DOCUMENT

GSM-AUS-CPL.028

DOCUMENT TITLE

CPL NAVIGATION 2 (AUSTRALIA)

CHAPTER 7 – DISTANCE MEASURING EQUIPMENT

Version 2.1
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DISTANCE MEASURING EQUIPMENT (DME)

7.1 Introduction

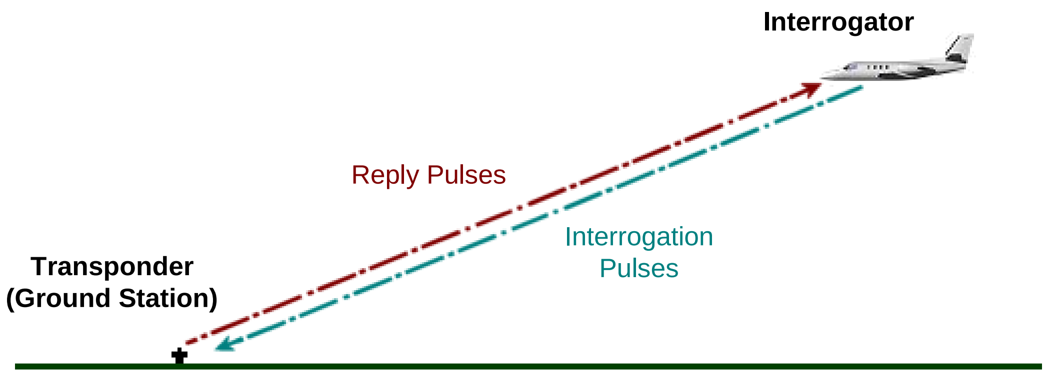
Since before World War 2, there has been an increasing demand in both military and civilian aviation for equipment that will enable aircraft to define their position accurately in terms of range and bearing relative to specific ground locations.

DME (Distance Measuring Equipment) was developed to provide the pilot with accurate and continuous indications of the distance between an aircraft and a ground station.

DME is a secondary radar system that requires the co-operation of a ground station in order to provide the pilot with distance information.

7.2 Principle of Operation

As DME is a secondary radar system, the airborne equipment requires the assistance of the ground station to function. The interrogator is located in the aircraft, with the transponder at the ground station.

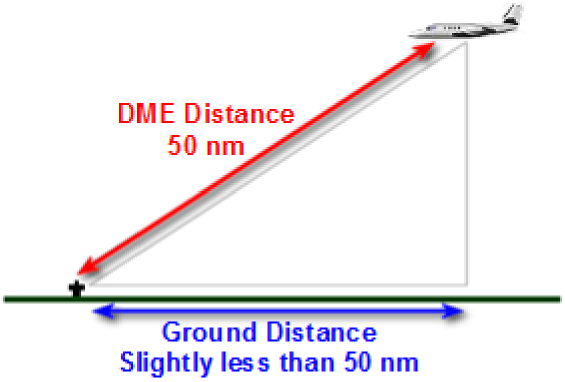


The interrogator in the aircraft transmits a stream of interrogation or latching pulses in all directions on the receiving frequency of the ground station.

The ground station receives the pulse stream, then waits for a fixed time period of 50 μsec (micro seconds). It transmits a strong **ranging or reply signal** on a frequency that is 63 MHz removed from the interrogation signal's frequency.

The airborne DME equipment detects the signal and measures the lapsed time between the transmitted interrogation and the received transponder signals (taking into account the 50 μsec delay). This time is converted to distance in nautical miles and displayed on a suitable DME indicator.

DME provides the pilot with accurate and continuous indications of the distance between an aircraft and a ground station.

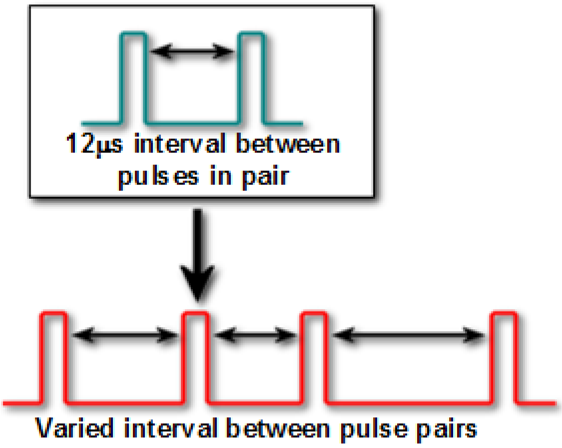


However, keep in mind that this distance is the direct distance between the ground station and aircraft, and as such is the **slant range**.

The actual **ground distance** from the ground station to a point directly below the aircraft will be slightly less that what is indicated by the DME.

The interrogator (in the aircraft) transmits a stream of interrogation pulses on the frequency allocated to the ground beacon (transponder).

The pulse stream consists of a continuous series of pulse pairs. The interval between the **two pulses of a pair** is 12 µs, but the interval between the transmission of pulse pairs (also known as PRF - Pulse Recurrence Frequency) is varied at random. This technique is called transmission at **random PRF**.



Interrogation Pulse Pattern

As transmission commences, the airborne equipment commences a search for any transponder replies and starts timing at the same time.

The ground beacon transponder replies to the interrogation signals by transmitting a stream of pulse pairs on its reply frequency.

All the responses that are transmitted by the transponder are received at the airborne receiver, but only those that match its own original random PRF are accepted.

The airborne receiver **searches for 3 – 4 seconds under ideal conditions**.

During the search period, the interrogator initially transmits at a PRF of 150 pulse pairs per second in order to ensure a quick lock-on condition.

However, if **lock-on** is not achieved after 100 seconds or transmission of 15,000 pulse pairs, the PRF is decreased to 60 pulse pairs per second.

Lock-On Condition. An aircraft is locked once the search phase has been successful at the DME ground beacon is providing continuous range indications to airborne equipment upon being interrogated.

The PRF is maintained until the search is successfully completed and lock-on is achieved.

