SECONDARY RADAR SYSTEMS

Secondary Surveillance Radar (SSR) & Distance Measuring Equipment (DME)

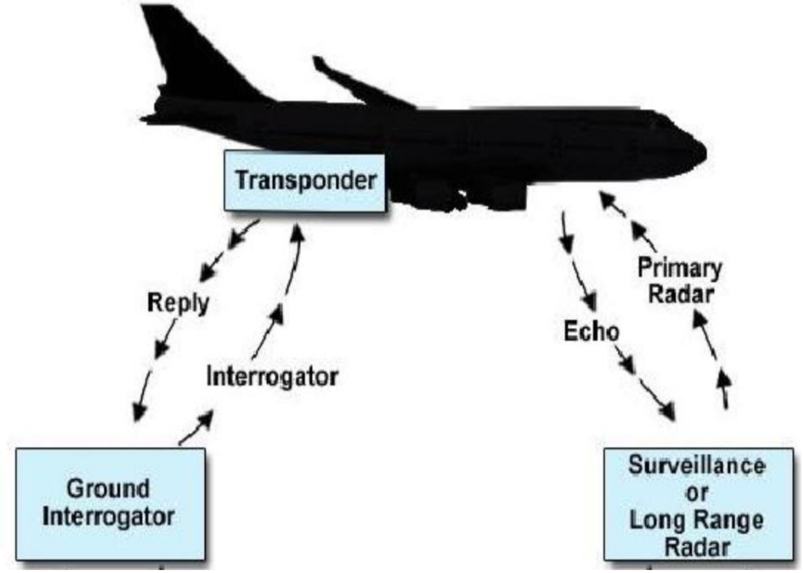
ECE 514 – RADAR & SATELLITE ENGINEERING

Wednesday, November 19, 2025

RECAP: PRIMARY Vs SECONDARY RADAR

1. **Primary radar** is a system where the ground-based antenna transmits a radar pulse, then listens for echo that is reflected from targets.

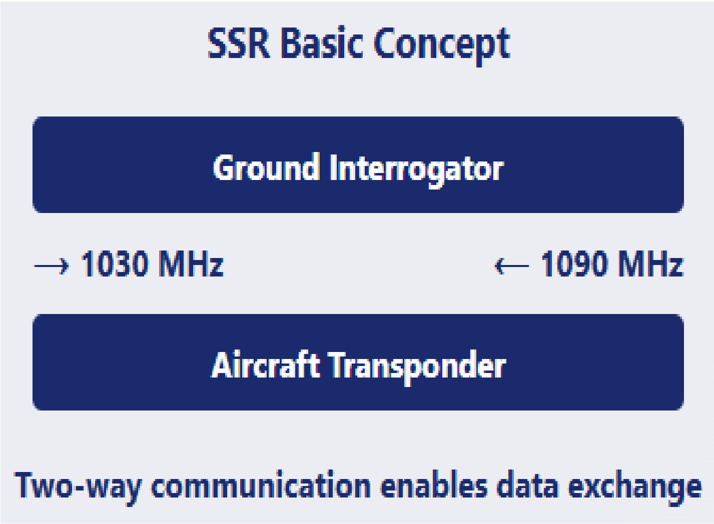
2. **Secondary radar** transmits pulses and receives digital data coming from the aircraft transponder. The transponder responds to interrogation by transmitting coded reply signal back containing information such as altitude, identification code etc.



(a) Secondary Radar (b) Primary Radar

SECONDARY SURVEILLANCE RADAR (SSR)

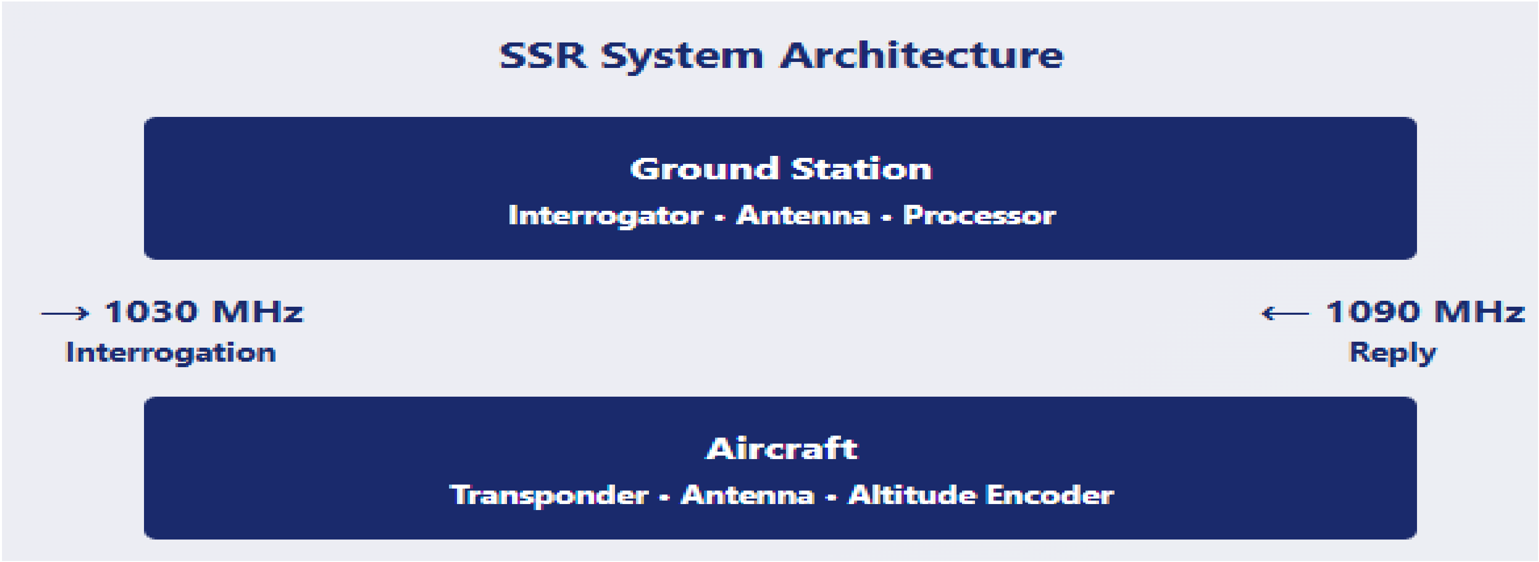
1. **Secondary Surveillance Radar (SSR)** is a radar system used in air traffic control (ATC) that enhances primary radar by enabling two-way communication between ground stations and aircraft.
2. **Unlike primary radar**, which only detects and locates objects, SSR can:
    1. Identify specific aircraft
    2. Determine aircraft altitude
    3. Exchange additional data with aircraft
3. **SSR operates in the L-band (1030 MHz for interrogation, 1090 MHz for reply)**.



