GLOBAL NAVIGATION SATELLITE SYSTEMS, INERTIAL NAVIGATION, AND INTEGRATION

FOURTH EDITION

SOLUTIONS MANUAL

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PREFACE

This solutions manual is to be used only by instructors using the textbook, who well understand the importance of guarding against disclosure of its contents to others. The utility of the textbook to you and your students will be compromised if any of the contents of this solution manual are allowed to be copied by others, so **PLEASE** be careful to keep it locked away.

The solutions given here are fairly detailed, and we have included some explanations of how the solutions use the materials in the textbook.

We also include some additional problems and solutions which instructors may find useful in teaching from the text.

It has been our experience that students often find different (and better) derivation methods and solution formats than those in the solutions manual, and we expect this one to be no different. We would be pleased to receive any such solutions, and also any corrections or suggestions that instructors may have for improvements in the textbook or this manual.

We thank you for using our textbook in your courses, and we welcome any suggestions you may have for making the book more useful to you in your work.

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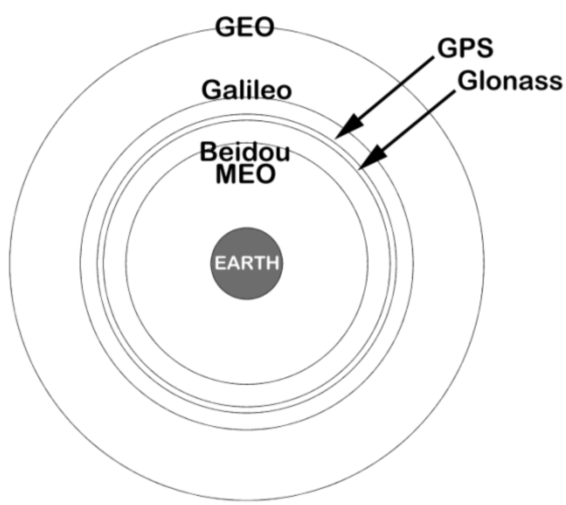
Solutions for Chapter One

Problem 1.1. How many satellites and orbit planes exist for GPS, GLONASS, and Galileo? What are their respective orbit plane parameters?

Problem 1.1 Solution:

	GPS	GLONASS	Galileo
Minimum Number of Satellites	24	24	30
Number of Orbit Planes	6	3	3
Orbit Plane Inclination	55.5^o	64.8^o	54^o
Orbit Radius [km]	26600	25510	**29600**

GNSS orbits drawn to scale:



Problem 1.2. List the differences in signal characteristics between GPS, GLONASS, and Galileo.

Problem 1.2 Solution:

GPS

$$\begin{bmatrix} f_0 = 1.023 \text{ MHZ} \\ f_1 = 1540 f_0 \\ f_2 = 1200 f_0 \end{bmatrix}$$

L1 signal from each Sat uses BPSK modulated by 2 PRN codes (C/A and P).

L2 signal from each Sat uses BPSK modulated by P/Y code.

C/A code chipping rate $f_0 = 1.023$ MHZ (1 msec)

P code chipping rate $10 f_0 = 10.23$ MHZ (259 days)

GLONASS

$$f_1 = (1.602 + 9k/16) \text{ GHZ}$$
$$f_2 = (1.246 + 7k/16) \text{ GHZ}$$
$$k = -7, -6, \cdots 5, 6 \text{ Sat \#}$$
$$\text{L1} = 1.598 - 1.605 \text{ GHZ}$$
$$\text{L2} = 1.242 - 1.248 \text{ GHZ}$$

C/A code chipping rate $= 0.511$ MHZ

P code chipping rate $= 5.11$MHZ

Galileo

4 categories: $\underbrace{\text{F/NAV}}_{\text{used for OS, CS, SOL}}, \underbrace{\text{I/NAV}}_{\text{Integrity}}, \underbrace{C/NAV}_{\text{C s}}, \underbrace{G/NAV}_{\text{PRS}}$

$E_{5a} - E_{5b}$ band freq. $1164 - 1214$ MHZ

Both codes' chipping rate 10.23 Mcps (Million chips/sec)

$L_1 - E_1$ band freq. $1559 - 1591$ MHZ

Modulation BOC

Problem 1.3. What are the reference points for GNSS and INS navigators? That is, when one of these produces a position estimate, what part of the respective system is that the position of?

Problem 1.3 Solution: For GNSS navigation, the navigation reference point is the theoretical location within the antenna structure where the signals from all satellites are summed before they are carried through coax to the receiver front-end. It is an important issue in antenna design that this point not depend upon the direction of arrival. However, calibrated errors due to direction of arrival can also be compensated in the pseudorange calculations.

For inertial navigators, the navigation reference point is the theoretical point about which pure rotations would not create any sensed accelerations due to rotation. This is not a problem for gimbaled systems, in which the accelerometers are isolated from rotations (except for leveling, in which case the rates are insignificant). For strapdown systems, elimination of the effect would require that the accelerometer *centers of percussion* be co-located[1]. In the design of a strapdown INS for navigation with very high rotation rates, the resulting errors can be calibrated and compensated using controlled rotations (e.g., on a rate table) and measuring the resulting changes in sensed acceleration. The effect can then be removed by using the measured rotation rates to compensate for differential centrifugal accelerations of the accelerometers.

In GNSS/INS integration, it is important that the relative offsets between the respective reference points be taken into account.

Problem 1.4. Would an error-free accelerometer attached to a GNSS satellite orbiting the earth have any output? Why or why not?

Problem 1.4 Solution: There would be no first-order[2] output—an effect used by astronauts in the Apollo command module to recalibrate their accelerometer output biases in Earth orbit before setting off for the moon. Conventional accelerometers measure specific force $a_s = f/m$, where f is the external physical force applied to the accelerometer housing and m is the accelerometer proof mass. A point mass in free fall (e.g., in orbit) has no applied force and hence no output except sensor errors.

Problem 1.5. Does the same fish, weighed on the same spring scale, appear to weigh more (as indicated by the stretching of the spring) at sea level on the equator or at the North Pole? Justify your answer.

Problem 1.5 Solution: The same fish would "weigh" more at sea level at the North Pole, in the sense that the weight of the fish would stretch the supporting spring more there. What causes this difference is the rotation of Earth about its polar axis, which adds an upward centrifugal acceleration of the fish at the equator to counter the downward gravitational acceleration. There is no net centrifugal force at the North Pole. The fact that centrifugal acceleration causes sea level to bulge out at the equator is another possible explanation, in that it makes sea level at the North Pole be closer to the center of mass of Earth. This means that fishermen might prefer to weigh their catch closer to the North Pole and their customers might prefer to weigh it closer to the equator. This effect had been predicted by Sir Isaac Newton.

[1] It is theoretically possible for the electrostatic gyroscope to function as a three-axis electrostatic accelerometer, using the rotor suspension servo outputs to calculate the forces applied to the spherical rotor.

[2] However, for sufficiently large bodies in free fall the local gravity gradients can be applying slightly different gravitational acceleration to different parts of the body. This effect has been used to some extent in space to stabilize rotational dynamics of satellites, and it has helped to create the asteroid belt by the large gravity gradient from Jupiter hindering the formation of larger planet-size bodies.