AE4-393: Avionics Exam Solutions 2007-10-29

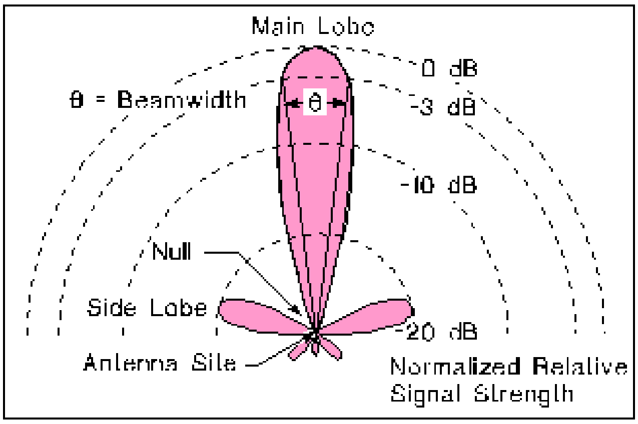
1. COMMUNICATION, NAVIGATION, SURVEILLANCE

[a] Pressure altitude and an aircraft identification.

[b] The two modes work as follows:

- SSR Mode A: interrogation interval P_1 and P_3 equals 8µs. The transponder replies with an Aircraft Identification Code (ACID), defined by ATC and set by the pilot on the transponder code interface. It is a 12 bit code, i.e. there are 2^{12} possibilities, or 4096 codes.
- SSR Mode C: interrogation interval P_1 and P_3 equals 21µs. The transponder replies the aircraft pressure altitude in steps of 100 ft (QNE).

[c] The transponder reply consists of twelve data pulses uniformly spaced between two framing pulses. The SSR transmits three interrogation pulses, P_3, P_2 and P_3. The position of P_3 w.r.t. P_1 and P_2 determines the mode (A/C) in which the transponder should reply. Every antenna, however, has a main lobe and several side-lobes. The signal is depicted in figure 1.1.



side lobe

Figure 1.1: SSR interrogation signal

[d] The main lobe interrogation of a far-away radar can well be the same as the strength of the side lobe interrogation of a near-by radar. The could lead to the transponder replying to the side lobe interrogations of the near-by antenna; which is called side-lobe interrogation. To prevent this, P_2 is sent with an additional omni-directional antenna with a magnitude larger than any of the antenna side lobes. P_2 is smaller than P_1 and P_3 only in their main lobes. Hence, the transponder only replies to the main lobes. Also see figure 1.2.

[e] SSR-Mode S permits discrete addressing of aircraft; a unique 24-bit Mode S address is assigened to each aircraft so that aircraft can be unambiguously identified amnd addresses worldwide: $2^{24} \approx 17$ million. It allows for:

- Private line communications
- Digital air-ground and air-air data link

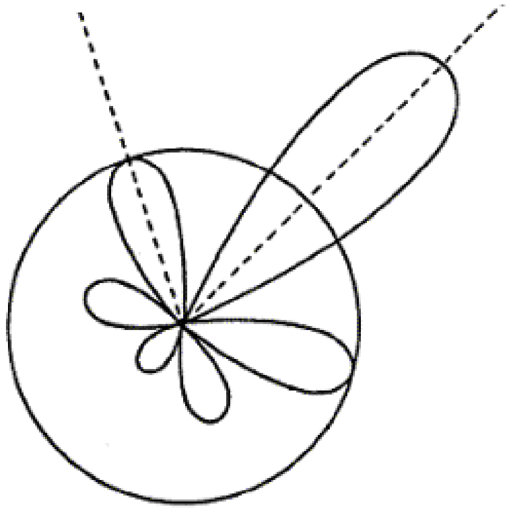


Figure 1.2: side lobe suppression

2. THE FUTURE AIR NAVIGATION SYSTEM

[a] The shortcomings of the current CNS services result in a lack of real-time information on present position and short and long term intent of the aircraft on certain parts of existing air-routes, which in turn requires the use of procedural methods of ATC. These do not provide the most efficient flight profiles or system capacity, as in general, flights must be planned via intermediate waypoints rather than on the most direct routes. There is also a limited opportunity to make changes to the cleared flight profiles. Hence, the capabilities of modern airborne systems cannot be fully exploited and the provision of ATS is not always efficient and cost effective. In addition, the lack of digital air-ground data interchange systems reduces the feasibility of automating the processing of ATS information. In short: the present system is incapable of making optimum use of ATC system capacity, available airspace and aircraft capability.