SSR COMPONENTS

The SSR system consists of two main components:

1. **Ground Interrogator**
   a) Transmits interrogation signals at 1030 MHz
   b) Receives and processes replies from aircraft
   c) Typically co-located with primary radar
2. **Aircraft Transponder**
   a) Receives interrogation signals
   b) Transmits reply signals at 1090 MHz
   c) Contains aircraft identification and altitude data



SSR OPERATION

The SSR system operates through a precise **interrogation-reply cycle**:

1. **Interrogation:** Ground station transmits coded pulses at 1030 MHz
2. **Reception:** Aircraft transponder receives and decodes the interrogation
3. Reply: Transponder sends encoded data back at 1090 MHz
4. **Processing:** Ground station processes the reply to extract information.

5. **Key technical aspects:**
   - Precise timing to calculate distance (slant range)
   - Antenna rotation provides azimuth information
   - Selective addressing in Mode S

SSR MODES

SSR operates in several modes, each serving different purposes:

1. **Mode A**
   a) Provides 4-digit aircraft identity code (4096 possible codes)
   b) Used for basic identification
2. **Mode C**
   a) Automatically reports aircraft altitude from encoding altimeter
   b) Uses Gillham code (11-bit)
3. **Mode S** (Selective)
   a) Advanced mode with discrete addressing
   b) Allows data link communications
   c) Reduces frequency congestion and interference
   d) Provides enhanced surveillance capabilities

Modern systems typically use Mode S, which includes:

- 24-bit aircraft address (unique worldwide)
- Extended squitter for broadcasting position
- Selective interrogation to specific aircraft

SSR LIMITATIONS & CHALLENGES

Despite its advantages, SSR has several limitations:

1. **Frequency Congestion**
   - All aircraft use the same reply frequency (1090 MHz)
   - Can lead to interference in dense airspace
2. **Garble**
   - Overlapping replies from multiple aircraft
   - Makes decoding difficult or impossible
3. **Fruit** (False Replies Unsynchronized in Time)
   - Replies from aircraft interrogated by other stations
   - Creates false targets on radar display
4. **Multipath Effects**
   - Signal reflections cause position errors
5. **Line-of-Sight Limitation**
   - Requires direct path between interrogator and transponder

DISTANCE MEASURING EQUIPMENT(DME)

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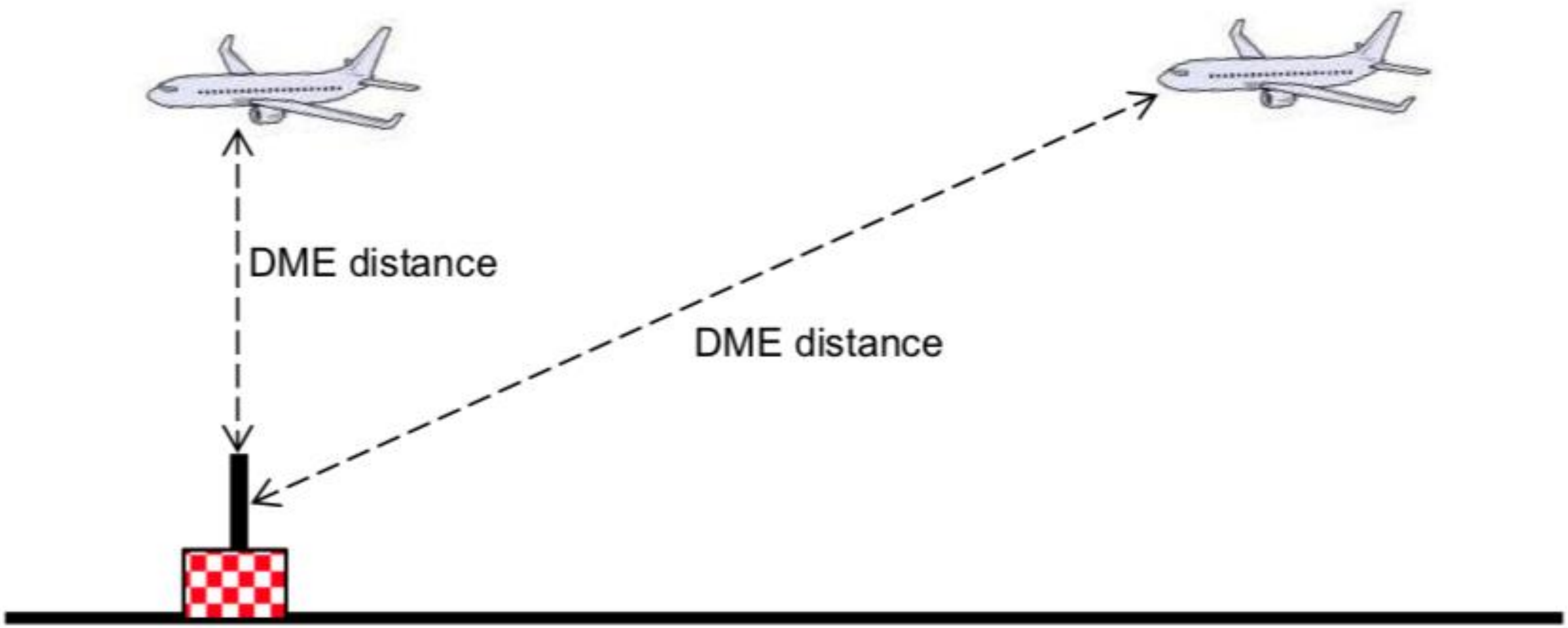
WHAT IS DME IN AVIATION?

1. **Distance Measuring Equipment (DME)** is a radio navigation technology used by aircraft to determine their slant range distance from a ground-based navigational aid.
2. **Key characteristics of DME:**
   a) Operates in the UHF band (962-1213 MHz)
   b) Provides continuous distance information
   c) Typical accuracy of ±0.1 nautical miles or 3% of distance
   d) Operational range up to 200 nautical miles
3. **DME is a critical component of:**
   a) Area navigation (RNAV) systems
   b) Instrument approach procedures
   c) En-route navigation

DISTANCE MEASURING EQUIPMENT (DME DEFINITION)

- **DME (or Distance measuring Equipment)** is a transponder-based radio navigation technology used to display the slant range by timing the propagation delay of a UHF signal.



