MODULE 5 | Radar and Navigational Systems (18ECE221T)

Session 7 | TACAN & TACAN Equipment

TACtical Air Navigation (TACAN) - Provides range and bearing information in the same radiation.

Bearing information

Antenna radiation has a cardioid polar diagram which made to rotate at 15 revolutions per second (rev/sec). Provides a variable phase signal in the form of AM of the pulse train.

A specialized group of pulses are sent. Each group consists of 12 pulses with 12 µsec and each has a twin which is 30 µsec apart.

Delay between chosen datum point of the variable phase signal and the marker pulse is computed and displayed.

To improve the accuracy, a 9-lobe pattern is superimposed on the cardioid. The antenna pattern is rotated at 15 rev/sec gives the signal has a modulation of 15 Hz and 135 Hz.

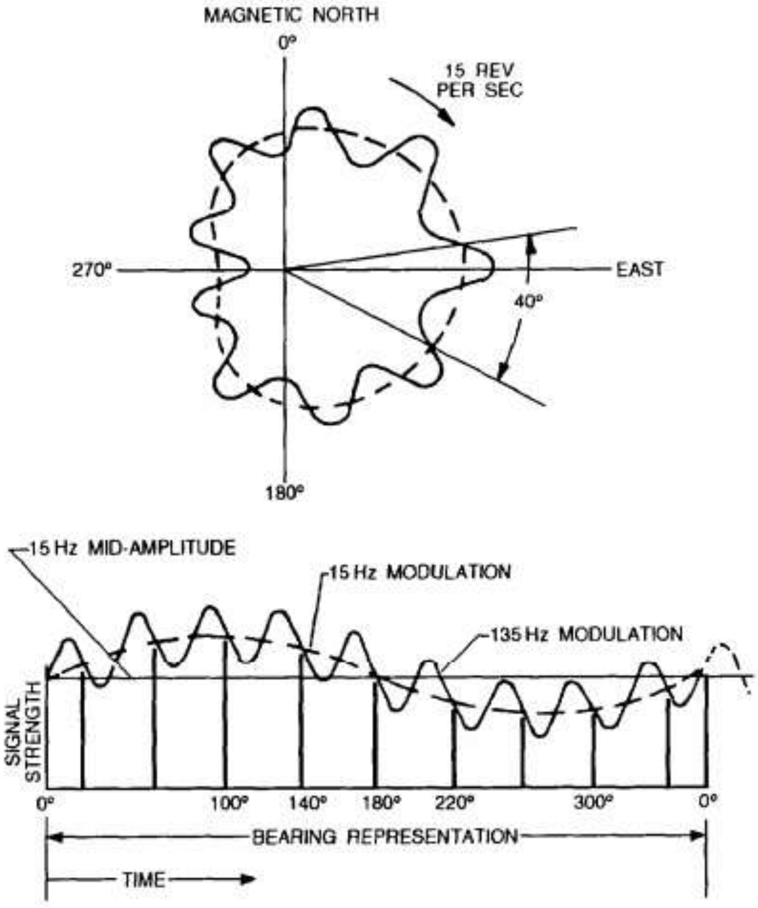

Figure 1. (a) Cardioid radiation pattern of TACAN antenna (b) TACAN Modulation Envelope [1]

The phase comparison at 135° increases the accuracy by 9-fold.

For 135 Hz group: Group of pulses consisting of 6, 12 µsec twins spaced 24 µsec is sent.

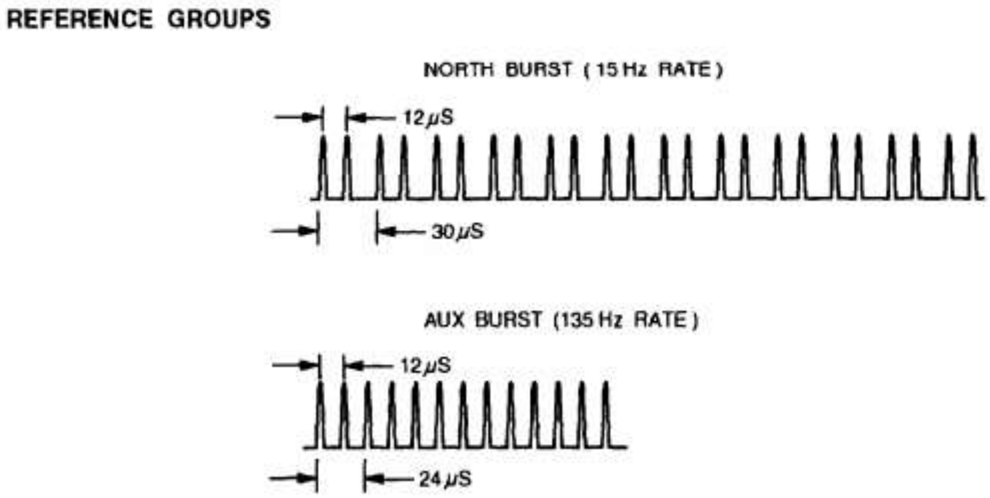

Figure 2. 15 Hz and 135 Hz pulse train. **Picture Courtesy [1]**

The field pattern of TACAN beam is

$$\varepsilon(t) = A + B\cos(\theta - \omega_s t) + C\cos 9(\theta - \omega_s t)$$

Where ω_s is angular velocity of pattern rotation

On demodulation of the pulse train, we get

$$E_1(t) = 1 + K_1\cos(\theta - \omega_s t)$$

$$E_2(t) = 1 + K_2\cos 9(\theta - \omega_s t)$$

The bearing is expresses as

$$\theta = n\frac{2\pi}{9} + \varphi$$

φ angle is less than $\frac{2\pi}{9}$.

