

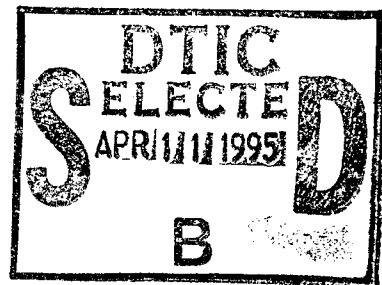
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DIFFERENTIAL GPS AND CHINA'S COASTAL HIGH  
PRECISION NAVIGATION GUIDANCE SYSTEM

by

Li Weirong, Yang Yongkang and Fang Naizheng



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TABLE OF CONTENTS

Graphics Disclaimer . . . . . i  
Table of Contents . . . . . ii  
Differential GPS and China's Coastal High Precision Navigation  
Guidance System . . . . . 1

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## DIFFERENTIAL GPS AND CHINA'S COASTAL HIGH-PRECISION NAVIGATION GUIDANCE SYSTEM

Li Weirong, Yang Yongkang, and Fang Naizheng, of Shanghai Maritime College

### Abstract

First, this article explains the necessity of establishing high-precision navigation guidance systems along China's coasts. Moreover, on the optimal basis of using intermediate-frequency directional beacon stations and differential GPS signals, the article proposed a concept of utilizing intermediate-frequency radio directional beacon stations to be organized into a highly precise differential GPS navigation guidance network. The article goes on to discuss the establishing of differential GPS and its data telegram format.

### I. Foreword

With China's reform and opening to the outside world, as well as its ever-increasing economic development, the domestic and international water transport volumes are growing rapidly; more and more civilian ships are operating for various trades in China's coastal waters. In particular, China's major ports are river estuary ports, which are silted with large amounts of mud from the upper reaches so that the water depths in the navigation channels are limited. Large ships enter and leave the ports by taking advantage of high tides; this is a bottleneck in

developing water transportation. Due to the above-mentioned factors, precision requirements on China's coastal navigation guidance systems are mounting; the current systems are unable to meet these requirements. Therefore, a highly precise navigation system should be established along China's coast.

Notwithstanding, after completion of the GPS system at the end of 1993 and the GPS will be the world's major navigation guidance system in the twenty-first century; however, the positional precision is 100m as under control by the U.S. SA [expansion unknown] policy. However, once a malfunction develops in the system (such as positioning cannot be determined in time due to satellite clock malfunctioning), the system ideal will be reduced. These above-mentioned factors make it impossible to satisfy the requirements of navigation positioning in China's coastal waters for ships entering and leaving ports. As revealed by large numbers of theoretical and experimental tasks performed by the U.S. Coast Guard on the differential GPS, the differential GPS system is the best selection for improving ideal and positioning precision of the GPS.

## II. Concept of Using Intermediate-Frequency Radio Directional Beacon Stations to Organize Differential GPS Guidance Network in China' Coastal Waters

### (A) Operational principle of differential GPS

Based on the known positional data of the beacon stations and the satellite positions obtained by multichannel GPS receivers installed at the stations, the calculated distance  $R_c$  from satellite to beacon station can be calculated. By comparing  $R_c$  with the pseudo-distance  $PR_{III}$  measured by a GPS receiver, the error  $\Delta PR$  can be obtained:

From the difference between the pseudo-distance measured value at this time and that of the last time, the variation rate  $PR$  of the pseudo-distance can be obtained. By using a Kalman filter, the revised variation rate of this particular pseudo-distance can be

obtained. Together with the satellite code and the time when the revised value was issued, a coded telegram can be composed in a certain format. After modulation, the telegrams are fed to transmitters for broadcasting to users. At the time  $t$ , the revised pseudo-distance obtained by the user can be calculated with the following equation:

In the equation,  $T_0$  is the time when the revised information was sent by the beacon station;  $\Delta PR_0$  and  $PR_0$  are the pseudo-distance and the revised variation rate of the pseudo-distance sent out by the beacon station at the time  $t_0$ .

(B) Advantages of using intermediate-frequency radio directional beacon station to broadcast differential GPS signals

Completion of sending the revised values to users is one of the key sectors for the entire differential GPS system. By operating the differential GPS in China's coastal waters, in addition to the technical problems of data signal format, frequency allocation, and service range, full consideration should also be given to economic benefits and management.

From the technical standpoint, a transmitter capable of modulating 50-bit data signals can be used to broadcast revised differential GPS signals. However, the intermediate-frequency radio directional beacon station has the following advantages: such stations will be used to broadcast differential GPS revised signals by China.

1. All intermediate-frequency radio directional beacon stations are situated along coastal waters; such waters require the service of high-precision positioning.

2. Based on the related articles of the International Radio Rules and Regulations, 285 to 325kHz band radio directional beacon stations (for service of radio navigation guidance) can adopt the narrow-band technique to send revised differential GPS signals. Therefore, it is not necessary to make any revisions to such rules or to re-allocate the frequencies.

