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DME-DME Network and Future Air Traffic Capacity

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Distance Measuring Equipment (DME) is based on the radar principle and provides information of distance (slant range) from the aircraft to the ground station. DME collocated with other navigational instrument (i.e. VHF Omnidirectional Range) allows aircraft to determine its location (longitude, latitude, and altitude) during flying. The Federal Aviation Administration's (FAA) has proposed Alternative Position, Navigation, and Timing (APNT) architecture when Global Navigation Satellite System (GNSS) is unavailable with alternate options of VHF Omnidirectional Range (VOR), DME, TACtical Air Navigation (TACAN) etc. This paper discusses the opportunities and challenges related to use of DME as an alternate source of positioning, navigation and timing, in absence of GNSS services. Also, paper proposes DME-DME network as a reliable APNT with Required Navigation Performance (RNP) to meet future air traffic capacity. This paper is based on the work carried out at Department of Aeronautical Engineering, Military Institute of Science and Technology (MIST), Dhaka, between Jun-2011 to Dec-2012, as the part of the studies in Airborne Radio Navigation System and future trends.

Key Words: DME/DME network, Airborne Navigation, APNT Architecture, Avionics and RNP

1. Introduction to DME Operation

Knowledge of the aircraft's position is a basic requirement for air navigation and one means of satisfying this requirement is to present the pilot with bearing and distance information. Bearing is the angular position of aircraft in air measured with reference to the magnetic north. It may be derived from VHF Omni Range (VOR) or Automatic Direction Finding (ADF) systems. Distance information can be derived by Distance Measuring Equipment (DME). There are four basic principles in airborne navigation; these are based on positional parameter computed on-board aircraft though ground based transmitter or data provided directly from ground, airborne or space based transmitter. These navigation principles are,

(a) **ρ-θ:** DME provides slant range, ρ, information of the aircraft. Depending upon this information aircraft could be at any position on the circle of radius ρ from its ground based station. VOR provides bearing, θ, which determines the angular position of aircraft reference to magnetic north. Considering both ρ and θ simultaneously pilot gets a point of intersection between circle and line which fixes the position of the aircraft.

(b) **θ-θ:** If there are two VOR stations, there will be two bearing, θ_1 and θ_2 respectively. These θ_1 and θ_2 angles intersect at a point and pilot can easily get a fix.

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(c) **ρ-ρ:** DME-DME network provides two slant ranges ρ1 and ρ2 of aircraft from two DME ground based station. These two ranges intersect at two points, which means aircraft could be at any of these two points. But pilot has other means of information by which position can be fixed.

(d) **Trilateration principle:** used by Global Positioning System in GNSS.

DME has an airborne interrogator working at 1025-1150MHz and a ground beacon in 962-1213 MHz. These frequencies are divided into 252 channels with 1 MHz separation. Each ground station has a unique fixed channel while aircraft DME interrogator is tunable to any of the frequencies. The interrogator initiates communication with the ground station by sending interrogations of 120 - 150 pulse pairs per seconds (ppps) at ground transponder frequency. The reply from ground station pulse is ±63 MHz apart from the interrogation pulse (Nagaraja N S 1996). The reply provides rho (slant range) data to aircraft. Hence,

$$D = (\Delta t - t_{pr})/T$$

Where,

D = Slant Distance in nautical mile

Δt = total elapsed time in seconds

T = Radar mile in second per nautical mile.

Here, radar mile is the time for a radio signal to travel a distance of one nautical mile (1852 m) and return to originator. A radar mile is 12.35 μs/NM.

2. Signal Format of DME

The DME signal format consists of a pair of interrogation pulses transmitted at specific pulse repetition period. Interrogation pulses after a finite propagation delay,t_{pd}, reach the ground beacon. Ground beacon processes the interrogation pulses in a processing time, t_{pr}= 50 µs and transmits reply pulse pair back to the interrogating aircraft at frequency ±63 MHz of airborne interrogation pulse pair frequency. After a second propagation delay the reply pulses reach the aircraft. The pulse is detected and decoded by airborne DME receiver to calculate slant distance between aircraft and ground beacon. DME requires two channels to function; an up link and down link. The technique to increase the DME channels is to divide DME into X and Y channels. For X channels, frequency of the reply pulse is 63 MHz above and for Y channels, frequency of the reply pulse is 63 MHz below the interrogation frequency. Since the same interrogation frequency is used for X and Y channels, spacing between two interrogation pulses are different. It is 12 µs for X channel and 36µs for Y channel. The time delay between receipt of an interrogation and the transmission of a reply for an X channel is 50 µs. Figure 1, shows the timing diagram of integration and reply pulses for an X Channel DME (Helfrick Albert 2010; Jeppesen 2006). Here,