[b] The ideal would be a single navigation system providing adequate navigation for all phases of slight under all meteorological conditions all over the world for all airspace users. The Global Navigation Satellite System (GNSS) applied within the RNAV/RNP (Area Navigation/Required Navigation Performance) concept is approaching this ideal. GNSS + RNAV/RNP provides the aircraft with the capabilities to fly through a pre-determined four-dimensional 'tunnel' from departure to landing. In order to enhance accuracy and to monitor the integrity, the following types of augmentation are being developed: on-board augmentation (RAIM), local area augmentation (LAAS) and regional area augmentation (RAAS).

RAIM, or Receiver Autonomous Integrity Monitoring is a technique whereby and airborne GNSS receiver processor autonomously monitors the integrity of the navigation signals form GNSS satellites.

For LAAS/RAAS, or Local/Regional Area Augmentation System ground-based reference stations monitor the 'health' of the GNSS satellites and determine the range error at its location. This information is then transmitted to the aircraft to increase the on-board position determination function and its integrity.

RNAV is a function of modern FMS, its operations permit flight in airspace within prescribed accuracy tolerances without the need to fly directly over the ground based navigation facilities.

The RNP concept recognizes that current aircraft navigation systems are capable of achieving a predictable level of performance accuracy and that a more efficient use of the available airspace cane be realised on the basis of the individual airborne navigation capacity.

3. INERTIAL SENSORS: GYROSCOPES

[a] Moving parts, and therefore wear, lower reliability, they are more sensitive to accelerations and vibrations

[b] A vertical gyro yields reference datums for the detection of aircraft pitch and roll angle changes.

[c] These two properties mean:

- Rigidity is defines as the property which resist any force tending to change the pane of rotor rotation.
- Precession is defined as the angular change in direction of rotation under the influence of an applied force. The change in direction take place not ion line with the force but always at a point 90 degrees away in the direction of rotation.

[d] As a vertical gyro has a fixed orientation with respect to the body, Figure 3.1 shows in what position the gyro will be at.