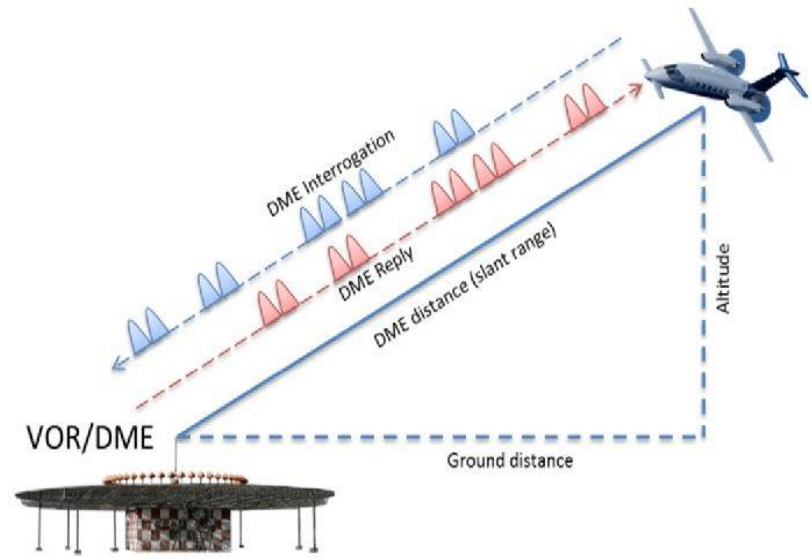
PRINCIPLE OF OPERATION (1)

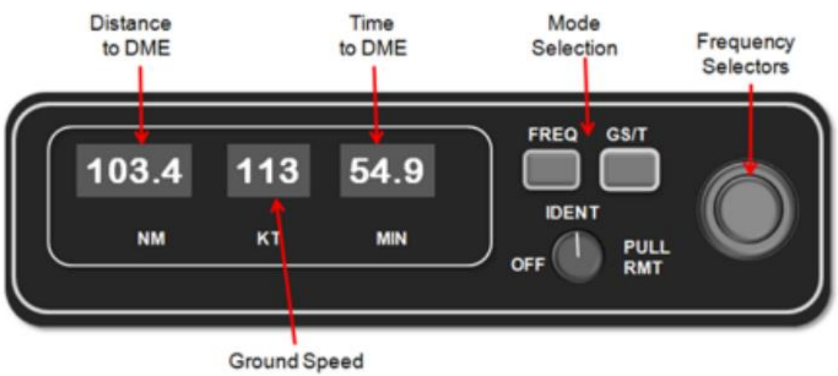
1. Distance Measuring Equipment operates on principle of secondary radar.

2. A ground beacon continuously responds to trigger pulses received from airborne interrogators.

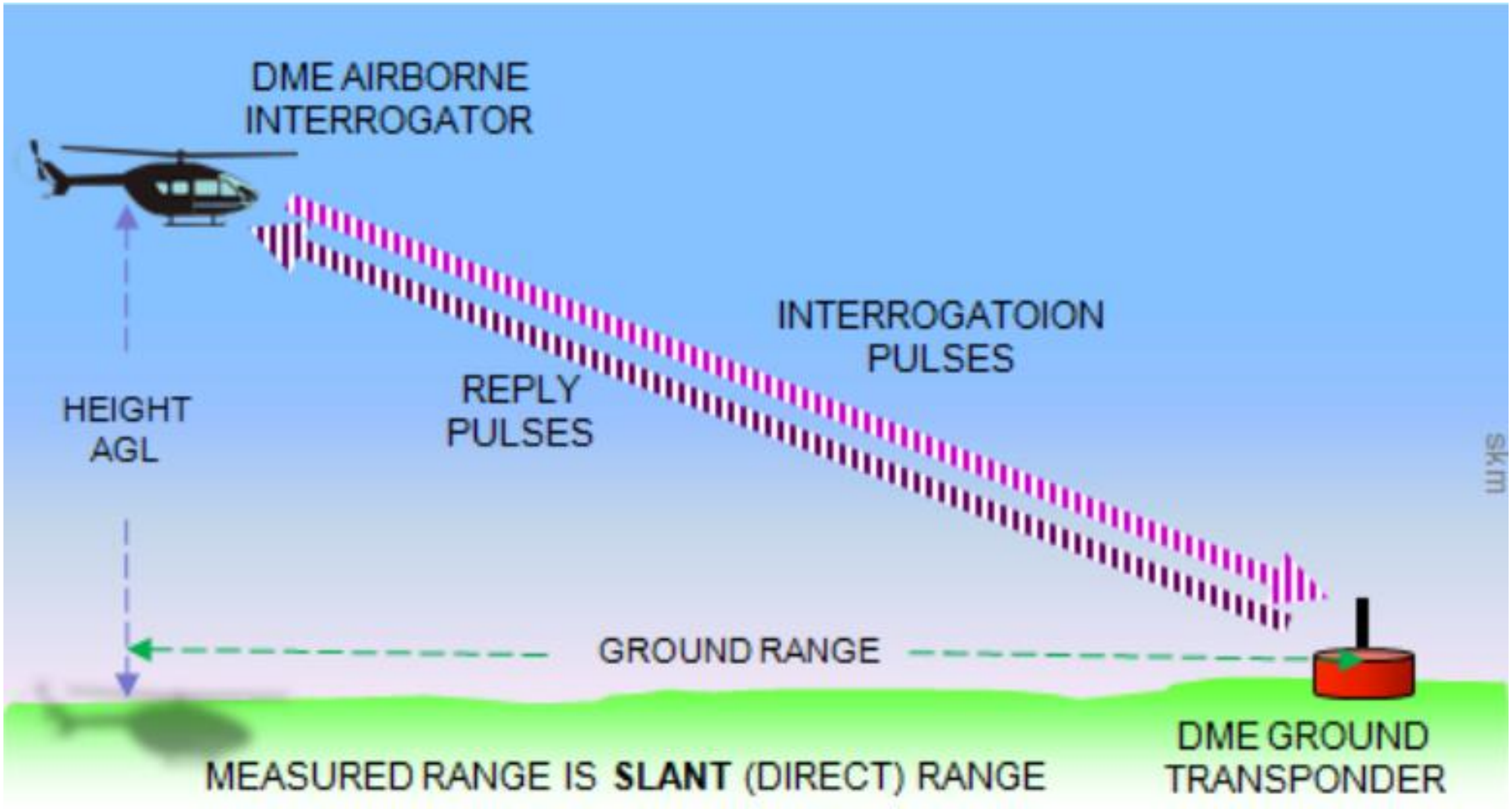
3. Airborne equipment receives all responses, determines the ones related to its transmissions and finds time delay between firing of interrogation pulses and corresponding reply pulses.