t_{pg} = Pulse pair gap time = 12 µs

t_{wt} = Pulse width time = 3.5 µs

Average PRT (pulse repetition time) = 16 ppps

t_{pd} = Propagation delay

t_{pr} = Processing time at ground transponder = 50 µs

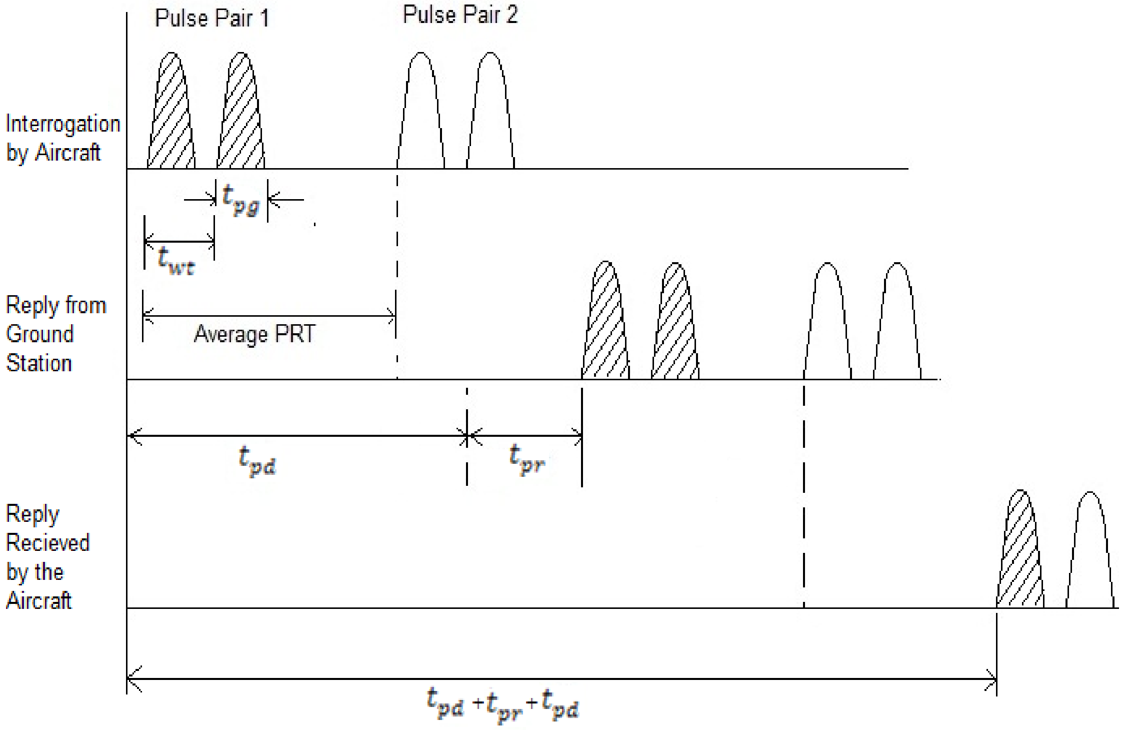

Figure 1: DME Pulse Waveform

3. Effect of Electromagnetic Interference on DME

The slant range calculated by DME is vital for flying the aircraft either under manual or autopilot control. The slant range is a decisive factor for an aircraft to take appropriate maneuvers during take-off, landing and en-route phases of flying. It is also vital for navigating an aircraft to a particular destination or fix geographical location from a specific beacon. As DME is operating in VHF band, it may be susceptible or can be affected by manual or atmospheric noise. Effect of noise on DME has been studied (Nagaraja N S 1996) in four conditions and result is summarized in Table 1,

Table 1: Effect of Different Noise on DME

Noise	DME Signal Frequency (MHz)	Avg. Power Expected (dBm)	Average Power after Noise Effect (dBm)	Result
a) No noise affect	1025	-64.751	-64.752	DME signal is not degraded
b) Pulse Noise Affect	962	-64.751	-13.179	DME is degraded very badly but it for a very short time.
c) Narrow band Noise Affect	962	-64.751	-60.362	DME signal is not degraded badly
d) Fluctuation Noise Affect	962	-64.751	-69.568	DME signal is not degraded badly

From Table-1 it is clear that due to electromagnetic interference the performance of the DME is not degraded obviously. The performance of DME is degraded for a very short time, so the receiver has a good compatibility to pulse interference.

4. APNT Concept of Operations

Global Navigation Satellite System (GNSS) is susceptible to interruption and degradation of precision by manmade and atmospheric effects. GNSS interference would represent a common mode failure, where both navigation and surveillance are lost. For this reason, FAA has recently initiated a program pursuing an Alternative Position, Navigation, and Timing (APNT) service that will continuously provide RNAV (Area Navigation)/RNP (Required Navigation Performance) capability during the GNSS outage. The concept of operations for APNT is built on four pillars (Chengbin Fu, Yan Liu, Donglin Su & Xi Chen 2011) which are:

a) Safe recovery (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under Instrument Flight Rule (IFR) operations.
b) Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area.
c) Continued dispatch of air carrier operations to deny an economic target for an intentional jammer.
d) Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event.

Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event. The focus on APNT research in respect of DME utility is as following points (FAA 2012):

a) Extend coverage of distance measuring equipment (DME) that can be used to provide most commercial aircraft with an RNAV capability independent of GNSS,
b) Define a minimum operating network of ground-based navigation aids to safely recover aircraft in the presence of interference, and
c) Examine the feasibility of being able to derive position based on the use of precision timing, independent of the GNSS performance.

