.15 Localizer	112.15 VOR
108.20 T-VOR	112.10 VOR
108.25 T-VOR	
108.30 Localizer	117.95 VOR
108.35 Localizer	

The ground equipment is set up on a fixed, surveyed site and consists of a transmitter driving a combined aerial system; one part producing the Reference (REF) signal, the other producing the Variable (VAR) signal. The REF signal is an omnidirectional continuous wave



transmission on the carrier frequency of that particular VOR station. It carries a 9960 Hz subcarrier that is frequency modulated at 30 Hz. Since this is an omnidirectional transmission, the polar diagram of the REF signal is a circle.

In the receiver, it is the 30Hz component of this signal that is used as a reference for measuring the phase difference. The variable signal (VAR) is transmitted from an aerial that is effectively a loop. This 'loop' produces a figure of 8 polar diagram, which is electronically rotated at 30 revolutions per second. When the two signals (VAR & REF) are mixed together, the resulting polar diagram will be a cardioid, but unlike the cardioid of the ADF, this does not have a «null» position. We call it a «limaçon». It rotates at 30 revolutions per second, indicated with an arrow on *fig. RN 4.2*

The rotation of the limaçon creates an effective amplitude modulation of 30 Hz. The VOR receiver splits these two signals into the two original components. The two signals are processed through different channels and the phase of the 30 Hz modulations of the fixed REF signal and the VAR signal are compared in a phase comparator. The phase difference between these two signals is directly proportional to angular position with reference to the VOR station.

As explained, magnetic North is the normal reference for the radials, so when 0° phase difference is detected, the receiver is on the 360° radial from the station. *Fig. RN 4.3* shows the phase difference and variable signal at the cardinal points.

The description above is valid for the conventional VOR, CVOR. The CVORs suffer from reflections

from objects in the vicinity of the VOR site and it was found that errors due to this could have been reduced if the horizontal antenna dimensions were increased. This was not practical to do and a new system had to be developed: the DOPPLER VOR, DVOR. The CVORs are now gradually being replaced by DVORs, that will be described in the next section.

### 4.3 Doppler VOR (DVOR)

The Doppler VOR is the second generation VOR, providing improved signal quality and accuracy. The REF signal of the DVOR is amplitude modulated, while the VAR signal is frequency modulated. This means that the modulations are opposite as compared to the conventional VORs. The frequency modulated signal is less subject to interference than the amplitude modulated signal and therefore the received signals provide a more accurate bearing determination.

The Doppler effect is created by letting the VAR signal be «electronically rotated», on the circular placed aerials, at a speed of 30 revolutions per second. With a diameter of the circle of 13.4 meters, the radial velocity of the VAR signal will be 1264 m/s. This will create a Doppler shift, causing the frequency to increase as the signal is rotated towards the observer and reduce as it rotates away with 30 full cycles of frequency variation per second. This results in an effective FM of 30 Hz. A receiver situated at some distance in the radiation field continuously monitors the transmitter. When certain prescribed deviations are exceeded, either the IDENT is taken off, or the complete transmitter is taken off the air. We come back to this in the section «Limitations and accuracy».

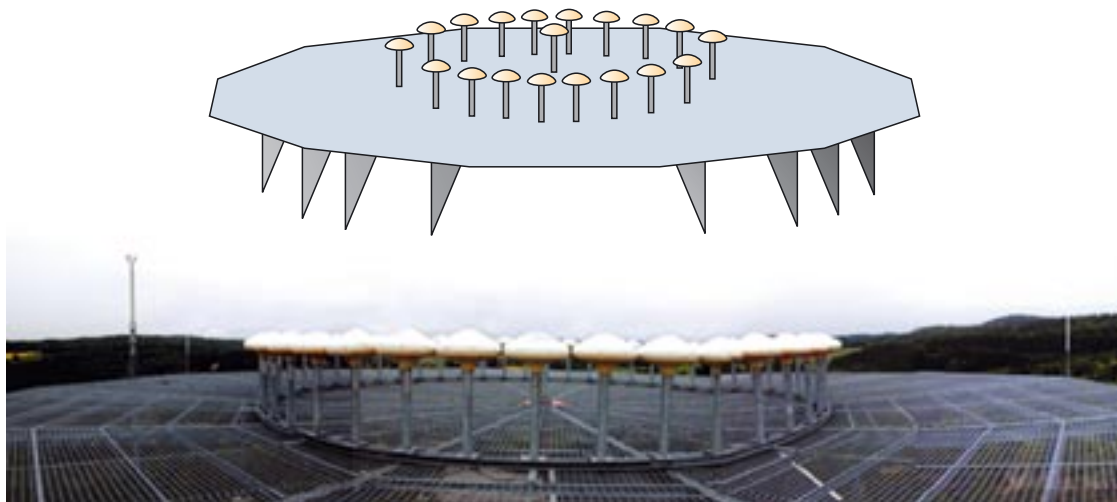


Fig. RN 4.4 A Dopplar VOR ground station

The VOR receiver does not know if it is receiving a signal from a CVOR or a DVOR and the pilot treats both types in the same way. The change of FM and AM for the REF and VAR signals, as compared to the CVOR, is compensated for by having the DVOR antenna pattern rotate the opposite way, compared to the CVOR.