Once lock-on has been achieved, the system operates on a PRF of 25 to 30 pulse pairs per second.

		Pulse Pairs/Sec	Time Period
Search Period	Initial	150	100 Secs
	Secondary	60	Until lock-on achieved
Lock-on		25 – 30	

7.2.1 Random PRF Technique

DME uses a technique called transmission at random PRF. This means that the time interval between pulse pairs is varied at random.

The transmission at a random PRF is to prevent the airborne equipment from locking on to transponder responses meant for other aircraft.

A primary radar system with a PRF of 25 pps would transmit a pulse at a PRP (Pulse Recurrence Period) of exactly 40,000 µs.

Calculation:

$$PRP = \frac{1}{PRF} \text{ seconds}$$

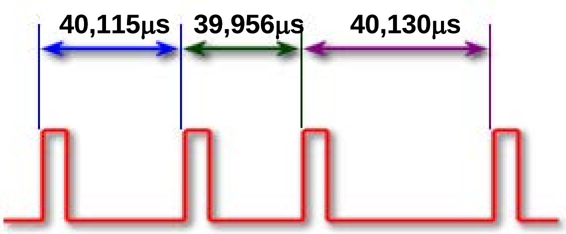
$$PRP = \frac{1{,}000{,}000}{25}\ \mu s$$

$$PRP = \underline{40{,}000\ \mu s}$$

Note: To convert seconds to microseconds (µs), multiply by 1,000,000

With DME, this PRP is internationally varied at random

With a DME system, the transmission pattern would look somewhat similar to the graphic below.



Interrogation Pulse Pattern

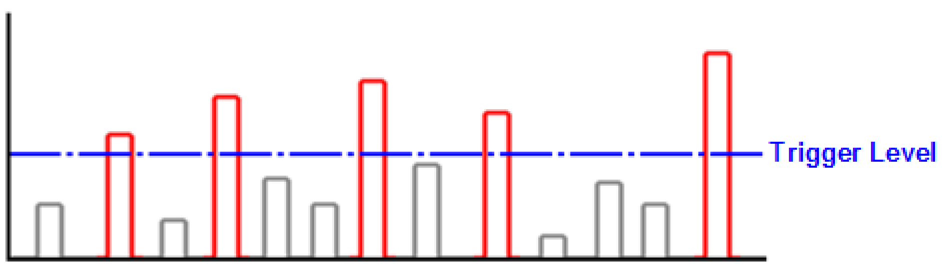
One pulse pair may be **40,115 μs** behind the previous one, but the next pair will follow it at **39,956 μs** and the next **40,130 μs** etc.

In this manner the time interval between pulse pairs will vary continuously by a small, but random value.

The ground beacon transponder will reply to all aircraft that transmitted interrogation pulse streams and which are strong enough to trigger it. This equates to approximately 100 aircraft at any one time

.

The amplitude of the received pulse must exceed a preset value. This acts as an electronic gate.

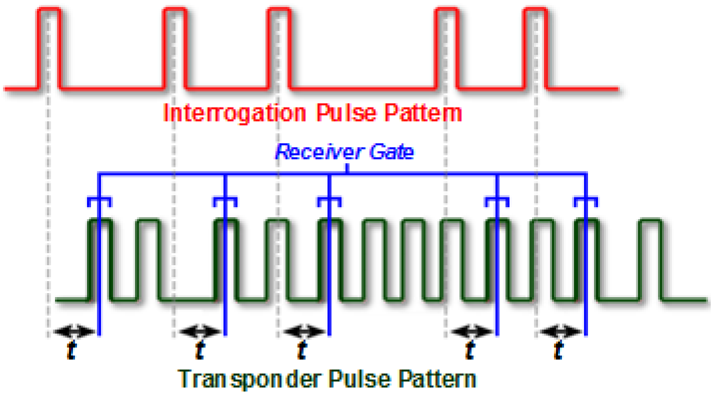


Received Pulses at Transponder

In the image, only the red pulses would be strong enough to trigger the transponder.

All the responses will arrive at the aircraft as the DME transponder responds on the same carrier frequency to all interrogations from all aircraft.

The interrogator stores the exact random PRF that it transmitted and compares all the return signals as it searches for its own random PRF. Its own pulse pairs will arrive back at the aircraft with a regular time delay (t).



A narrow **gate in the receiver** admits only those pulses that fall inside it, while all other responses are excluded. The value of "t" is momentary, but the gate is wide enough and moves with the progressively changing time delays to keep its own responses in the lock (lock-follow technique) and so ensure that the DME remains locked on.

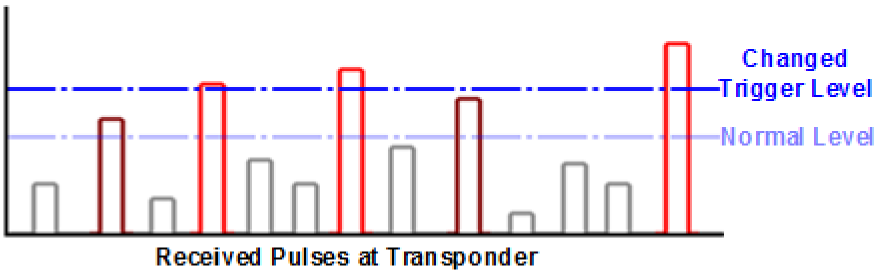
7.3 Beacon Saturation

A DME ground beacon has a random PRF of 2,700 pulse pairs per second, irrespective of whether it is being triggered for information or not. When an aircraft interrogates the beacon, some of the 2,700 pulses are used to reply and are thus not available to other aircraft.

Once locked on, the system operates at a random PRF of 25 - 30 pulse pairs per second with an **average random PRF of 27 pulse pairs per second**. This means that for each aircraft that triggers the DME transponder and locks on, 27 fewer pulses are available to the remaining aircraft yet to trigger the transponder.

With 2,700 pulses available, the transponder's capacity will be exhausted if 100 aircraft are locked on simultaneously. **When a transponder's capacity becomes exhausted, it is said to be saturated**.