4. This delay is displayed as slant (direct) range at the airborne equipment as distance from the ground station.





PRINCIPLE OF OPERATION (2)



LOCATION OF DME EQUIPMENT

1. Ground transmitter beacons of DME are co-located with **V**HF **O**mni-directional **R**ange) **VOR** equipment at all major aerodromes and enroute reporting points.

2. The system operates on frequencies between 960 MHz and 1215 MHz in the UHF band.

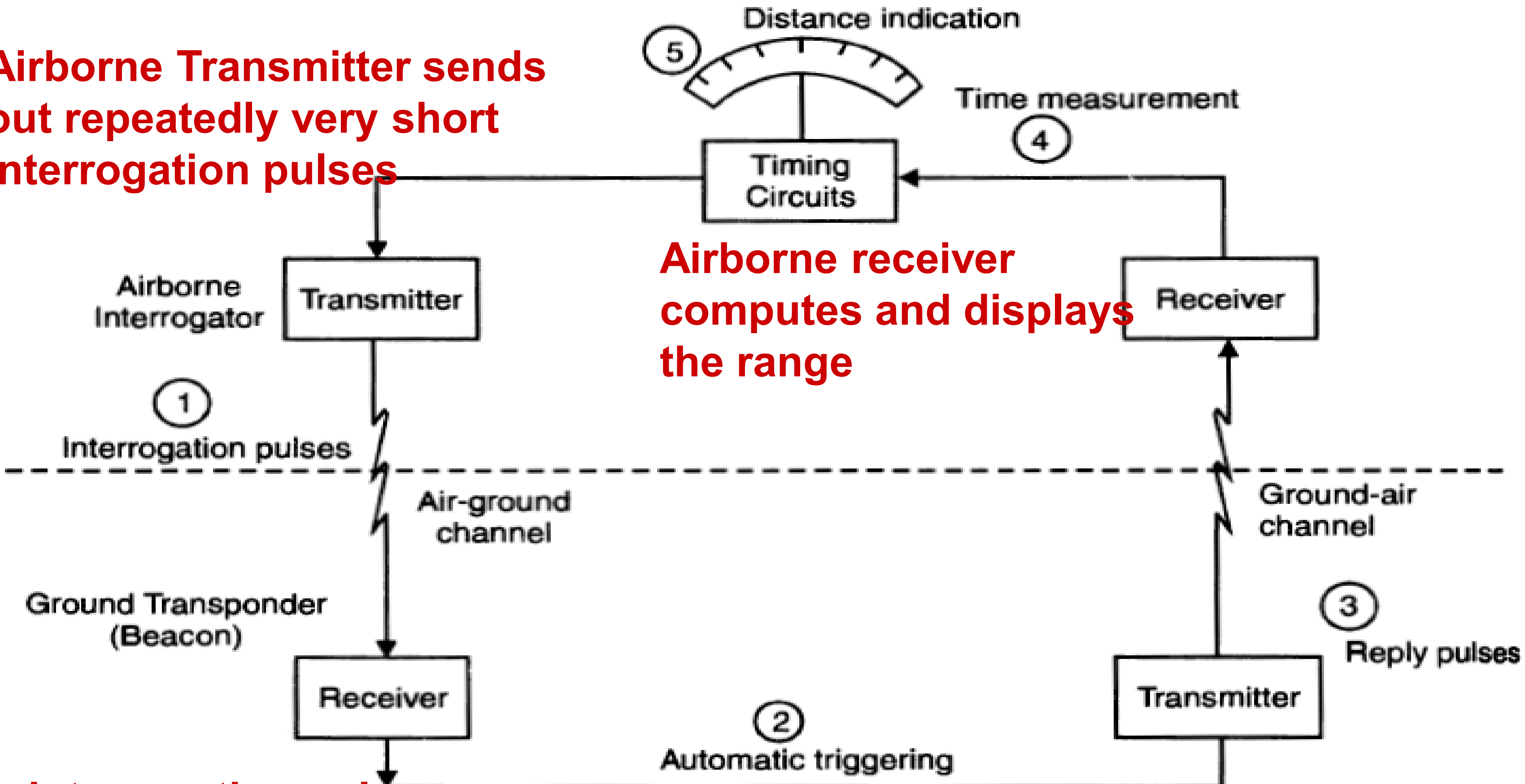
3. DME provides line of sight range.