The phase measurement at $9\omega_s$ gives rise to the angle 9φ

TACAN Equipment

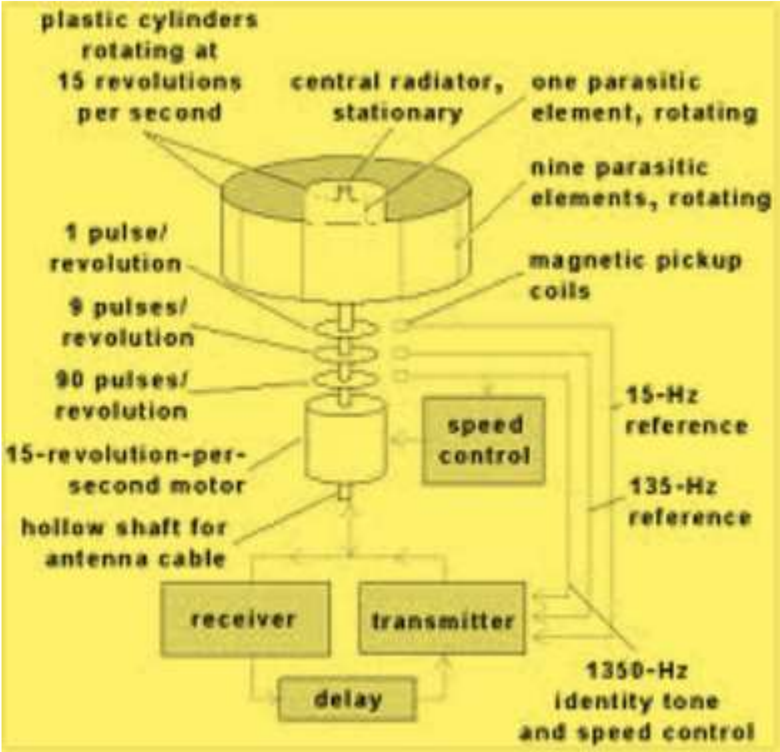

Figure 3. TACAN Equipment Picture Courtesy [2]

Construction

- Duplexer separate Transmitter (Tx) and Receiver (Rx) for isolation.
- Duplexer has tuned cavities to reject undesired signals
- The inner cylinder has diameter of 15 cm. It contains one parasitic element (reflector)
- Outer cylinder has diameter of 90 cm It has 9 parasitic elements directors.
- The radiator has stack of discone antenna (at centre not shown in figure)
- The two cylinders are rotated at 900 rev/min by a motor.
- This structure is functionally similar to Yagi-Uda antenna (one reflector + 9 directors)

References

1. https://www.globalsecurity.org/military/library/policy/navy/nrtc/14090_ch2.pdf

2. http://aviationengine.blogspot.com/2011/11/tactical-air-navigation-system-tacan.html

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Session 8 | Case study on Airborne Tactical networks- Instrument Landing System

Airborne Tactical Networks

Airborne tactical networks (ATN) have been a critical communications capability for a number of decades, enabling information sharing between both manned and unmanned military aircraft as well as surface and ground platforms.

To enable the promise of net-centric operations for the war fighter, technologies for the next generation airborne tactical network must evolve to provide more capacity, higher robustness, increased flexibility, better connectivity, improved interoperability, and faster response times for airborne and ground users.

Challenges in designing ATNs arise from the high cost of platform integration, limited availability of spectrum, the need to support larger numbers of users in an infrastructure-less environment, the desire to provide much higher data rates and lower latencies, and the complexity in managing the numerous potential network requirements.

Although the concept of **modularity** is a foundation of the current Internet, the air tactical domain has embraced a tightly coupled, vertically integrated architecture in hopes of increasing efficiency. Unfortunately, this has led to a lack of interoperability and the inability to upgrade layers independently. Future ATNs will need a hierarchical, modular architecture similar to that of the Internet to knit together the various heterogeneous systems at a common convergence layer and improve interoperability.