When stating that 100 aircraft will saturate a DME beacon, aircraft that operate at a higher PRF (during search mode) have not been considered. Fortunately, the initial search mode (at a PRF of 150 pulse pairs per second) does not last long. A search at 60 pulse pairs per second will likewise also not last long, because if lock-on does not take place, the aircraft is still likely to be out of range.



In order to cope with the saturation, the beacon adjusts by reducing the receiver gain. This has the effect of excluding **weaker signals** from aircraft that are further away.

Aircraft excluded from a beacon due to saturation, will unlock. As aircraft come closer, their signal strength will increase and they will be able to lock-on again. The system allows lock-on of other aircraft when a current aircraft flies beyond the beacon range and unlocks.

The system will give preference to the aircraft that are nearest to the beacon. However, the amount of aircraft being provided with range will not decrease below 70.

When an aircraft is out of range of a selected beacon, no signals will be received. As it is pointless to transmit interrogation pulses, when no reply can be received, the airborne equipment will switch to an automatic standby mode.

The interrogator will wait until it receives pulses (300 - 400 pulse pairs per second) from the selected DME beacon.

When this occurs, it is within range and will commence with the transmission of interrogation signals and DME range will be displayed.

Beacon Transmissions

A DME beacon only responds to interrogations from an aircraft. To prevent the problem as to who will transmit first, a DME transponder that is not being interrogated, transmits dummy pulse pairs (called ‘squitter’ or filler pulses) at random.

These pulses are received by aircraft once they are within beacon range. Interrogation can now commence and the beacon will start to provide the range once lock-on has been achieved.

7.4 Airborne Equipment

Airborne equipment consists out of the following components:

- **Interrogator** consists of a combined receiver/transmitter. The interrogator is housed in a “black box" which is installed in the aircraft avionics bay.
- **Omni-directional blade antenna** is capable of receiving vertically polarised signals.
- Suitable **selector/indicator** in the cockpit.

Omni-directional Antenna

7.4.1 Indicator

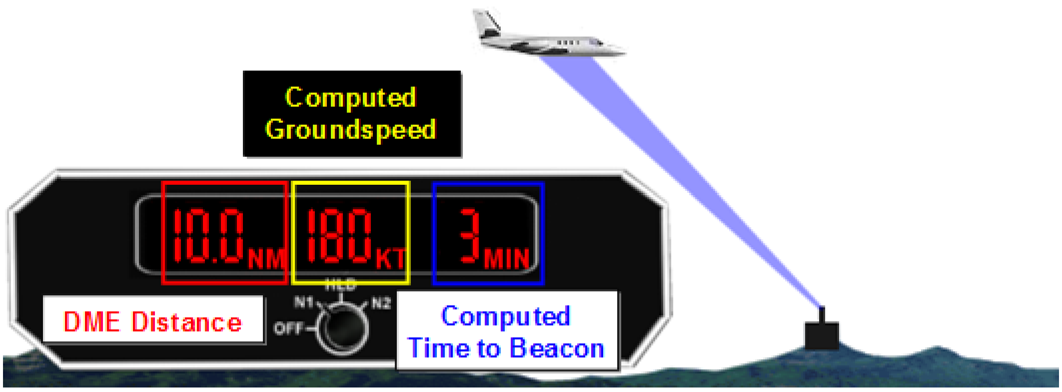
On this type of display, the DME is selected on a NAV controller. By selecting either **N1** or **N2** with the selector knob, the pilot selects the frequency as set up on the NAV1 or NAV2 VOR controller.

Once the DME information is displayed on the indicator, the pilot can select hold "**HLD**". The DME will now hold the selected frequency while the pilot can select another VOR frequency on that NAV controller. DME frequency is selected automatically and tuned internally by the DME receiver unit, when a paired VOR frequency is selected.

DME will provide distance information irrespective of whether the VOR (or ILS localizer) is used for tracking or orientation purposes.

Some DME indicators are capable of computing the rate of closure of the aircraft with the DME ground beacon or rate of change of DME distance.

This rate of closure of the aircraft with the DME ground beacon is displayed on the cockpit display. If the aircraft tracks directly towards or away from the DME ground beacon and assuming slant range equals ground distance, then the rate of closure will represent the groundspeed of the aircraft.



Some DME indicators also have the capability to display the time to the DME beacon at the current rate of closure. This is computed by comparing the groundspeed with the DME distance.

7.4.1.1 Failure Indications

When the received transponder signal is below a preset value, the airborne equipment will go into a "memory mode" for 8 - 10 seconds. It will continue to display the ranges based on the last known change in range. If the DME still does not receive a signal of acceptable strength, it will unlock and commence a fresh search. It will only lock-on once signals of sufficient strength are received again.

DME unlock is indicated by a cleared display and will occur under the following conditions:

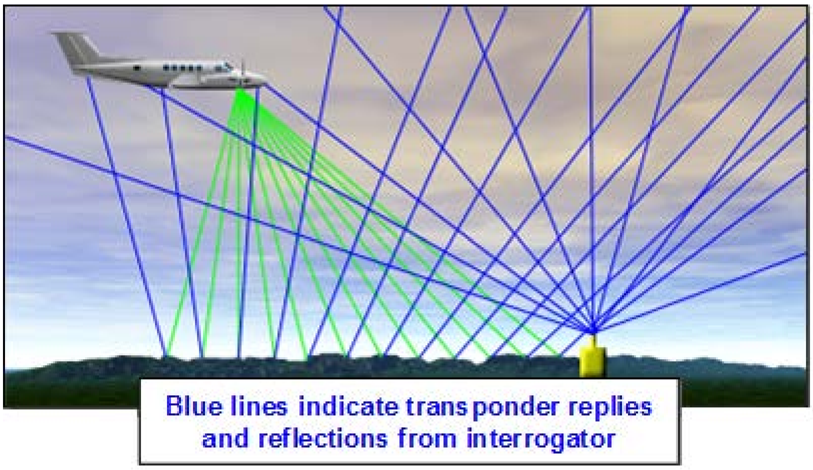
- With the DME switched on, but no signals are being received.
- The received signals are below the minimum strength value.
- The aircraft is out of range of the transponder (ground beacon) and no reply signals are received.