4. Each ground station transmits its unique identification signal comprising three bytes.

BASIC BLOCK DIAGRAM OF DME SYSTEM

Airborne Transmitter sends out repeatedly very short interrogation pulses

Airborne receiver computes and displays the range



interrogation pulses are picked up by Ground Transponder

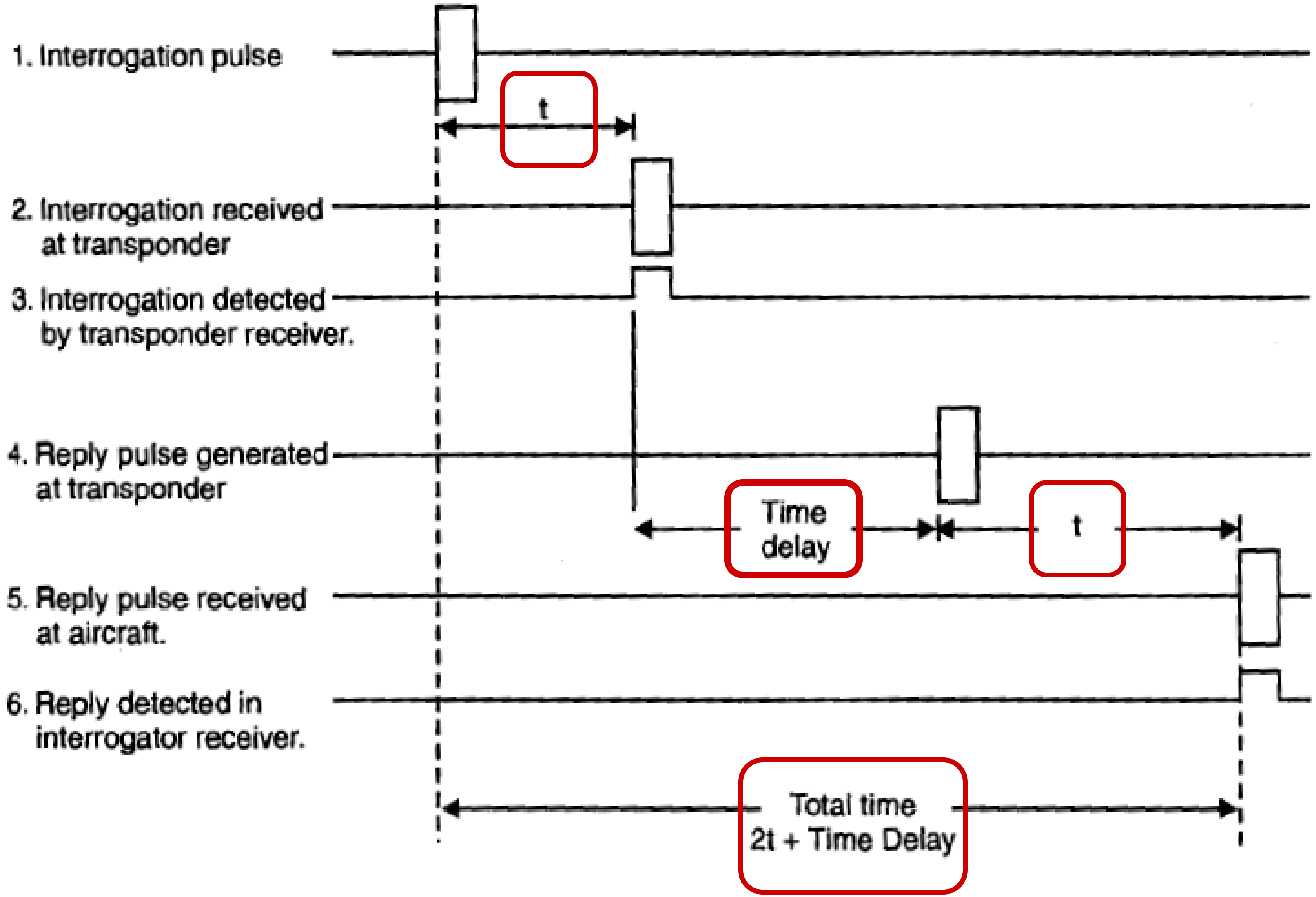
Transponder Responds with reply pulses

DME MODES OF OPERATION

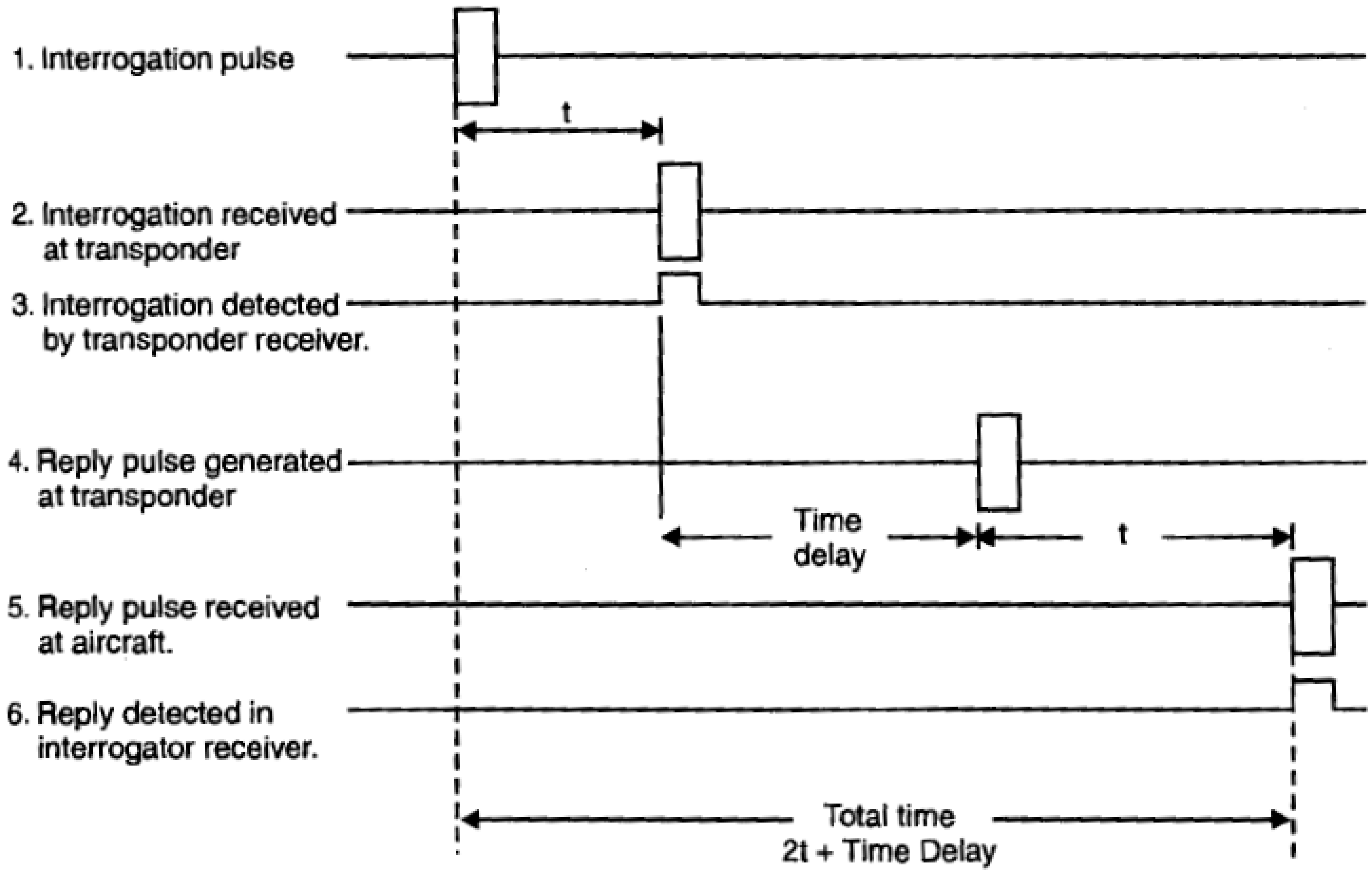
- **SEARCH MODE:** DME transmits interrogates at a higher rate typically 150 per second

  When Aircraft receives at least 65% replies, it changes to Track Mode.
- **TRACK MODE:** Interrogation rates reduce to approximately 30 per second.
- This allows more aircrafts to use the DME near airports.