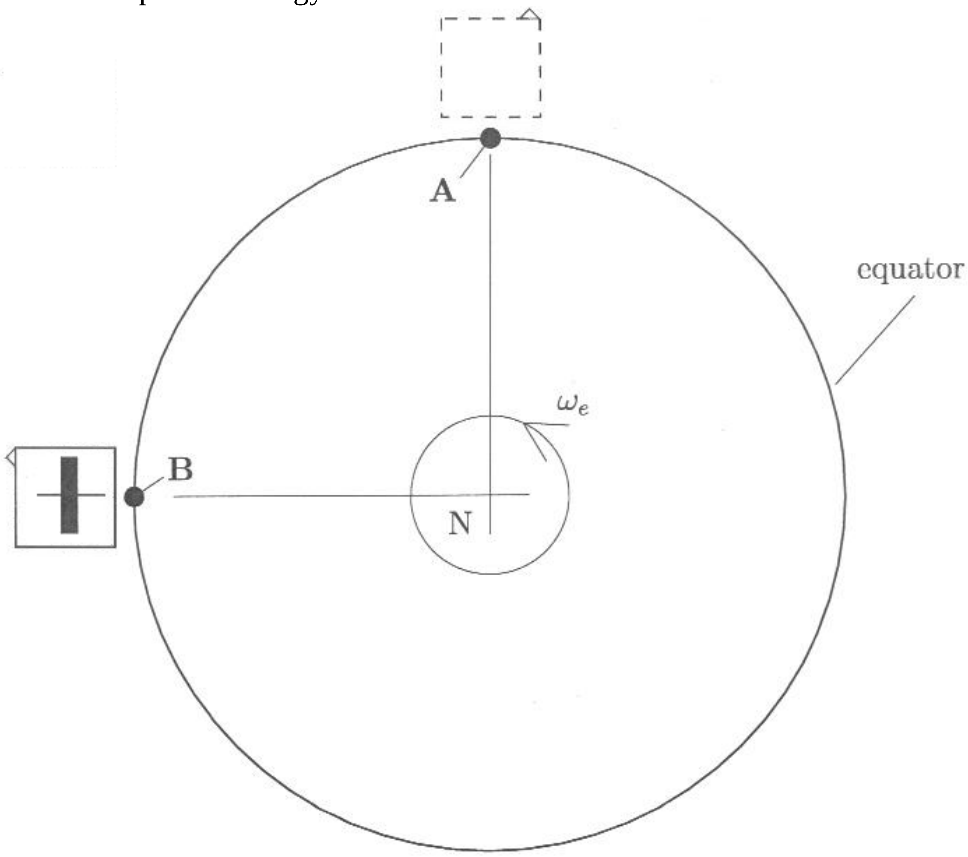


Figure 3.1: Vertical gyro

[e] A gyroscope is an inertial machine, in other words, it keeps the plane of the rotor fixed relative to an inertial frame F^i. To make it useful, it must be converted to what is termed an Earth gyroscope, i.e. maintaining a fixed reference with respect to the earth. In order to do this, corrections have to be made for drift and transport wander.

- Drift can be categorized in two forms:
  - Apparent drift, due to the earth rotation. The gyroscope senses the various components of the Earth rotation as an angular input, For the observer the gyroscope would appear to drift.
  - Real drift, due to imperfections in a gyroscope, such as bearing friction, gimbal system unbalance, mass unbalance
- Transport wander: carry a gyroscope over the earth surface, while keeping the gyro level with the Earth horizontal plane, means that the gyro must be rotated w.r.t. the inertial reference plane.

[f] Drift of the vertical gyro is usually in the order of 20 deg/h. Various monitoring systems have been designed to constrain the error in keeping the vertical reference.

4. TERRESTRIAL RADIO NAVIGATION

[a] In free space, all radio waves, regardless of frequency, are propagated in straight lines at the speed of light. Along the surface of the Earth however, two methods of propagation are of importance: up to about 3MHz and appreciable amount of energy follows the curvature of the Earth, called the *ground wave*. Up to about 30 MHz, appreciable energy is reflected form the ionosphere, this is called the *sky wave*. Line-of-sight waves are radio waves that follow a straight line and the range of these waves is determined by the height of the transmitter, height of the received and curvature of the Earth.

[b] The signal sent by the VOR ground station is omnidirectional: it is the carrier wave signal, amplitude modulated with a sub-carrier wave with frequency 9960 Hz that itself is frequency modulated by a 30 Hz sinusoid signal. This signal is being sent in all directions with a special antenna, the limacon, that has a cardioid pattern. This antenna rotates at 30 rps. The VOR receiver on board of the aircraft interprets the changing amplitude of the VOR signal due to this rotation as an amplitude modulation with a 30 Hz signal. The trick is that the phase of the 30 Hz amplitude modulated signal due to the cardioid rotation depends on the position of the aircraft w.r.t. the VOR beacon, whereas the phase of the 30 Hz frequency modulated sub-carrier hidden in the VOR signal does not. The heading of the aircraft is derived form the phase difference between these two signals. The line on Earth with a constant phase difference is called a *radial*. A VOR has 360 radials, which correspond with the magnetic heading at the VOR station. A pilot can select the radial to be flown with the Omni Bearing Selector (OBS).

[c] DGOP is the Geometric Dilution of Precision, see figure 4.1.