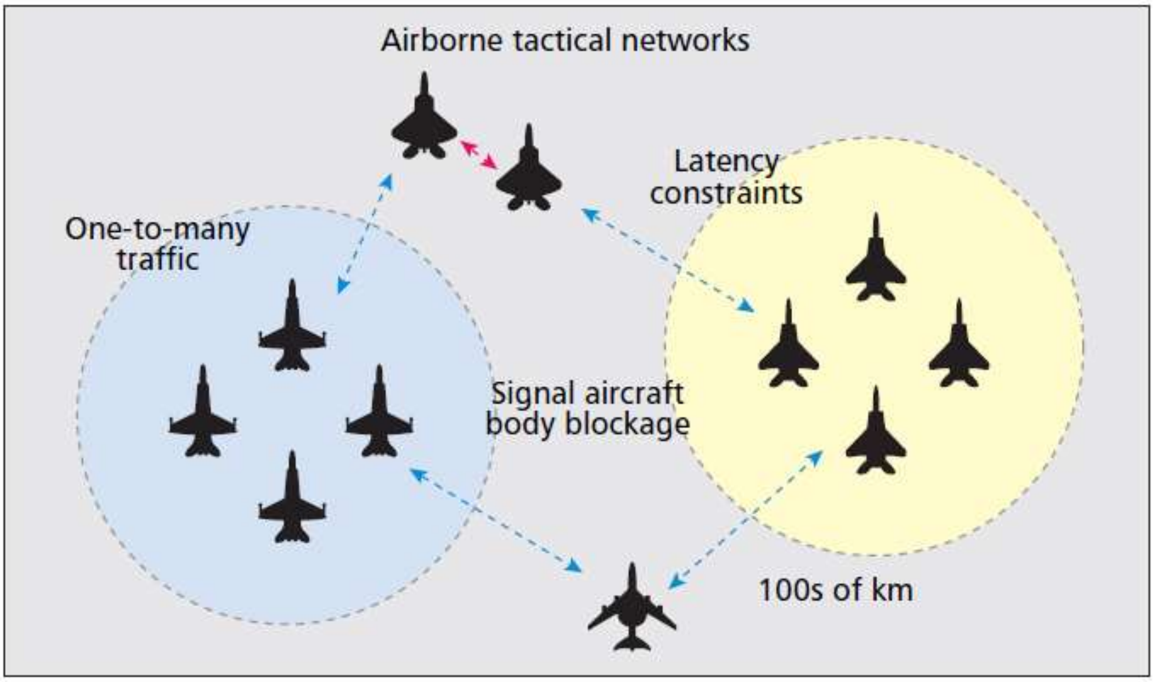

Figure 1. Unique domain characteristics of airborne tactical networks.

Low data rates: Many of today's tactical applications require transmitting short messages and as such, many communications needs can be fulfilled with low data rates. Future applications, however, could potentially consume larger data rates. Due to limited spectrum and the need for interference mitigation capabilities, ATNs typically operate on the order of 10's of Kbps to 100's of Kbps. Protocols that rely on flooding and network-wide synchronization of link information can consume too much bandwidth.

Significant multicast traffic: Much of the traffic carried by ATNs is designed to be received by multiple participants. Network design must prioritize one-to-many type traffic over traditional unicast approaches.

Latency constraints: ATNs carry time-sensitive information, thus much of the pipeline is optimized for latency guarantees, and it is important to drop out-of-date messages to reduce inefficient resource utilization.

Long transmission ranges: Typical transmission ranges can exceed 500 kilometers, depending on altitude, modulation, code rate, and transmit power. Additionally, because neighboring aircraft can be anywhere from a few meters to hundreds of kilometers away, propagation delays between nodes vary from nanoseconds to milliseconds, and the received powers from different transmitters can differ by several 10s of decibels. Such large differences in power can cause the weaker signal from the far node to be completely lost due to interference from the stronger near node.

Body blockage effects: Although there is little to no multipath fading in airborne links, aircraft body blockage can add seconds to minutes' worth of outages that need to be accounted for in protocol design. Body blockage effects vary significantly due to operational frequencies, the placement of the antenna(s), and orientation of the aircraft.

Platform Integration: Modular designs enable easier technology refresh and decoupled evolution of algorithms and technologies. Although improved antenna and radio frequency (RF) technologies can increase potential data rates and performance, the cost of platform integration of these new components can be prohibitive, and the ability to procure spectrum in alternate bands is becoming more difficult. As a result, we consider signal processing and networking technology approaches that may reuse existing or planned platform RF antenna and hardware technologies with or without substantial RF hardware upgrades

Mobility patterns: Some tactical aircraft maintain predictable orbits to form communications relays while others fly attack runs. When aircraft are engaged, the mobility patterns can be very sporadic.

Reference

1. Cheng, Bow-Nan, Frederick J. Block, B. Russ Hamilton, David Ripplinger, Chayil Timmerman, Leonid Veytser, and Aradhana Narula-Tam. "Design considerations for next-generation airborne tactical networks." *IEEE Communications Magazine*, vol. 52, no. 5, pp.38-145, 2014.

Instrument Landing System

- It is a ground-based navigation system
- It is most accurate
- It is used by airlines
- It provides accurate information to the pilot of runway in both (1) Horizontal plane – azimuth (2) Vertical plane – elevation (altitude)

ILS Overview

- The ILS system uses VHF radio (at the airport) to transmit signals that are received by the VOR receiver (in the airplane) and display guidance information on the flight director or send information to the autopilot.
- The ILS components consist of a Localizer, Glideslope and Marker Beacon System
- The radio signal that lines up the airplane with the runway is called the Localizer.
- The radio signal that keeps the aircraft descending at a safe angle is called the Glideslope.
- The Marker Beacon is 3 radio beacons positioned along the extended centerline of the runway that alert the pilot for glideslope intercept, decision height and when to go around.