5. APNT Performance Requirements

The accuracy requirement for navigation, i.e. Total System Error (TSE), is sum total of Navigation System Error (NSE) and Flight Technical Error (FTE). The accuracy requirement can be translated to Horizontal Dilution of Precision (HDOP) using the following relationship (Euiho Kim 2012)

$$HDOP_{Nav} = \sqrt{\frac{TSE^2 - FTE^2}{4\sigma_{range}^2}}$$

An APNT system would need to support at least Required Navigation Performance (RNP) 0.3 to sustain departure and arrival paths at high-density airports and support navigation to an ILS intercept for aircraft recovery in the presence of interference. RNP 0.3 is needed in the terminal airspace to increase the number of arrival and departure paths available to manage the density of traffic. An RNP of 0.3 means the aircraft navigation system must be able to calculate its position to within a circle with a radius of 3 tenths of a nautical mile.

6. DME for APNT- ‘P-P’ Principle of Radio Navigation

DME/DME has many desirable features for providing APNT service. It can support RNAV en-route operations when used with an inertial reference unit (IRU). Although in future high-density airspace, a beacon may need to support 260 aircraft (ADS-B Technical Link Assessment Team 2001), but newer DME can transmit more replies, which will improve capacity (Sherman C. Lo. Engi 2011).The coverage gaps against navigation accuracy requirement using the currently deployed by DME /DME networks exist within RNP 0.3 (Euiho Kim 2012) which is equal to FAA proposed APNT required performance.

In DME/DME ranging system transmitter-receiver geometry influences position precision. In the figure 2 uncertainty of the airborne receiver’s position indicated by the pattern area. When two DME transmitters are far apart, position uncertainty is small (low dilution of precision) and when two DME transmitters are very close position uncertainty is high (high dilution of precision). So Dilution of Precision (DOP) is very much related to accuracy for the navigation. According to FAA's APNT performance requirements the accuracy requirement for navigation, at least Required Navigation Performance (RNP) should be 0.3 and Horizontal Dilution of Precision (HDOP) influences a lot on this RNP value.

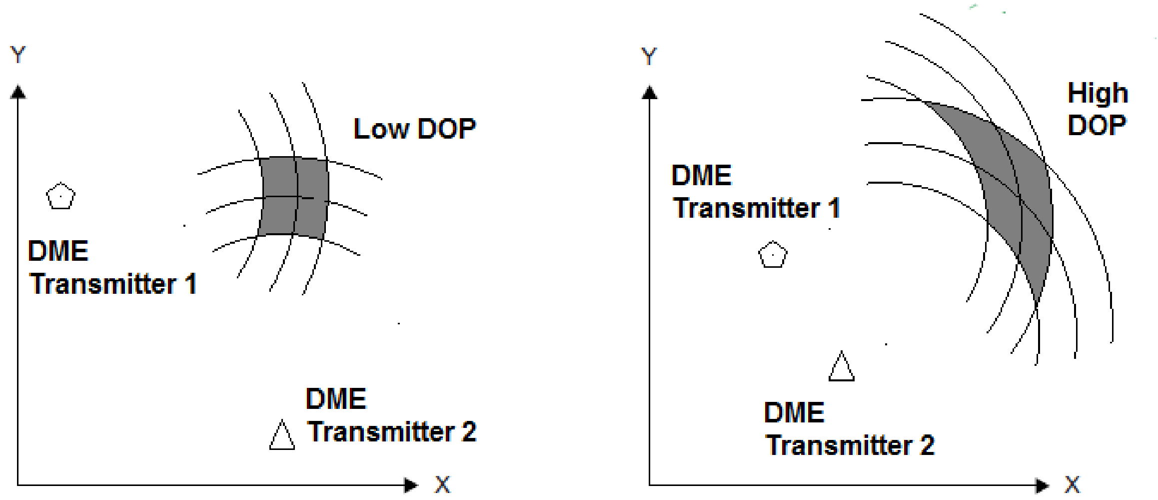

Figure 2: Uncertainty of Receiver's Position Depending on Transmitter's Geometry

According to FAA's APNT performance requirements RNP 0.3 is required and for RNP 0.3 at least reply efficiency should be 70%. Reply efficiency in the two optimized DME-DME networks has been studied from a 5 minutes simulation period (Euiho Kim 2012) and from simulation result the average REs of the DME networks are 77% for navigation which is acceptable according to FAA.

7. Conclusion

DME is less affected or affected for a very short time by any type of electromagnetic interference. Also from DME/DME positioning performance analysis, availability analysis and efficiency analysis it is clear that DME/DME network fulfills FAA's APNT required navigation performance. In comparison to other FAA-proposed APNT architectures, namely DME pseudo lite network and passive Wide-Area Multilateration, DME/DME network is more attractive for navigation back-up, as this solution requires no change to avionics used by nearly all commercial aircraft, thus reducing equipage costs to private companies. It can be concluded that despite GNSS development DME is not going to be obstacle in near future for an alternative means of providing a Next Generation Air Transportation System Alternative Positioning, Navigation and Timing (APNT) service to support the safe, secure, and efficient operations of aircraft.

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