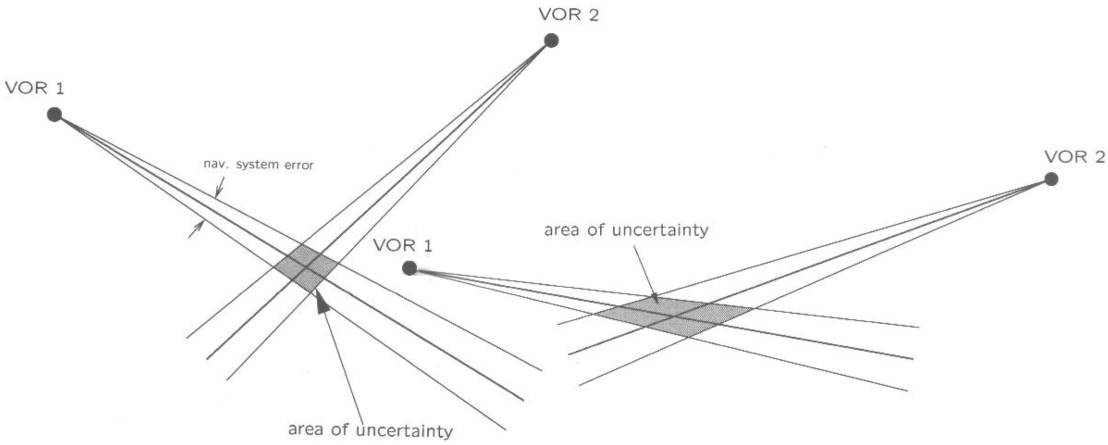


Figure 4.1: change in GDOP

[d] TACAN us a military omnibearing (like VOR) and distance measurement (like DME) system. Civil aircraft can use the TACAN beacon as if it would be a DME beacon. They cannot use the omnibearing facility of TACAN. For this purpose, TACAN beacons are often augmented with a VOR transmitter, yielding the so called VORTAC station.

5. SATELLITE RADIO NAVIGATION

[a] The basic principle is to measure the spherical ranges form the user from a minimum of four GPS satellites.

1) Measuring the time delay for the satellite transmission to reach the user yields the spherical range. The systems thus depends on very precise time measurements and requires atomic lock standards (10ns time error results in a distance error of 3 m). Each GPS satellite carries an atomic clock, synchronized with GPS time, which provides the time reference for the satellite data transmission. The user equipment carries a crystal clock as time reference is less accurate, resulting in a time bias in the measurement of the transit time form satellite transmission. The control segment comprises a master control station at Colorado Springs, five monitor stations and 3 uploading stations located worldwide. The control segment tracks the satellites and predicts their future orbital position data and the required satellite clock correction parameters, and updates each satellite on the uplink as it goes overhead.
2) GPS satellites use two frequency transmissions, L1 and L2 for transmitting the digitally encoded navigation message data. L1 provide the coarse/acquisition (C/A) code which is available to all users and which used to be deliberately degraded: selective availability (SA). It also provides the Precision (P) code which is encrypted and is only available to authorized military users. L2 also provides the P code. The dual frequency transmission of P code enables corrections to be made for ionospheric delay uncertainties. L1 and L2 both send the navigation message.
3) A GPS receiver obtains an estimation of the position via the Pseudo Range, it assumes the clock error of the satellite and sum of various measurement errors

as known or modeled. Now, four non-linear equations with four unknowns (x_u, y_u, z_u and Δt_u) can be solved with special computer algorithms.

4) The estimation of velocity is obtained through the range-rate equations. They allow the user's velocity to be computed with a high level of accuracy, typically one order of magnitude better than the pistion. The Doppler shift is determined by the GPS receiver. Using four satellites yields for non-linear equations with four unknowns ($\underline{v}_u$, $\Delta\dot{t}_u$)

[b] Differential GPS (DGPS) requires a reference station at a know location that receives the same GPS signals as does the avionics user. The reference station uses its GPS measurements with respect to its exactly known location to determine correction factors about each satellite and sends this data to the GPS receivers in the same area. The avionics user the applies those corrections to its own measurements canceling all common errors.

[c] The GPS system is augmented to increase accuracy, integrity, availability and continuity. There are 3 main forms of augmenting GPS:

1) RAIM, Receiver Autonomous Integrity Monitoring
2) WAAS, Wide Area Augmentation System, which augments GPW with three services:
    i) A ground integrity broadcast
    ii) Wide area DGPS corrections, improving accuracy
    iii) A raging function, providing additional availability and reliability
3) Pseudolite (PL) Augmentation; a pseudo-satellite is comprised of a GNSS-like signal generator at a fixed know location that broadcasts DGPS corrections as well as a raging code. Equal to WAAS, but now the signal is generated form the ground.