SYSTEM TIMING



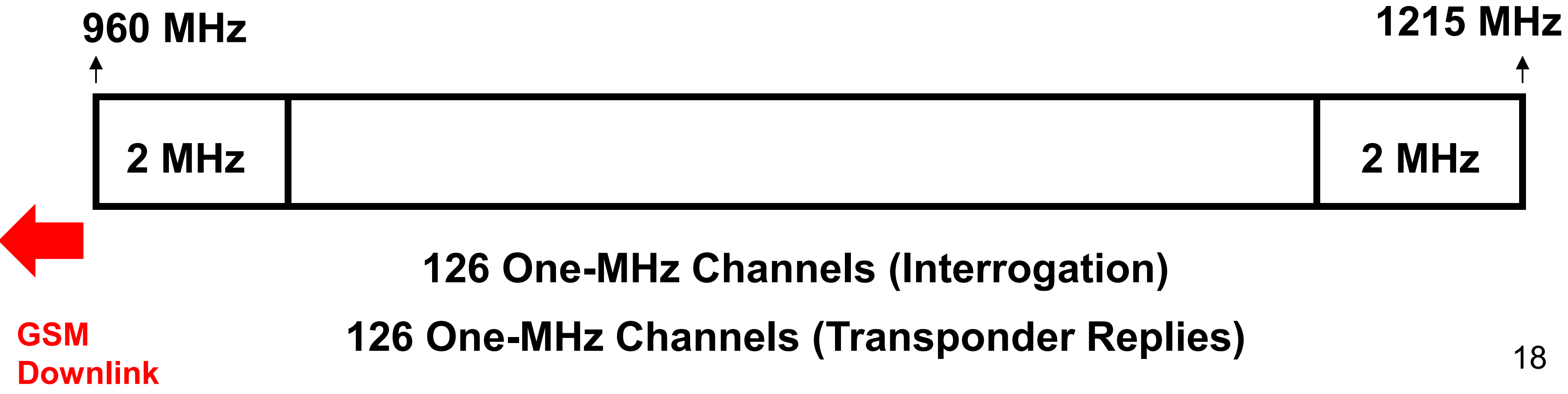
RANGE CALCULATION



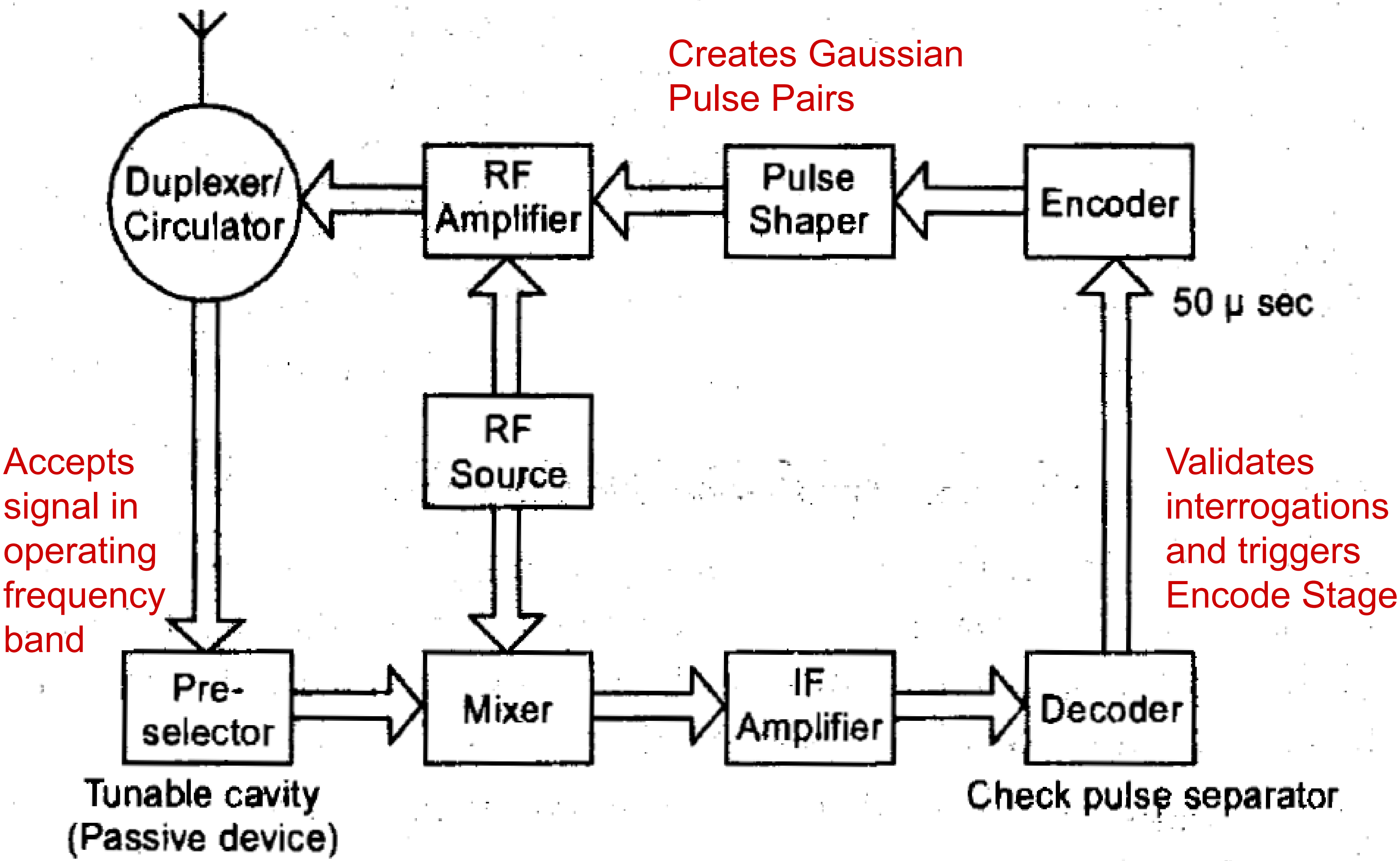
Range, R = c x (2t–t_d)