7.5 Prevention of DME Self Triggering

DME is a secondary radar system that transmits and receives on two different frequencies. The use of two frequencies is very necessary for two reasons:

Consider an aircraft transmitting an interrogation signal on a specified beacon frequency.

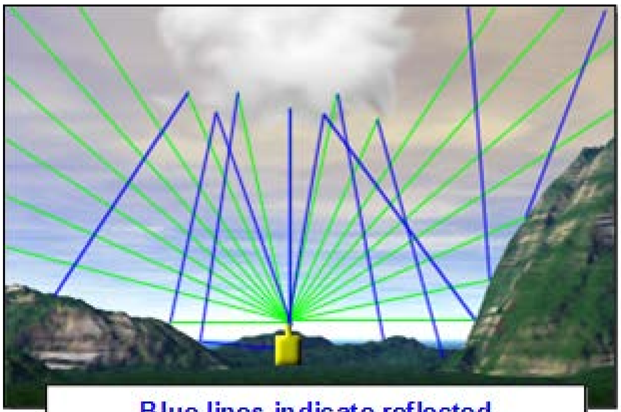
If the transponder transmits its reply on the same frequency, all the ground reflections from the original interrogation transmission will swamp the transponder reply.



This will result in the aircraft receiving a multitude of erroneous ranges together with the correct range from the transponder.

The converse is also true, as obstacles and objects in the vicinity of the transmitter will reflect transponder transmissions.

Some of these reflections will arrive back at the transponder, and as it unable to discern between reflections and interrogations, the transponder will be triggered and commence to supply ranges to the reflecting objects (self triggering).



Blue lines indicate reflected transponder replies

By using two different frequencies, the airborne receiver will not accept its own reflections, nor will the ground transponder be triggered by its own transmissions.

7.6 Operating Frequency and Channel Spacing

DME operates in the UHF band in the frequency range of 962 - 1213 MHz with a frequency spacing of 1 MHz. The frequencies are divided into a low and high band with a total of 252 channels. Of the 252 channels there are 126 "X"-channels and 126 “Y” channels.

LOW FREQUENCY BAND

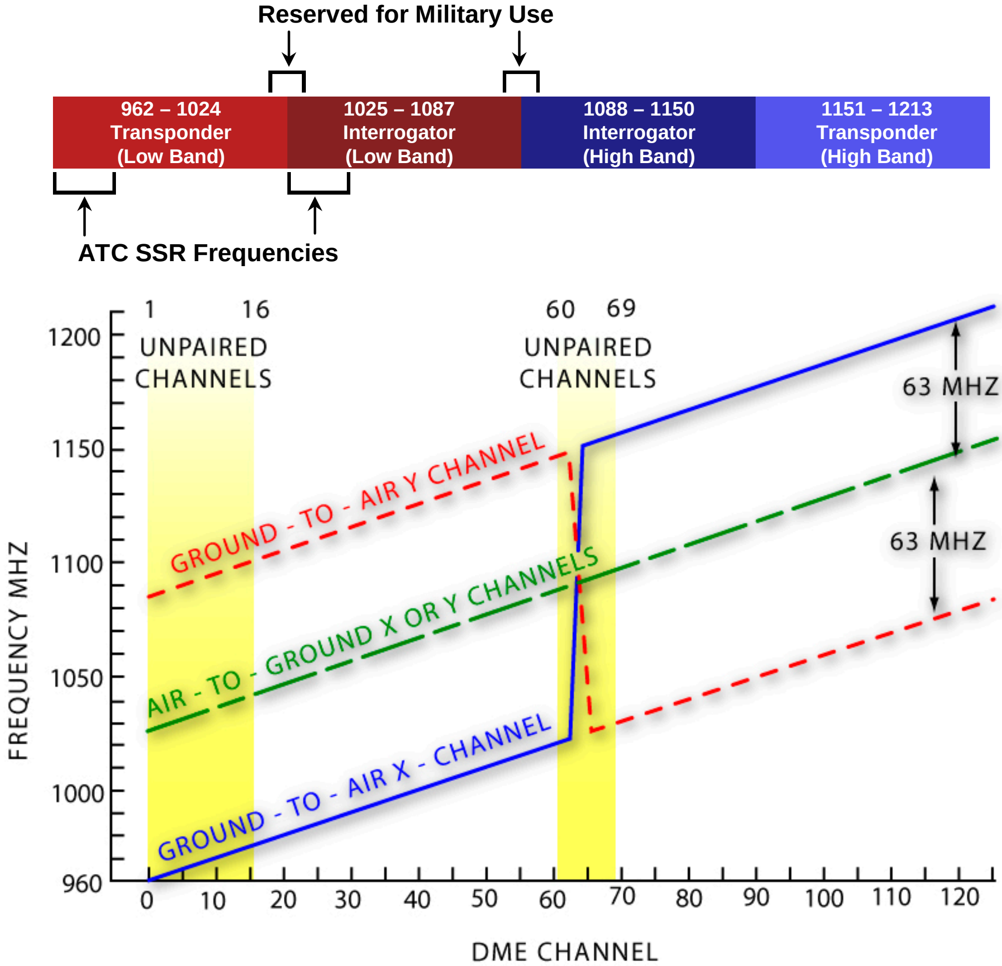
63 channels numbered: 1 - 63
Interrogator: 1025 - 1087 MHz
Transponder: 962 - 1024 MHz
-63 MHz difference

HIGH FREQUENCY BAND

63 channels numbered: 64 - 126
Interrogator: 1088 - 1150 MHz
Transponder: 1151 - 1213 MHz
+63 MHz difference

Interrogator frequencies below 1041 Mhz and transponder frequencies below 978 MHz are reserved for use by military aircraft.