6. LANDING GUIDANCE SYSTEMS

[a] ILS is the Instrument Landing System.

[b] The three main components of ILS are:

1) ILS localizer, see figure 6.1.
2) ILS Glide Slope, see figure 6.2.
3) ILS Markers, see figure 6.3.

[c] An ILS glide slope antenna generally consists of two dipole antennas at 5λ and 10λ form the ground, with λ the carrier wave wavelength. The reflections of the antenna's signals due to the Earth surface yields a radiation pattern with multiple lobes (direct signal, reflected signal)

[d] See Figure 6.4. **1** is the carrier wave generator, **2** is the 90 Hz modulator, **3** the 150 Hz modulator, **4** the antenna bridge, **5** has a length of 0.25λ, **6** has a length of 0.5λ, **7** adds a 90 degree phase, **8** is the central antenna, **9** the right antenna and **10** the left antenna. The localizer antenna principle is based on phase differences. The 90 Hz AM modulated carrier wave (cw) is attached to the antenna bridge at **A**. The 150 Hz AM modulated cw is attached at **B**. At **C** we get cw + 90 + 150. This seignal will be taken as 'reference' w.r.t. phase i.e. phase is zero at **C**. The central antenna the transmits **cw + 90 (0) + 150 (0)**. At **D** the cw-90Am signal (phase 0) is added with the cw-15AM signal (phase 180 due to path length difference of λ/2). Hence, the carrier wave is reduced and the remaining signal is **90 (0) + 150 (180)**. At **7**, 90 degrees pase

is added, so the signal at **E** is **90 (90) + 150 (270)**. This signal is led unchanged to **F** and is transmitted at the right antenna. The signal arrives form **E** in **G** with another 180 degree phase difference. The signal at **G** is then **90 (270) + 150 (90)**, which is transmitted at the left antenna.

[e] At position A, 90 Hz AM and 150 Hz Am are equal and at B, 90 Hz is dominant. See figure 6.5.

[f] Obstacles in terrain (other aircraft, vehicles) result in disturbances of the ILS signal (multipath effects).