DME FREQUENCY RANGE

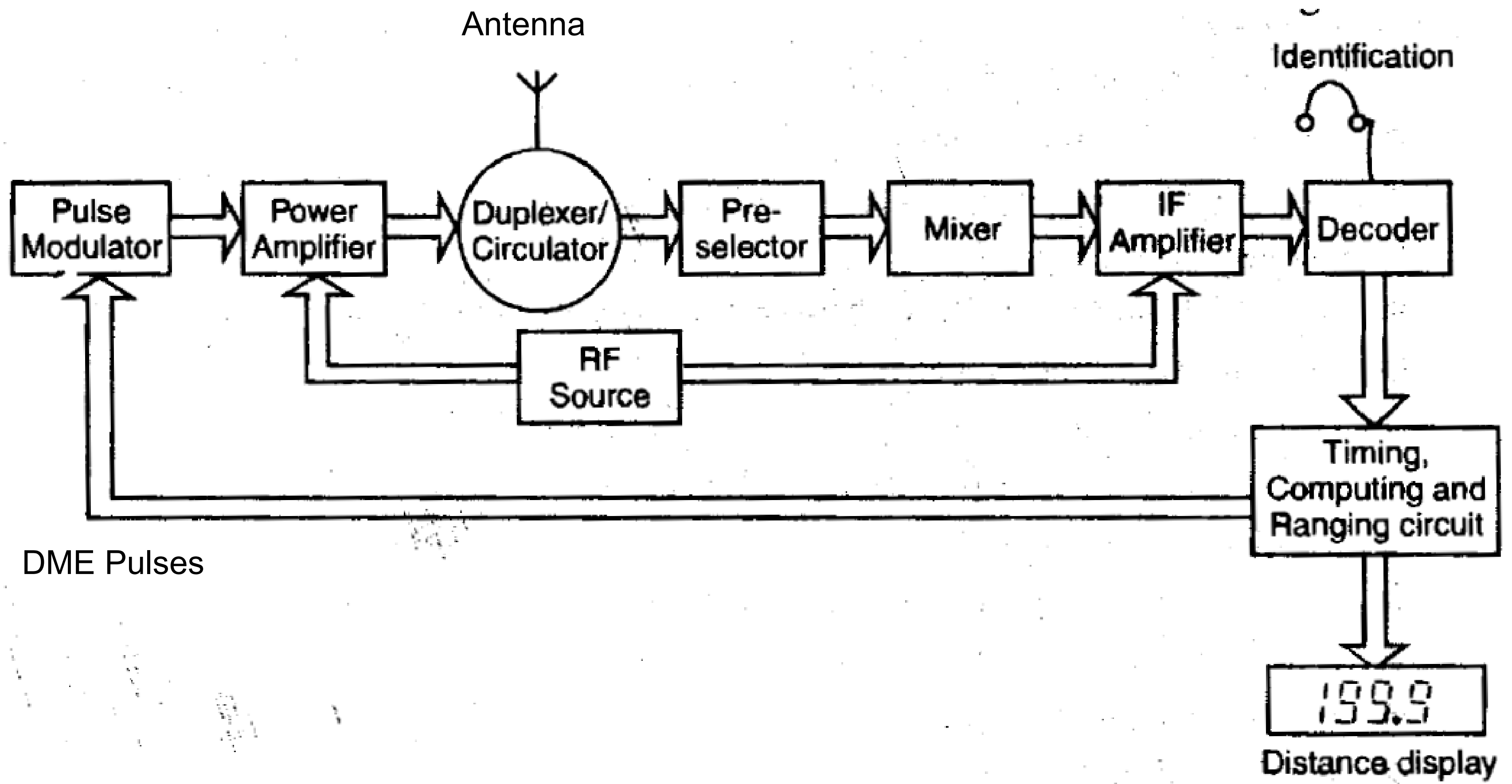
- DME frequency band: 960 – 1215 MHz
- Lowest operating Frequency – 962 MHz
- Highest Operating Frequency – 1213 MHz
- Guard Bands of 2 MHz on either side.



BLOCK DIAGRAM OF TRANSPONDER

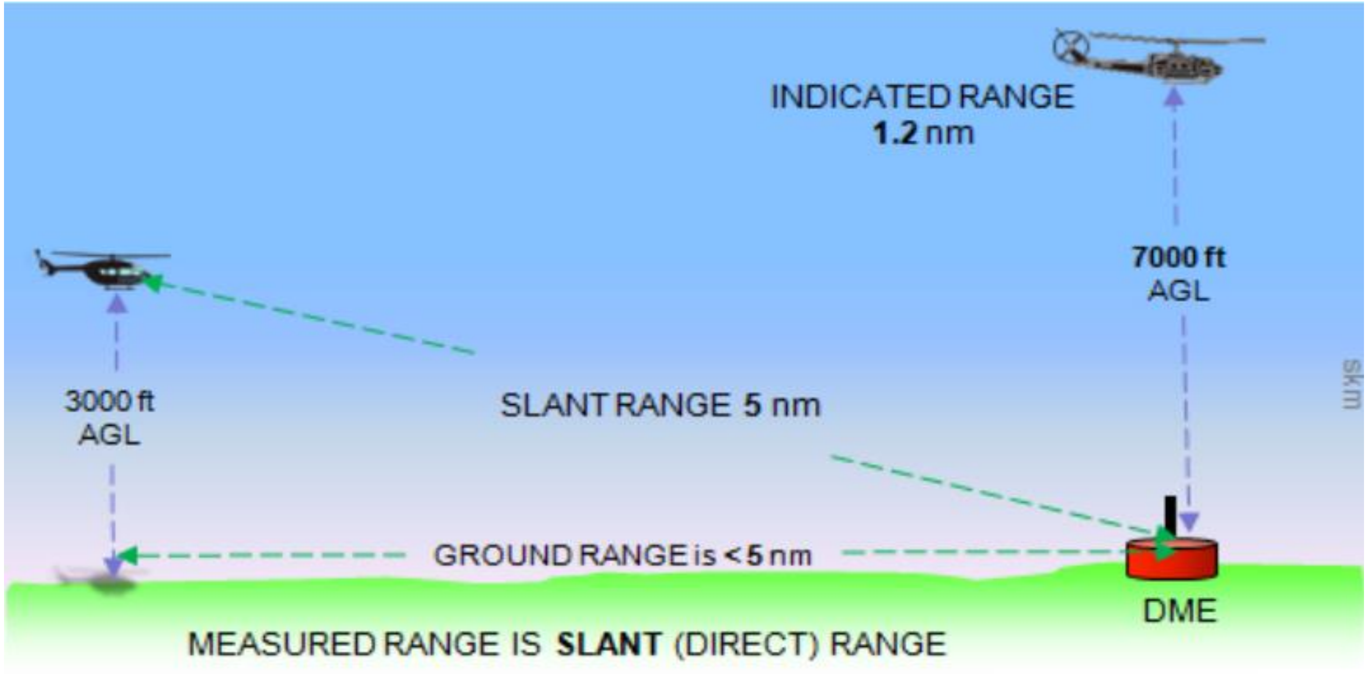


BLOCK DIAGRAM OF AIRCRAFT INTERROGATOR



SLANT VS GROUND RANGE

- Flying overhead DME station will not indicate zero range, but the height above ground as the distance to beacon.