Frequencies 1084 - 1093 MHz and 1021 - 1030 MHz are not used so as to protect ATC SSR frequencies.



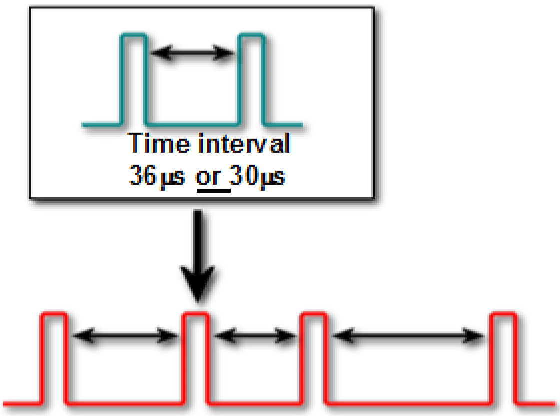
7.6.1 Difference Between X and Y Channels

To prevent an "X"-channel transponder replying to a "Y"-channel interrogation, "X" and "Y" beacons differ as follows:

- Different time interval between pulses of a pair of pulses.
- Different fixed transponder delay time.

7.6.1.1 Time Interval Between Pulses of a Pair

Although interrogation takes place on the same frequencies, the time interval between the two pulses of an interrogation pulse pair is 36 µs instead of 12 µs and the time interval between the two pulses of a reply pulse pair is 30 µs instead of 12 µs.



7.6.1.2 Beacon Reply Delay Time

"X"-beacons have a 50 µs fixed reply delay time while "Y"-beacons have a fixed reply delay time of 74 µs.

Replay Delay Time

As no transponder replies instantly to an interrogation, a fixed and constant time interval is introduced between receiving an interrogation and transmitting the reply. The airborne equipment takes this fixed delay into account when calculating the range.

7.6.2 VOR-DME Frequency Pairing

DME is commonly use in conjunction with VOR, ILS and MLS. To facilitate the use of the two navigation aids together DME channels are frequency paired. **Frequency pairing allows the pilot to use one frequency to tune two navigation aids**. For a VOR/DME the DME frequency is automatically tuned to its appropriate frequency as the VOR frequency is being selected, reducing cockpit workload.

VOR and DME transmitters are usually placed at the same installation and are said to be “co-located”. The advantage being that bearing can be obtained from the VOR and range from the DME providing the aircraft with an instantaneous position fix.

7.6.3 VOR-TACAN Frequency Pairing

VOR may also be paired and co-located with a TACAN. The TACAN is a navigation aid used by military aircraft to obtain bearing and distance information.

The distance element of the TACAN is identical to DME it therefore can be accessed by a civilian aircraft's DME to obtain distance information. If a VOR is present along with a TACAN, the TACAN will be frequency paired with that VOR frequency to allow civilian aircraft to obtain distance information from the TACAN and bearing information from the VOR.

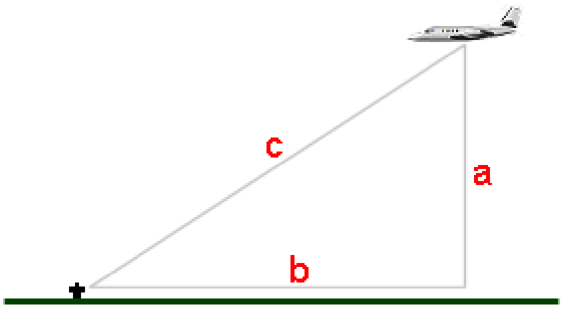
If no VOR is available at the location of the TACAN a 'ghost' VOR frequency will be published. The selection of that frequency by civilian aircraft allows it access to the distance information from the TACAN.

Refering to the Edinburgh TACAN on the Adelaide VNC, there is no physical VOR at the Edinburgh aerodrome and to allow civilian (DME equipped) aircraft to access the distance element of the TACAN, a ghost VOR frequency of 114.7 MHz is used.

7.7 Range

As DME operates in the UHF frequency band, it is a short-range navigation aid which provides coverage up to a maximum range of 200 nm at 30,000 feet.

DME provides slant range, but ground range can be calculated by using the **Pythagoras** theorem.



Pythagoras states that: $\mathbf{c^2 = a^2 + b^2}$ where:

- **a** is the aircraft height in nautical miles.
- **b** is the ground distance in nautical miles.
- **c** is the slant range or DME range in nautical miles.

Aircraft height is normally available in feet and must first be converted into nautical miles before substituting the value in the formula.

This formula can be transposed so that the aircraft height can be calculated from known values of DME slant range and ground range. Note the formula will provide aircraft height in nautical miles, since both the DME and ground range is normally given in nautical miles.

DME ground range calculation: An aircraft at 35,000ft is 60 DME from a ground station. What is the ground range?

Re-arranging the formula gives:

$$(\text{Ground Distance})^2 = (\text{Slant Range})^2 - (\text{Height})^2$$
$$(\text{Ground Distance})^2 = (60)^2 - (5.76)^2$$
$$(\text{Ground Distance})^2 = 3600 - 33.182$$
$$\text{Ground Distance} = \sqrt{3566.818}$$
$$\text{Ground Distance} = \mathbf{59.72nm}$$