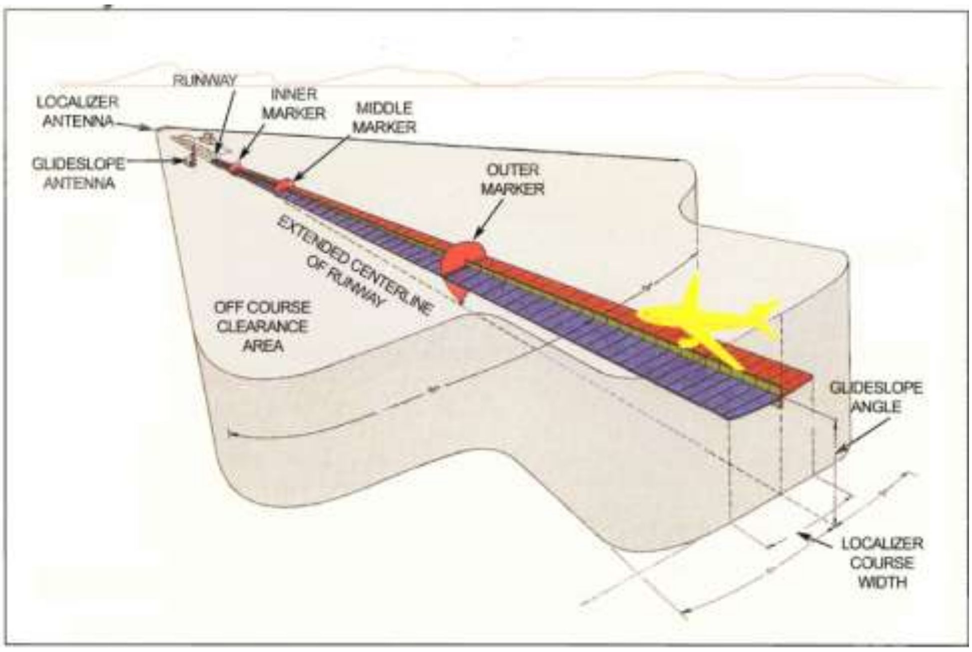

Figure 1. Instrument Landing System. **Picture Courtesy: [1]**

Two types of antenna are used (1) Localizer (2) Glideslope antenna – for vertical angle

A. Localizer

- Placed at the end of the runway
- Built with number of directional antennas
- They send out radio signals in the horizontal axis of the runway
- From the ground, a localizer transmitter projects radio beams aligned with the centerline of the runway.

- It operates in the VHF band from 108.1-111.95 MHZ.
- The localizer transmits 2 tones: 150Hz and 90Hz, and one tone is on one side of the runway, the other on the other side

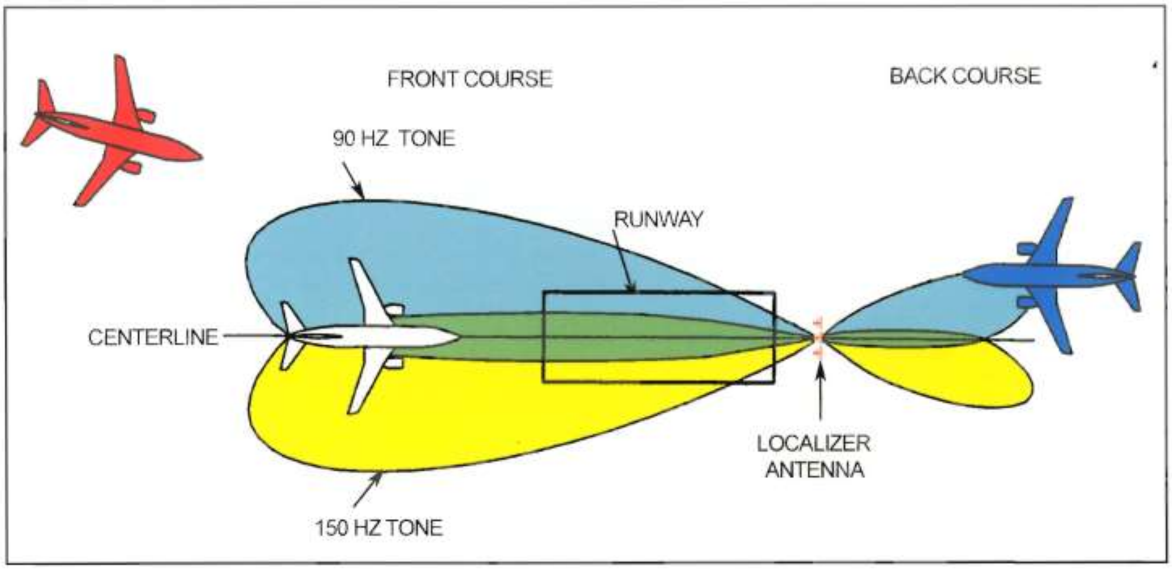

Figure 2. Localizer radiation pattern   Picture Courtesy [1]

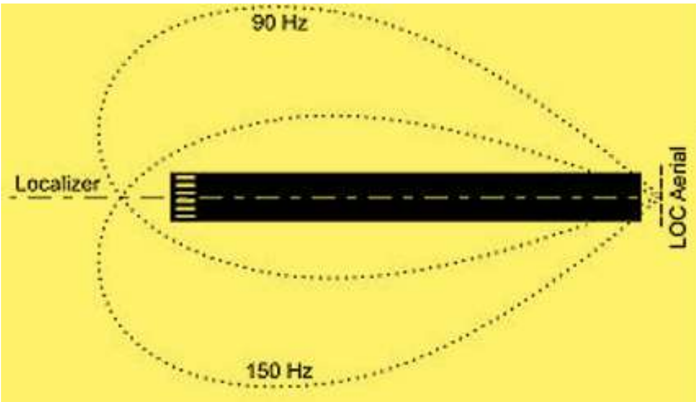

Figure 3. Localizer for Horizontal Axis correction. TOP VIEW   Picture Courtesy [1]

- The ILS receiver measures the difference of strength of the 2 tones to compute whether or not the aircraft is centered or off course.

From the right it moves to the centre line (creates green light). It means you have to move to the left to join with the localizer. ILS sends out its Morse Code with that the pilot gets connected with ILS receiver (i.e.) beep tone. Now the flight joins the localizer in horizontal axis.