## 4.4 Airborne Equipment

The airborne system of the VOR installation consists of three main elements:

### 4.4.1 Aerial, Receiver and Indicator

The aerial is a small, horizontal dipole, designed to receive the horizontally polarised signals transmitted from the ground station. Its size is designed with the frequency band of 108 MHz - 118 MHz in mind. The aerial must be mounted in such a place that it offers 360° reception of the radio signals. It must also be shielded from transmissions from the VHF communication radio aerial. Aerials are

frequently mounted on the fin. The frequency selector knob on the control panel is used to select the required station. The signal from the aerial is filtered through the high frequency part of the receiver and only the signals from the desired VOR station are passed through to the detectors and filters. The receiver compares the reference signal and the variable signal in order to detect the phase difference between the two. The phase comparator compares the phase of the two signals and the difference is fed to the indicator. A special circuitry, within the receiver, detects the identification signal and amplifies it for a speaker or headphones. Some VORs can also transmit «voice», either radio communication, identification, met-information or other voice transmissions. The receiver panel has a frequency selector knob, a dial indicating the selected frequency and a selector switch with a position for IDENT and Voice.

The IDENT position is selected when we want to hear the identification signal of the VOR. It is

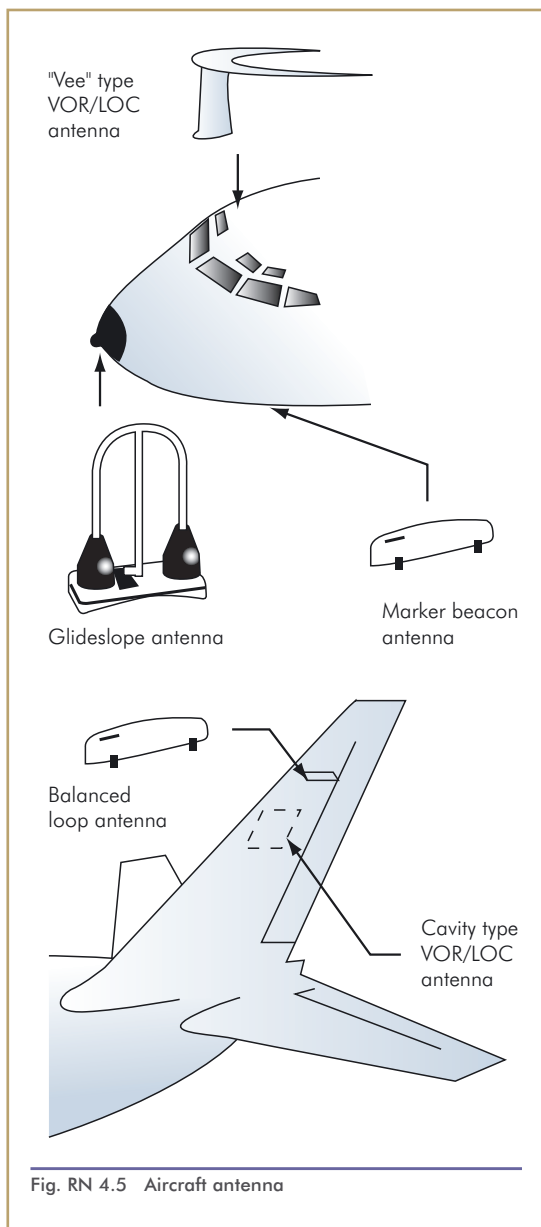


Fig. RN 4.5 Aircraft antenna

very important to check the ident before using the navaid, otherwise you cannot rely on the displayed navigational information. The ident is transmitted according to ICAO recommendations and consists of a two or three letter Morse code

transmitted at a rate corresponding to seven words a minute and the signal shall be repeated at least once every 30 seconds. The modulation tone is 1020 Hz.

The VOICE position is selected to improve the reproduction of speech, and is selected when the transmission contains voice messages (for instance ATIS), or if the station serves as a regular voice transmitter. The indicator can be in many different forms, from the simplest to the most complex, as a part of an electronic flight information system. We will cover the basic indicator and its parts and functions, because it displays all the basic information provided by the VOR receiver, and it also forms the basis of the more complex systems.

#### 4.4.2 Course Deviation Indicator (CDI)

The indicator, which is shown at *fig. RN 4.6*, consists of three main elements:

- OBS                      Omni Bearing Selector  
(button, lower left on figure, with associated compass scale).
- TO/FROM              Flag
- CDI                      Course Deviation Indicator  
(vertical white needle on figure)

A warning flag is also a part of the indicator, most commonly an "OFF" flag.

The OBS is used to select the desired bearing in relation to the VOR station. In the model illustrated the OBS knob is turned to bring the selected bearing on the compass scale to the top of the indicator. In this example we have selected a bearing of 180°. On another popular type of indicator the selected bearing is shown digitally in a window on the indicator face.



The TO/FROM indicator tells you if the selected bearing will take you to or away from the VOR station. The CDI indicates your position relative to the selected bearing and it will move to the left or right according to relative position to the bearing selected. The needle moves across a scale of dots, each representing a certain number of degrees of deviation. There are indicators with a 5 dot scale (to each side) or, less commonly, some with a four dot scale. Deflection to the last dot (left or right) represents 10° displacement from the bearing selected. The vertical needle may deflect further out than to the last dot, and will then represent more than 10° displacement. On a five-dot scale each dot represents 2° of deviation while, on the four-dot scale, each dot represents 2,5 °.

The warning flag appears when no signal is received, or when the one received is too weak. Most common is a flag with the text «OFF» or

«NAV». The warning flag circuit also monitors the receiver itself and will appear if the receiver or indicator is malfunctioning. Another way of putting it: The OFF (NAV) flag will show until an acceptable VOR signal is received and processed by the receiver. The OFF (NAV) flag will then disappear. If the warning flag is appearing, the indications are not to be trusted, even if a valid identification signal is being received.

The indications on the CDI are totally independent of aircraft heading. It displays the aircraft position in relation to the bearing selected. When the OBS is turned to centre the CDI needle, with the FROM flag showing, the number indicated on the top of the compass scale is the radial on which the aircraft is situated.

The radial can be plotted on an aeronautical chart, thus giving you a line of position. If the