Conversion: Feet → nm

1 nm = 6076ft

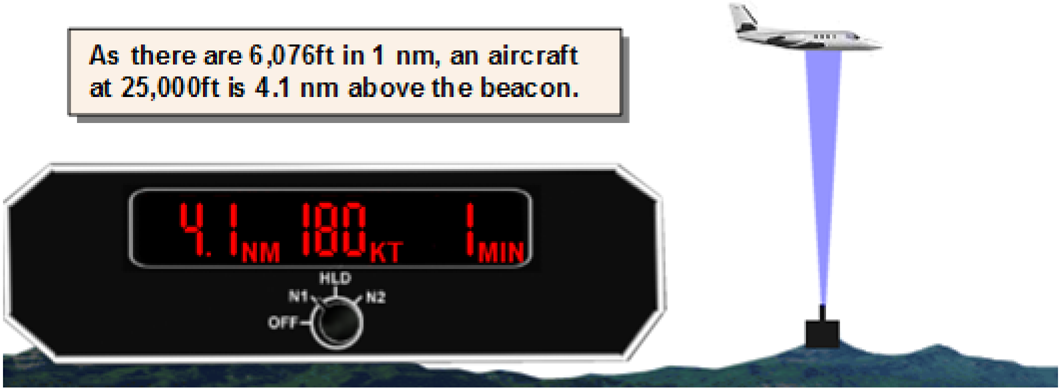
Therefore, to convert 35,000ft to nm:

$$\frac{35,000}{6,076} = 5.76\text{nm}$$

At long ranges the error between slant range and ground distance is practically negligible.

At close ranges inaccuracies are revealed. When overhead a beacon, the DME will indicate the height in nautical miles above the beacon, instead of a 0 nm range.

This means that an aircraft overhead a DME at 25,000ft, will indicate a DME range of 4.1 nm. (Assuming the aircraft is 25,000ft above ground level).



The factors affecting the actual range available from a DME system are the same as those that affect direct waves:

- The aircraft height
- The transmitter height
- Any intervening high ground that will cut off the signals and reduce range.

Range = $1.25\sqrt{H_R} + 1.25\sqrt{H_T}$

H_R = Height of Receiver

H_T = Height of Transmitter

As DME signals are also space waves, the range for different heights is calculated by using the same formula as for theoretical VHF range.

To use DME in the aircraft in Australia, you have to be within the area of rated coverage.

7.7.1 Rated Coverage of DME

The rated coverage for DME beacons can be found in the AIP GEN section and also in the Jeppesen Radio Aids section, page AU1 par 3.2. An extract from the Jeppesen is included below:

3.2 RATED COVERAGE

3.2.1 VOR and DME

Aircraft Altitude (feet)	Range (NM)
Below 5000	60
5000 to below 10,000	90
10,000 to below 15,000	120
15,000 to below 20,000	150
20,000 and above	180

NOTE: The above ranges are quoted for planning purposes. Actual ranges obtained may sometimes be less than these due to facility and site variations.

DME beacons may have additional restrictions on range and/or accuracy limitations due to the location of the specific beacon and the nature of the surrounding terrain.

These additional restrictions affecting the rated coverage of a specific DME can be found in the Jeppesen Radio Aids section, from page AU37 onwards. This is the same table used to find NDB rated coverage. An extract from this table is shown below:

AU-38 RADIO AIDS 27 JAN 17 JEPPESEN

NAVAID LIMITATIONS - AUSTRALIA

LOCATION IDENT	NAVAID	LIMITATIONS
Condobolin, NSW		
CDO	NDB	Range: 40
Coober Pedy, SA		
CBP	NDB	Range: 50
Cooktown, QLD		
CKN	NDB	Range: 40, over water 100.
Dysart, QLD		
DYS	NDB	Range: 80
East Sale, VIC		
ESL	NDB	Range: 140HJ/90HN
IES	DME	Not to be used for enroute navigation

7.7.2 DME Position Fixing Rules

There are specific rules to apply when using the range information from a DME for position fixing purposes or when fixing the aircraft's position as the aircraft flies over the DME beacon and the indications of station passage are observed.

These rules can be found in the Jeppesen Air Traffic Control section, page AU507 par 5.5 and an extract is shown below:

5.5 POSITION FIXING

5.5.1 A positive fix is one determined by the passage of the aircraft over:

a. a NDB; or

b. a VOR station, TACAN site or marker beacon; or

c. a DME; or

d. is one determined by the intersection of two or more position lines which intersect with angles of not less than 45° and which are obtained from NDBs, VORs, localizers or DMEs in any combination. For the purpose of this paragraph, a position line must be within the rated coverage of the aid with the exception that if a fix is determined entirely by position lines from NDBs, the position lines must be within a range of 30 NM from each of the NDBs; or

e. is one determined by GNSS meeting the equipment and pilot requirements of Area Navigation Systems Approval and Operations.

NOTE: GNSS is not a positive fix for separation purposes.

7.7.3 DME Information Available on Charts

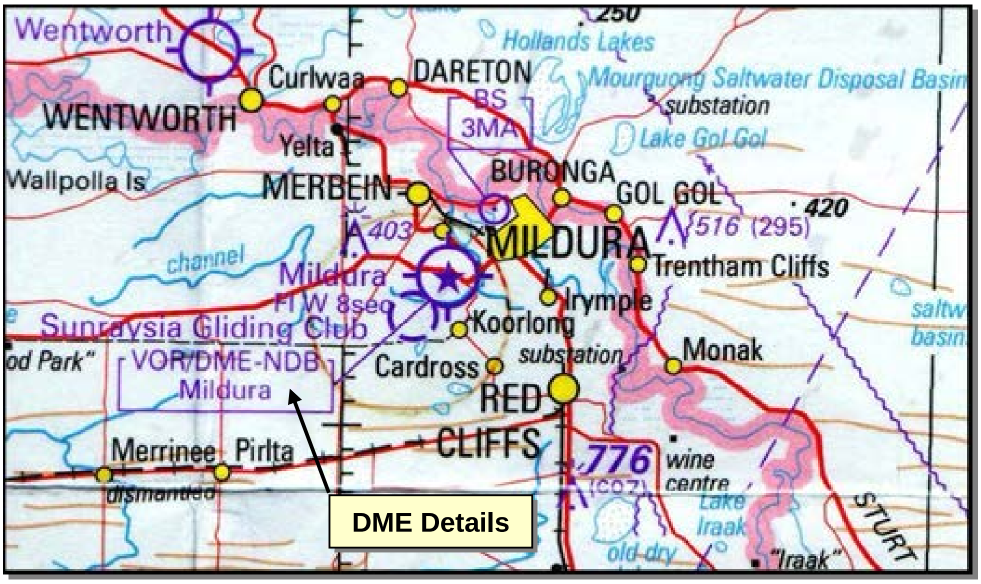
Limited information regarding DME beacons can be obtained from the various aeronautical maps and charts available in Australia.