B. Glideslope

- The glideslope operates on the UHF band from 329.15 MHz to 335 MHz.
- Just like with the localizer, it transmits 2 tones: 150 or 90Hz to indicate whether the airplane is above or below the glide path.
- In the meter, marker (____)has to match with the glidepath (---- lines)

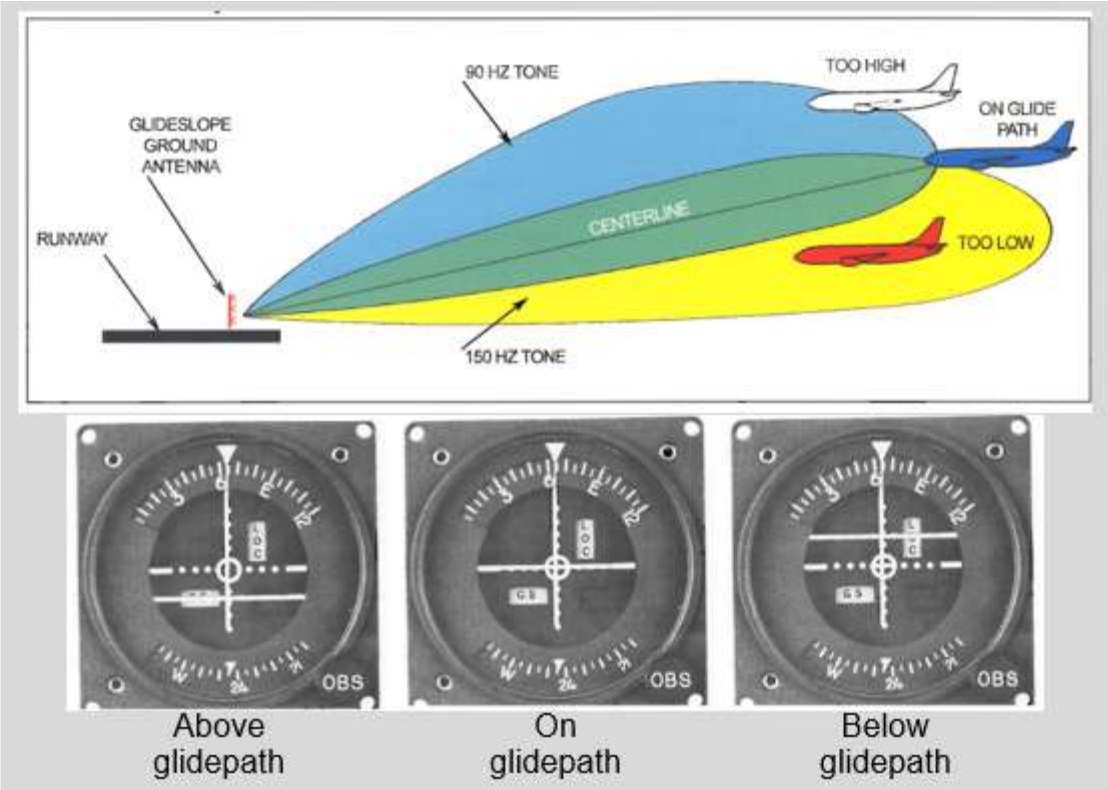

Figure 4. Working of Glideslope   Picture Courtesy [1]

Trivia: London has the steepest ILS approach.

Now, we have reached the centre of ILS horizontal and vertical axis.

C. Marker Beacon

Next, to know how far the runway exists. So, we are using markers for speed management.

Let us see 2500 feet and you know that glide slope angled towards the runway.

- Outer Marker:
  When flying over the outer marker a little blue light will start flashing on you and 400 Hz tone and beeping code (dash dash) can be heard. Compare with the map.
- Middle Marker:
  When flying over the outer marker a little yellow light will start flashing on you and 1400 Hz tone and beeping code (dot dash) can be heard.
- Inner Marker:
  The third antenna is attached at the inner marker called Distance Measuring Equipment (DME)