3. Besides transmitting the discrimination Morse code signals by the intermediate-frequency radio directional beacon station, these stations mainly transmit continuous wave so it is easy to attach supplementary modulation. Therefore, interference is not likely to occur, thus degrading the performance of the directional beacons.

4. In an announcement by the International Light Tower Association, the intermediate-frequency radio directional beacon stations along coastal waters are the best-suited to broadcast the revised signals.

5. There are reliable units of equipment in intermediate-frequency radio directional beacon stations managed by navigation beacon department; these equipment units would be used continuously. At present, these signals have covered most of China's coastal waters, therefore it is convenient to expand the differential GPS in China's coastal waters to form a differential GPS navigation guidance network, thereby saving heavy expenditures in constructing radio stations.

Therefore, whatever the conditions, technically or economically, in China's coastal waters this is the best scheme for a high-precision navigation guidance positioning system that uses intermediate-frequency radio directional beacon stations to broadcast revised differential GPS signals.

(C) Consideration of using the intermediate-frequency radio directional beacons for the differential GPS navigation guidance network regional coverage range

1. Selection of differential GPS navigation guidance station sites and signal coverage range

As reported in the literature, the signal effective distance of the differential stations is 2.5 to 3 times that of the directional surveying signals. In China's coastal waters, it is okay to use intermediate-frequency radio directional beacon stations with a range of more than 100 nautical miles to broadcast differential GPS signals with an effective range of 200

nautical miles.

In China's coastal waters, the distribution of intermediate-frequency radio directional beacon station is not very uniform. In North China Sea areas and East China Sea areas, the distribution of such stations is more concentrated; in the South China Sea and the southern East China Sea, the distribution is relatively scattered. Altogether there is a total of 22 stations, with an effective range in six categories between 25 and 200 nautical miles. However, the most effective range is between 100 and 200 nautical miles; the transmitted frequencies applied are between 291 and 320kHz, in a total of 11 kinds of frequencies. Those intermediate-frequency radio directional beacon stations selected that can be used to organize the differential GPS navigation guidance network are listed in Table 1.

Table 1. INTERMEDIATE-FREQUENCY RADIO DIRECTIONAL BEACON STATIONS

地 <sup>a</sup> 点	位 <sup>10</sup> 置	作用距离 <sup>11</sup>	调制方式 <sup>12</sup>	频率 <sup>13</sup>
1 北塘镇	39° 06' 25.0" LN 117° 47' 06.8" LE	200海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	295KHz
2 圆岛	38° 40' 33.0" LN 122° 09' 42.0" LE	100海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	307KHz
3 成山角	37° 23' 37.7" LN 122° 42' 06.7" LE	200海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	319KHz
4 王家麦	36° 04' 22.8" LN 120° 26' 25.8" LE	200海里 <sup>14</sup>	A, 调整 <sup>15</sup>	291KHz
5 琼岛	32° 45' 42.3" LN 122° 46' 15.2" LE	150海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	311KHz
6 花鸟山	30° 51' 14.0" LN 122° 40' 20.0" LE	100海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	300KHz
7 牛山岛	26° 10' 00.0" LN 119° 56' 09.0" LE	140海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	
8 抱虎角	20° 00' 20.0" LN 110° 55' 48.0" LE	100海里 <sup>14</sup>	A, 调幅 <sup>15</sup>	310KHz

KEY: 1. Beitang Zhen 2. Tuan Dao 3. Chengshanjiao  
 4. Wangjiamai 5. Qiongdiao 6. Huaniaoshan  
 7. Niushandao 8. Baohujiao 9. Sites  
 10. Position 11. Effective range 12. Modulation mode  
 13. Frequency 14. Nautical miles  
 15. Modulated amplitude

2. Signal coverage after building some intermediate-

frequency radio directional beacon stations

Because of the nonuniform distribution of intermediate-frequency radio directional beacon stations from south to north along China's coastal waters, there are major gaps in signal coverage. To change this situation so that better coverage can be achieved for all coastal sites in China after completing the differential GPS navigation guidance network for positioning precision of 8 to 20m (2 drms) for any coastal ports, the following intermediate-frequency radio directional beacon stations should be built along coastal waters:

(1) Yulin, (2) Shekou, (3) Shantou, (4) Taishan Islands

In Fig. 1, "O" markings are the selected station sites; "DELTA" markings are four station sites that have been built. It is clear from Fig. 1, after the four above-mentioned intermediate-frequency radio directional beacon stations are built, combining with the original intermediate-frequency radio directional beacon stations a relatively complete differential GPS navigation guidance coverage network can be basically formed in China's coastal waters.

### III. Composition of Differential GPS System

Fig. 2 shows the composition of the differential GPS system. The system is composed of the following portions:

(1) Satellite -- providing GPS navigation guidance signals.

(2) Geodesic coordinates -- adopting Beijing-54 coordinate system.