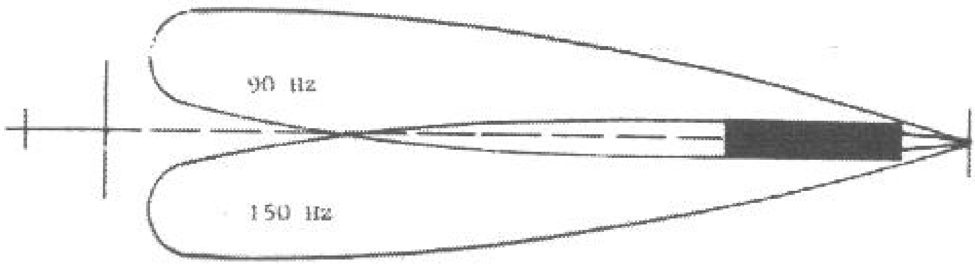


Figure 6.1: ILS localizer

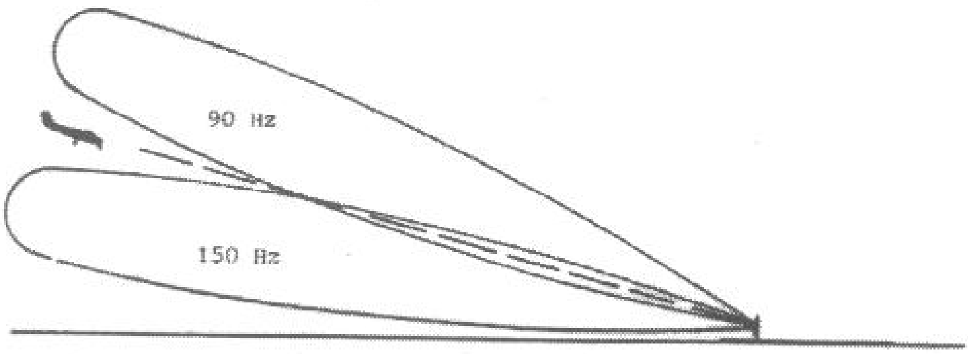


Figure 6.2: ILS Glide Slope

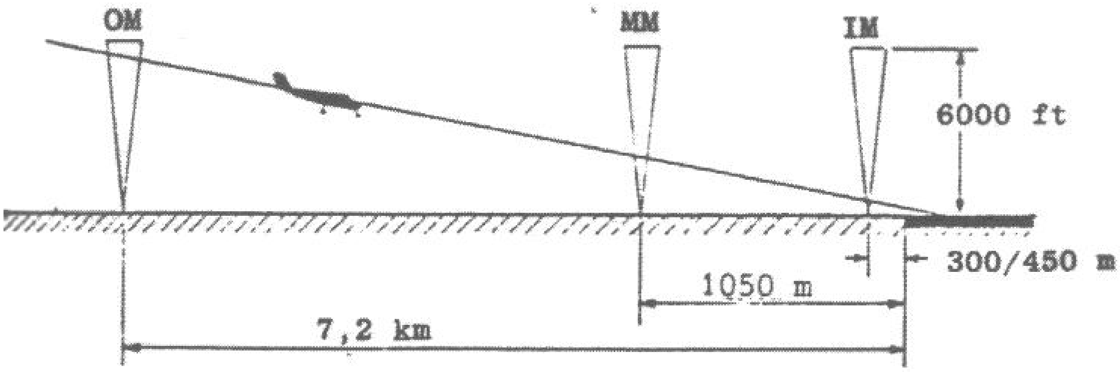