The amount of information available varies between the charts, with the WAC having the least information, the VNC and VTC having slightly more information and the en-route radio navigation charts from the Jeppesen or Airservices (ERC) having the most information. Examples of the level of information available on each chart type can be found below:

7.7.3.1 DME Information on the WAC

Minimal information is shown on the WAC regarding DME beacons. In the picture below it can be observed that there is DME available at Mildura. The chart does not show the frequency, ICAO identifier or even the symbol of the beacon.

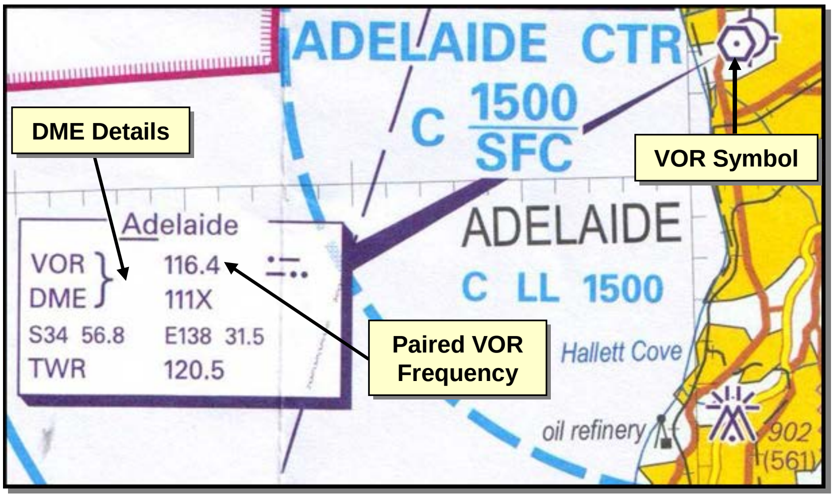
The WAC also does not use the ICAO standard symbol for a DME beacon and would instead use a single circular symbol for any radio beacon type.



7.7.3.2 DME Information on the VNC

On the VNC extract below only the ICAO standard VOR symbol is visible. The DME is also located at the aerodrome and the symbol is not shown to reduce clutter on the map. Refer to the chart legend for an example of the ICAO standard DME symbol. A text box next to the beacon depicts the following:

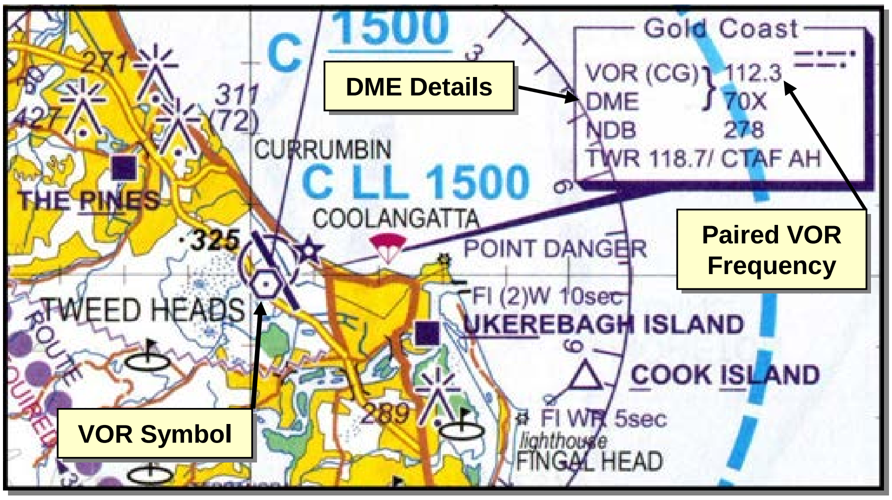
- Paired VOR frequency – 116.4 MHz
- DME channel number – 111X (Take note that the DME channel number is **not used** to select the DME. It is selected through the paired VOR frequency.
- The bracket in the information box indicates that the DME is frequency paired with the VOR – Refer Jeppesen Radio Aids section, page AU1 par 4.



7.7.3.3 DME Information on the VTC

The level of information shown on the VTC is similar to the VNC and the layout is similar depicting:

- Paired VOR frequency – 112.3 MHz
- DME channel number – 70X (not used, use paired VOR frequency for DME)

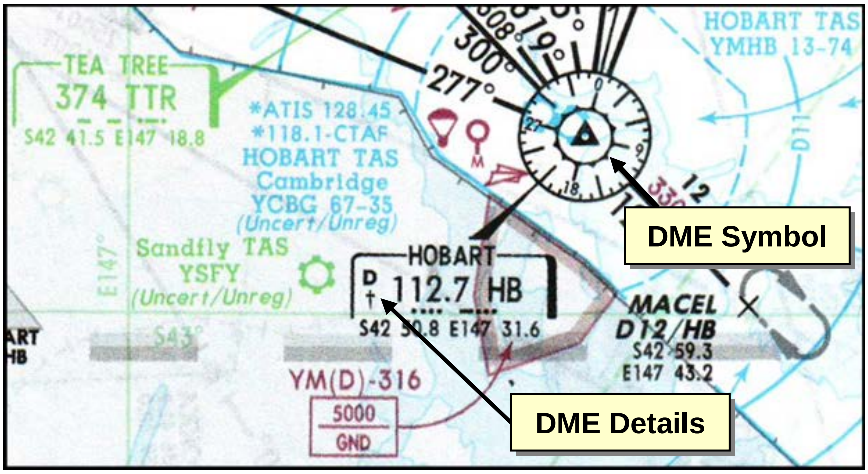


7.7.3.4 DME Information on the Jeppesen En-route Charts

The highest level of beacon related information can be found on the en-route charts. The symbol used for DME on these charts is the same symbol used to depict a TACAN beacon. A text box next to the beacon clarifies whether it is DME or TACAN and depicts the following:

- Plain language name of the VOR – Hobart
- VOR ICAO Identifier – HB
- Paired VOR frequency – 112.7 MHz

- The "D" symbol to the left of the frequency denotes that this VOR is frequency paired with a DME beacon. (DME or TACAN depicted by the gear shaped black symbol).
- Morse Code decode for Hotel Bravo
- Coordinates of the VOR



7.8 Accuracy

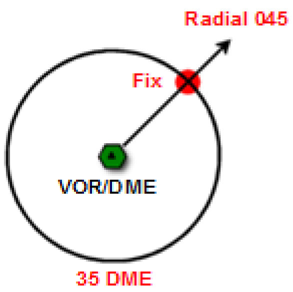
The receiver in the airborne equipment determines slant range by measuring the elapsed time between the transmission of the interrogation signal and the receipt of the reply signal.

The accuracy of the slant range DME measures is of a very high order. DME systems have been designed to produce total system errors that are no greater than ±5 nm or 3% (whichever greater) of the slant range measured between 0 - 200 nm. These errors will produce a worst-case error of 6 nm at a range of 200 nm.

Modern DME systems are capable of providing slant ranges with an accuracy of ±0.2 nm or 0.25% (whichever greater) at ranges between 0 - 200 nm. This means a worst-case error of 0.5 nm for 95% of occasions.

7.9 Uses

- A single DME provides a circular position line and when used in conjunction with a co-located VOR, provides a positive fix.
- DME range indications are very useful while flying instrument approaches.
- When an aircraft reports its position in terms of a bearing (radial) and range from a VOR/DME station, it is easy for ATC to identify such an aircraft on radar.

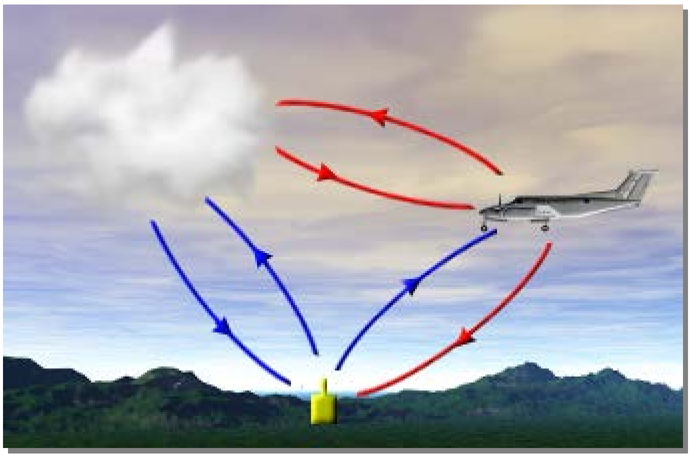


- DME provides positive ranges when two aircraft on the same track have to be separated by ATC.
- When a DME operates in conjunction with an ILS, accurate ranges can be read off to touch-down.
- DME provides a basis for more accurate holding patterns.
- It is possible to carry out area navigation when the DME is coupled to an R-NAV navigation computer.

7.10 Advantages

By now you know very well that DME operates on the secondary radar principle. This has certain distinct advantages.

- Lower power output required. As the same signal does not travel out and back, the power output from both transmitters only has to be sufficient to produce a signal that will be strong enough to travel one way.



- Ground station does not suffer from self-triggering. Due to the fact that two different frequencies are used. This has the added advantage that the airborne equipment does not receive erroneous range information from signals reflected from the surface or clouds.

7.11 Worksheet – Distance Measuring Equipment

1. Which statement best describes the principle of operation of DME?
   - a. Primary radar
   - b. Loop theory
   - c. Timing of signal and reply
   - d. Phase comparison.

2. In which frequency band does DME transmit?
   - a. VHF band
   - b. UHF band
   - c. LF and MF bands
   - d. HF and VHF bands.

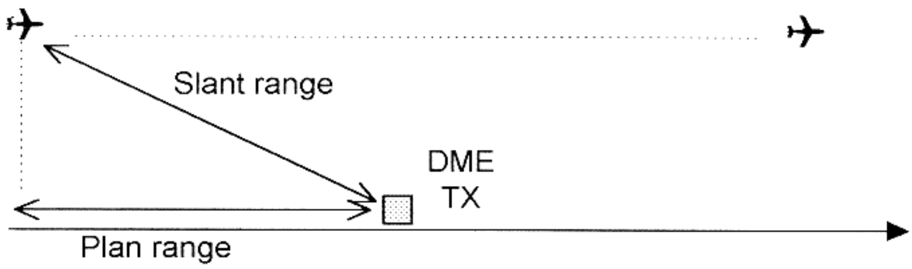
3. What information is available to civilian aircraft from a TACAN?
   - a. Range information only
   - b. Range and bearing information
   - c. Computed groundspeed and time to station
   - d. Bearing information only.

4. What information can DME display?
   - a. Range and bearing
   - b. Plan range and time-to-station
   - c. Slant range and groundspeed
   - d. Bearing and time-to-station.

5. International DME is often frequency paired with VOR. What is the purpose of frequency pairing?
   - a. VOR and DME can transmit on the same frequency.
   - b. Less work for pilot.
   - c. You can select the DME frequency and automatically receive the VOR.
   - d. VOR and DME use the same receiver on the aircraft.

6. Which of the following are factors affecting accuracy of DME?
   a. Thunderstorm error
   b. Night effect
   c. Total ground beacon error
   d. None of the above.

7. An aircraft at plan range 8 nm has a DME reading of 10 nm.



   a. What will the DME read as the aircraft passes over the DME transmitter?
   b. At what range will the aircraft leave the rated coverage of the DME?

7.11.1 Worksheet Answers

1C	2B	3A	4C
5B	6D	7(a) 6nm	7(b) 180nm