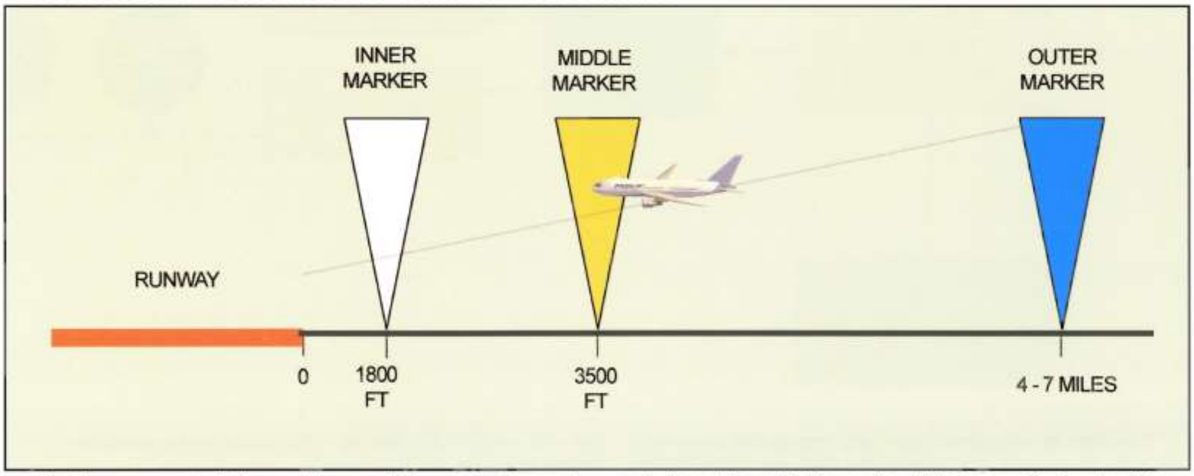

Figure 5. Marker Locations in airstrip **Picture Courtesy [1]**

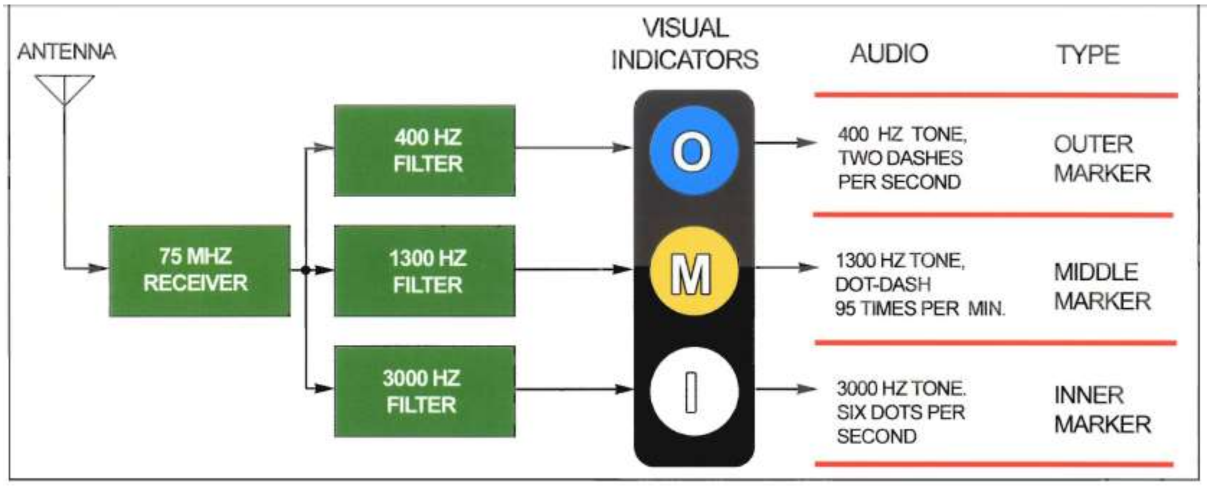

Figure 6. Marker Receiver **Picture Courtesy [1]**

- The Marker Beacon receiver is fixed-tuned to 75 MHz.
- There is a 3-light indicator in the flight deck which will light up the respective light for each marker as the aircraft passes over the marker.
- There is also an audio tone which sounds, and the pitch increases and sounds faster as the beacon is approached.

References

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2. Mr. E. Elamaran, AP/ECE class notes.

Session 9 | Introduction to satellite Radio Navigation – Navstar Global Positioning System (GPS)

Introduction to satellite Radio Navigation

The idea of using artificial satellites for navigation was conceived way back in 1957. American scientists in the Applied Physics Laboratory demonstrated that they could establish the ephemeris (a set of 16 constants from which exact position of satellite in the orbit can be determined) of the satellite by carefully measuring the Doppler shift of the transmission. Later they realized by knowing the ephemeris of a satellite, a receiver on earth could determine its position by Doppler shift. In 1967 'Transit System' was developed for US Navy.

They use Doppler profile to find location. The time of zero Doppler can be used to calculate latitude of the receiver.

Navstar Global Positioning System (GPS)

The NAVSTAR Global Positioning System (GPS) was conceived by US Department of Defence in 1973.

It is an all-weather global radio-navigation system. GPS is a passive, survivable, continuous, space-based system that provides to the receiver highly accurate 3-D position, velocity and information anywhere on the earth.

Principles of GPS

GPS is a ranging system. It is based on time-of-arrival measurements. It is very accurate. For that GPS uses atomic clocks. To provide continuous 3-D navigation solution to dynamic users, sufficient numbers of high-altitude satellites are required.

GPS satellites are in 11 hours, 57 minutes (approx. 12 hours) orbits at an altitude of 11,000 nmi.

Each GPS satellite transmits signals at two frequencies at L-Band (L1 - 1575.42 MHz and L2 - 1227.6 MHz). This signals contain satellite-unique pseudorandom noise (PRN) codes. Using this range can be calculated.

GPS provides two positioning services namely Precise Positioning Service (PPS) and Standard Positioning Service (SPS). SPS is available free of charge to any user worldwide. PPS is for authorized user only i.e., US and NATO military only.

TABLE 5.1 GPS segment functions

Segment	Input	Function	Product
Space	Satellite commands Navigation messages	Provide atomic time scale Generate PRN RF signals Store and forward navigation message	PRN RF signals Navigation message Telemetry
Control	PRN RF signals Telemetry Universal coordinated Time (UTC)	Estimate time and ephemeris Predict time and ephemeris Manage space assets	Navigation message Satellite commands
User	PRN RF signals Navigation messages	Solve navigation equations	Position, velocity, and time