Figure 6.3: Marker Beacons

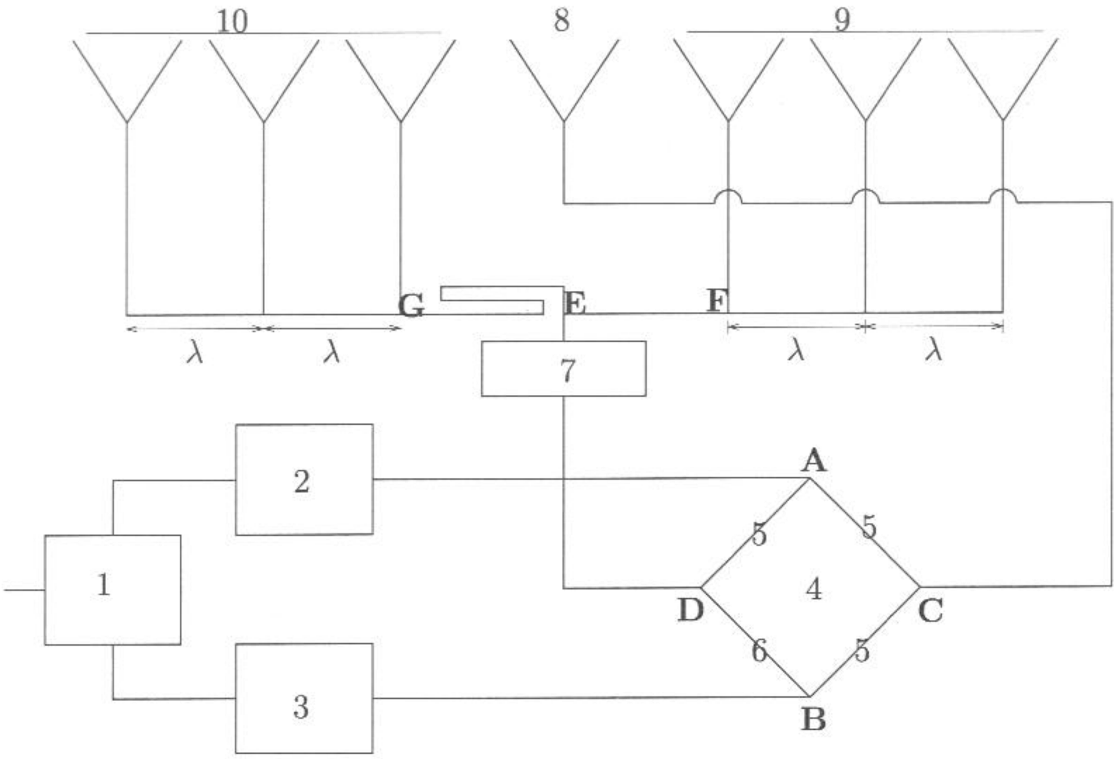


Figure 6.4: The ILS localizer antenna

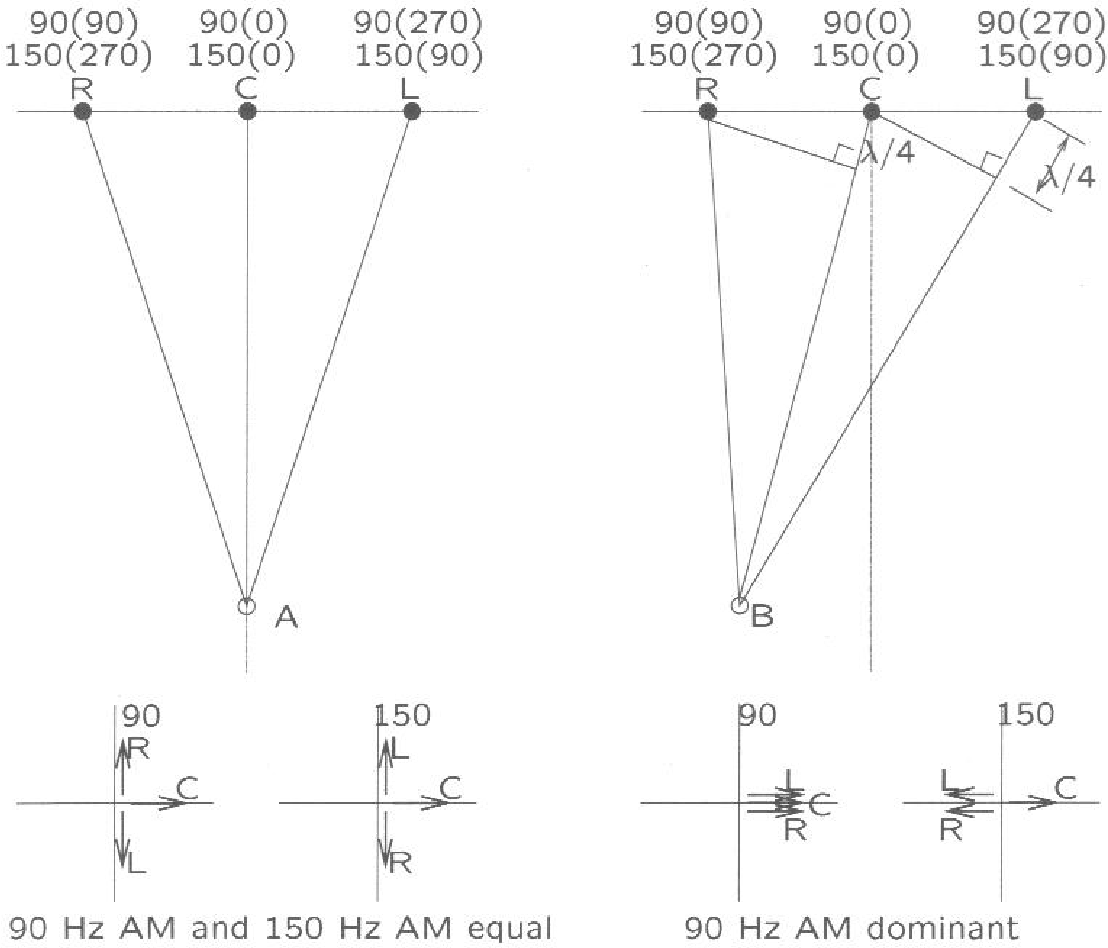


Figure 6.5: signal shift at ILS localizer antenna