SUMMARY OF TECHNICAL SPECIFICATIONS

- DME operates within specific technical parameters:
- **Frequency Range**: 962-1213 MHz (UHF band)
- **Channel Spacing**: 1 MHz
- **Number of Channels**: 252 (126 X and 126 Y channels)
- **Pulse Width**: 3.5 μs
- **Pulse Spacing**:
  - X-channel: 12 μs
  - Y-channel: 36 μs
- **Ground Station Delay**: 50 μs fixed
- **Interrogation Rate**: ~30 pulses per second (variable)
- **Accuracy**: ±0.1 NM or 3% of distance, whichever is greater
- **Range**: Up to 200 NM (line-of-sight limited)
- Frequency pairing with VOR:
- DME channels are paired with VOR frequencies
- When a pilot tunes a VOR frequency, the corresponding DME channel is automatically selected
- This integration simplifies cockpit operation

DME ACCURACY & LIMITATIONS

While DME is a highly reliable navigation aid, it has specific limitations:

1. **Line-of-Sight Limitation**
   - UHF signals require direct path between aircraft and ground station
   - Maximum range limited by Earth's curvature and antenna height
2. **Slant Range Error**
   - DME measures straight-line distance, not horizontal distance
   - Error becomes significant when close to the station at high altitude
3. **Frequency Congestion**
   - Limited number of channels (252 total)
   - Can be challenging in dense airspace
4. **Multipath Errors**
   - Can cause inaccurate distance measurements

SSR & DME INTEGRATION

SSR and DME are often integrated in modern aviation systems to provide comprehensive surveillance and navigation capabilities:

1. **ATC Surveillance**
   - SSR provides identification, position, and altitude
   - DME can supplement position accuracy in certain applications
2. **Area Navigation (RNAV)**
   - DME-DME positioning provides accurate area navigation
   - SSR Mode S can transmit position data to ground systems
3. **Approach and Landing**
   1. DME provides precise distance information for approach procedures
   2. SSR enables positive identification and monitoring by Air Traffic Controllers

SSR VS. DME COMPARISON

PARAMETER	SECONDARY SURVEILLANCE RADAR (SSR)	DISTANCE MEASURING EQUIPMENT (DME)
Primary Function	Aircraft identification and surveillance	Distance measurement for navigation
Frequency Band	L-band (1030/1090 MHz)	UHF (962-1213 MHz)
Communication Type	Interrogation-Reply (Two-way)	Interrogation-Reply (Two-way)
Information Provided	Identity, altitude, position	Slant range distance only
Typical Range	200-250 NM	200 NM
Accuracy	Position: 0.05-0.5 NM, Altitude: 100 ft	±0.1 NM or 3% of distance
Number of Channels	Modes (A, C, S) rather than channels	252 channels (126X + 126Y)
Primary Users	Air Traffic Control	Pilots/Navigation Systems
Integration	Often with primary radar	Often with VOR (VOR/DME)

KEY SIMILARITIES BETWEEN SSR & DME

Key Similarities:

1. Both use interrogation-reply principle
2. Both are line-of-sight systems, i.e use space wave communication
3. Both are critical for modern aviation
4. Both can be affected by similar interference issue

SIGNAL PROCESSING IN SSR & DME

Both SSR and DME rely on sophisticated signal processing:

1. **Pulse Detection and Validation**
   - Detection of valid pulse pairs amid noise
   - Validation of proper pulse spacing and shape
2. **Time Measurement**
   - Precise timing of pulse transmission and reception
   - Compensation for system delays
3. **Error Correction**
   - Detection and correction of transmission errors
   - Rejection of multipath and interference
4. **Data Encoding/Decoding**
   - Encoding of identity and altitude data in SSR
   - Channel identification in DME

MODERN DEVELOPMENTS

Both SSR and DME continue to evolve with new technologies:

1. **ADS-B (Automatic Dependent Surveillance-Broadcast)**
   - Aircraft broadcast position derived from GPS
   - Uses SSR Mode S transponders (1090 MHz)
   - Provides more accurate and frequent position updates
2. **Multilateration (MLAT)**
   - Uses multiple SSR receivers to precisely locate aircraft
   - Time Difference of Arrival (TDOA) techniques
   - Provides surveillance where radar coverage is limited
3. **Wide Area Multilateration (WAM)**
   - Extends MLAT principles over large areas
   - Uses existing SSR signals
   - Cost-effective surveillance solution

SAFETY AND REGULATORY ASPECTS

SSR and DME systems must comply with strict international standards:

1. **ICAO (International Civil Aviation Organization)**
   - Annex 10 to the Chicago Convention specifies technical standards
   - Defines performance requirements for SSR and DME
2. **National Regulations**
   - FAA (USA), EASA (Europe), and other national authorities
   - Certification requirements for equipment
   - Operational procedures and mandates
3. **Safety Requirements**
   - Redundancy and fault tolerance
   - Electromagnetic compatibility (EMC)
   - Interference mitigation

FUTURE TRENDS: EVOLUTION OF SURVEILLANCE AND NAVIGATION

The future of SSR and DME involves integration with newer technologies:

1. **Satellite-Based Augmentation**
   - Increased reliance on GNSS (GPS, Galileo, etc.)
   - SBAS (Satellite-Based Augmentation Systems) improving accuracy
2. **Space-Based ADS-B**
   - ADS-B receivers on satellites for global coverage
   - Eliminates terrestrial coverage limitations
3. **5G AeroMACS**
   - Broadband data links for aviation
   - Potential to supplement traditional systems
4. **Quantum Technologies**
   - Potential for more precise timing and navigation
   - Quantum-enhanced sensors

APPLICATIONS BEYOND AVIATION

The principles underlying SSR and DME find applications in various other fields:

1. **Maritime Surveillance**
   – AIS (Automatic Identification System) uses similar concepts
   – Vessel tracking and collision avoidance
2. **Military Systems**
   – IFF (Identification Friend or Foe) based on SSR principles
   – TACAN (Tactical Air Navigation) uses DME-like distance measurement
3. **Spacecraft Tracking**
   – Ranging systems for satellite orbit determination
   – Similar pulse timing techniques
4. **Autonomous Vehicles**
   – LIDAR systems use time-of-flight measurement similar to DME
   – Vehicle-to-vehicle communication inspired by SSR data exchange
5. **Wireless Positioning**
   – UWB (Ultra-Wideband) positioning systems
   – Indoor location tracking technologies.

CONCLUSION

SSR and DME are foundational technologies in modern aviation:

1. **SSR** enables aircraft identification, altitude reporting, and surveillance
2. **DME** provides precise distance measurement for navigation
3. **Both systems use interrogation-reply principles** but serve different purposes
4. **They operate in different frequency bands** with specific technical parameters
5. **Key technical concepts for electrical engineers:**
   a) Pulse timing and measurement techniques
   b) RF circuit design for UHF/L-band operation
   c) Signal processing for pulse detection and decoding
   d) Multiple access and interference mitigation