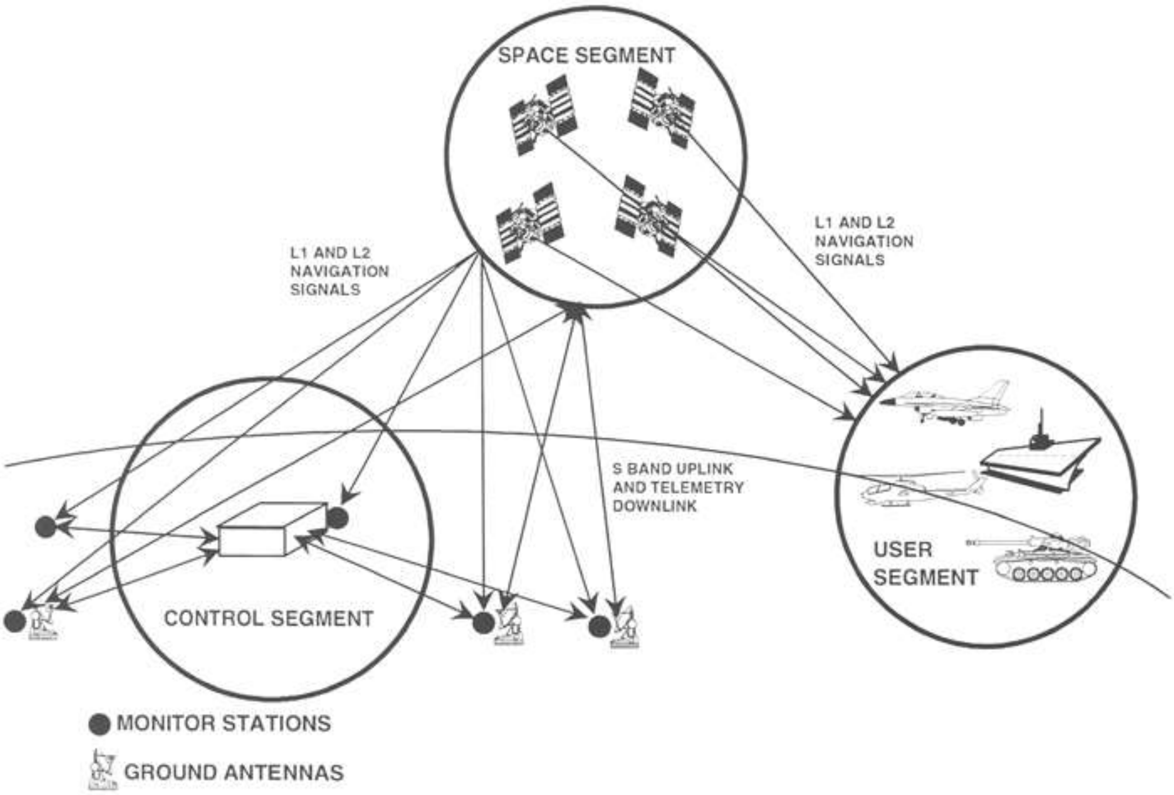

Figure 5.8 GPS system configuration.

GPS Satellite Constellation: The fully operation GPS satellite constellation comprises 24 satellites, four each in six 55° inclined orbit planes spaced 60° apart in longitude.

Satellites are designed in such a way that they cross same location every day. The time at any point along the path occurs 3 minutes earlier every day. This known as sidereal day.

Simply having visibility of 4 satellites are not sufficient to calculate the location. To measure the geometry GDOP parameter is used.

GDOP is defined from the linearized navigation/time solution derived from a vector of N ($N \geq 4$) pseudorange residuals:

$$\delta\overline{\mathbf{PR}} = \overline{\mathbf{H}}[\delta\overline{\mathbf{X}}_u^{\mathrm{T}} \quad -\delta c\Delta t_u]^{\mathrm{T}} \tag{5.40}$$

where the ith row (for satellite i) of the measurement matrix $\mathbf{H}(\mathbf{h}_i)$ is given as

$$\mathbf{h}_i = [1_{xi} \quad 1_{yi} \quad 1_{zi} \quad -1] \tag{5.41}$$

in terms of Equation 5.3. (The first three elements of Equation 5.41 are the directional cosines from the user position to the satellite position.) GDOP is defined as

$$\mathrm{GDOP} = \sqrt{\mathrm{trace}[\mathbf{H}^{\mathrm{T}}\mathbf{H}]^{-1}} \tag{5.42}$$

where trace[·] indicates the sum of the diagonal elements of [·].

Position dilution of Precision (PDOP) is computed by deleting the fourth diagonal element in trace of equation 5.42.

Space Segment

Navigation Payload: It consists of following key components and assemblies.

- Transmitting antenna array
- Redundant atomi clocks
- Digital processing or baseband assemblies
- RF equipment

GPS antenna array is formed by inner quad helics encircled by a ring of eight outer helics. This structure provides equal power density to all terrestrial users. This gives beam having 28.6° field of view.

GPS Control Segment

The principal product of the GPS control segment (CS) is the GPS navigation message data representing the predicted state of each GPS satellite. The CS control an maintain the status, health and configuration of the space segment (SS) assets.

CS can be subdivided into Master Control Station, Monitor Stations, and Upload Ground Antennas. The functions are mentioned in the Fig. 5.11 clearly.

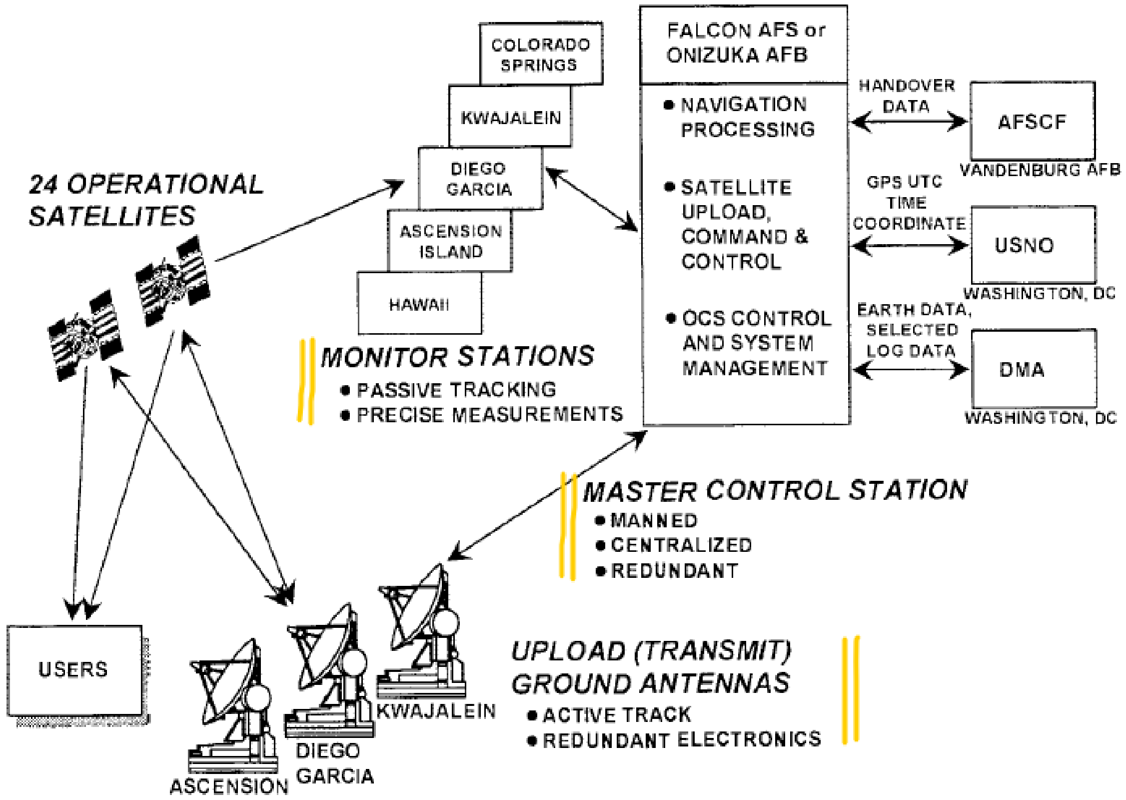

Figure 5.11 GPS control segment configuration.

GPS Signal Structure

The GPS satellite broadcast two signals: Link 1, L1, at a center frequency of 1575.42 MHz and Link 2, L2, at the center frequency of 1227.6 MHz. Each of these frequencies is an integer multiple of 10.23 MHz Clock.

$$120 \times 10.23 \text{ MHz} = 1227.6 \text{ MHz}$$

$$154 \times 10.23 \text{ MHz} = 1575.42 \text{ MHz}$$

The L1 signal consists of two carrier components: One carries a precise (P) pseudorandom noise (PRN) code, while the other, transmitted in quadrature carries a course/ acquisition (C/A) code. The L2 signal carries P code only. Both are modulated with a 50-bps data message. Each satellite will have a unique PRN code.

GPS Receiver

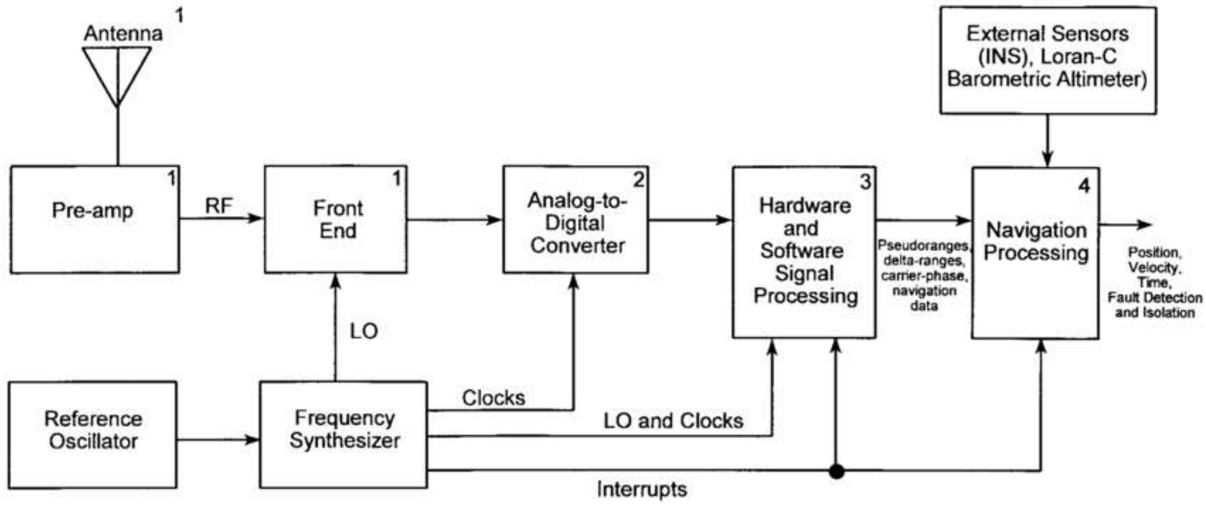

Figure A. Block diagram of GPS receiver [3]

1) Antenna/Front-End: single-frequency designs pass the L1 (1575.42-MHz) signal only; dual-frequency designs pass both the L1 and L2 (1227.6-MHz) signals.

2) Analog-to-Digital (A/D) Converter: several types may be found in current receivers, such as single-bit (i.e., hard limiting), multibit, and adaptive threshold types.

3) Hardware/Software Signal Processing: single-channel designs sequentially process each satellite being tracked; multichannel designs multiplex the A/D output into parallel channels with each channel tracking separate satellites.

4) Navigation Processing: integration of GPS and external sensor data may occur outside the GPS receiver.

References

1) N. S. Nagaraja, “Elements of Electronic Navigation Systems”, 2nd Edition, TMH, 2000.
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3) Braasch, Michael & Dierendonck, A. J. (1999) “GPS Receiver Architectures and Measurements”, *Proceedings of the IEEE*. 87. 48 - 64. doi: 10.1109/5.736341.