(3) Beacon station -- composed of an omnidirectional GPS multichannel receiver and a microcomputer for processing information, thus receiving the navigation guidance information, calculating errors of pseudo-distance, and generating differential information according to the RTCM-SC-104 format. The telegram text should include information from 12 differential GPS stations. When more differential GPS stations are built, or when the present stations are remodeled to requirements, this information should be appropriately revised. At the same time,

based on the actual situation along China's coasts, the related additional measuring and testing information can be added to the telegram as per requirements.

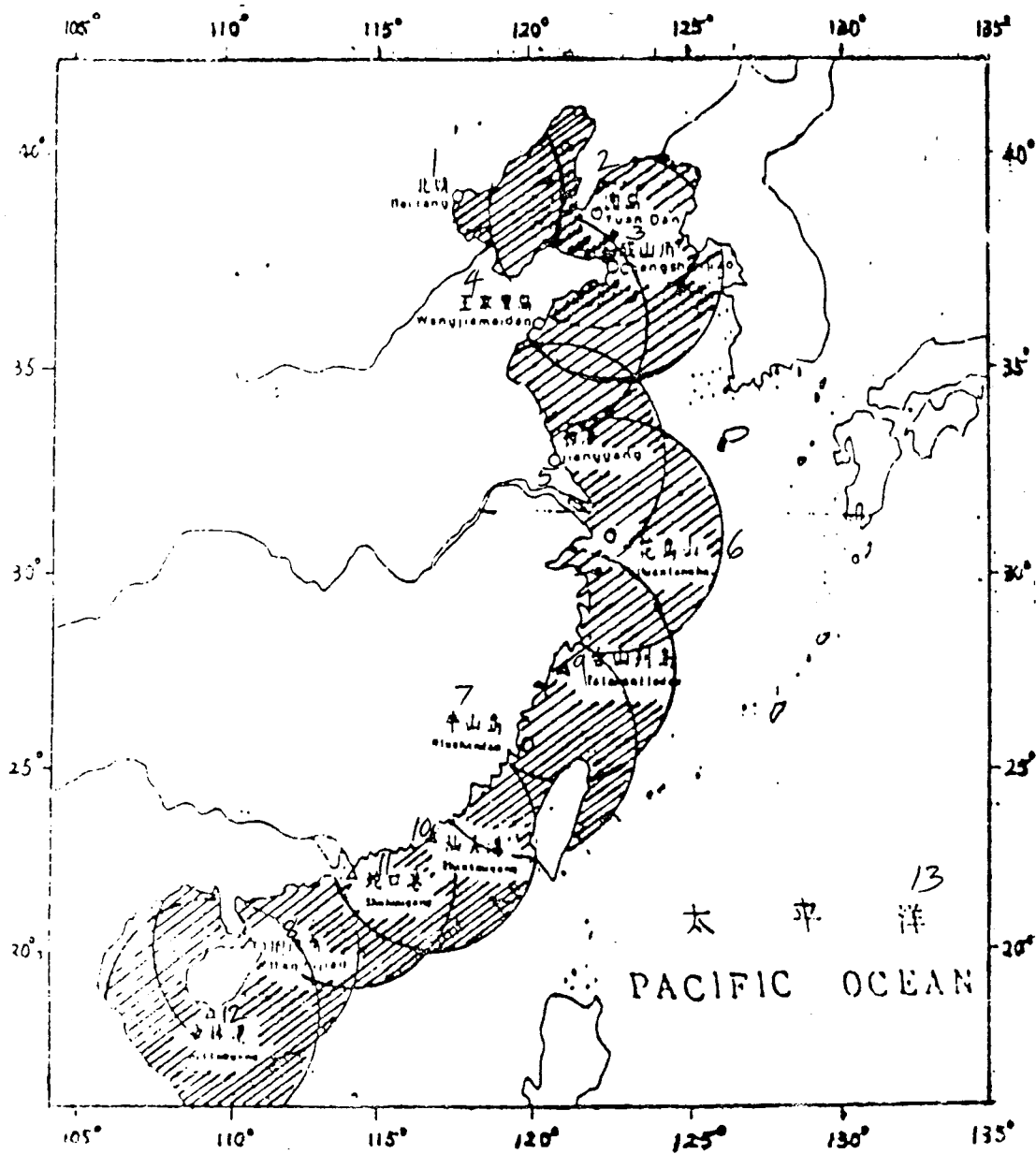


Fig. 1. Regional coverage of differential GPS navigation guidance network  
 KEY: 1. Beitang 2. Tuandao 3. Chengshanjiao  
 4. Wangjiamai 5. Qiongdao 6. Huaniaoshan 7. Niushandao  
 8. Baohujiao 9. Taishan Islands 10. Shantou Port  
 11. Shekou Port 12. Yulin Port 13. Pacific Ocean

(4) Broadcast transmitter -- the transmitter broadcasts to users the real-time differential GPS information relating to navigation guidance in certain formats on intermediate-frequency radio directional beacon signals after MSK modulation.

(5) Broadcast standard -- based on broadcast signal structure and data format recommended by the International Radio Technology Committee, and based on actual requirements of navigation guidance positioning for various applications in China, special data can be added in some typical telegrams.

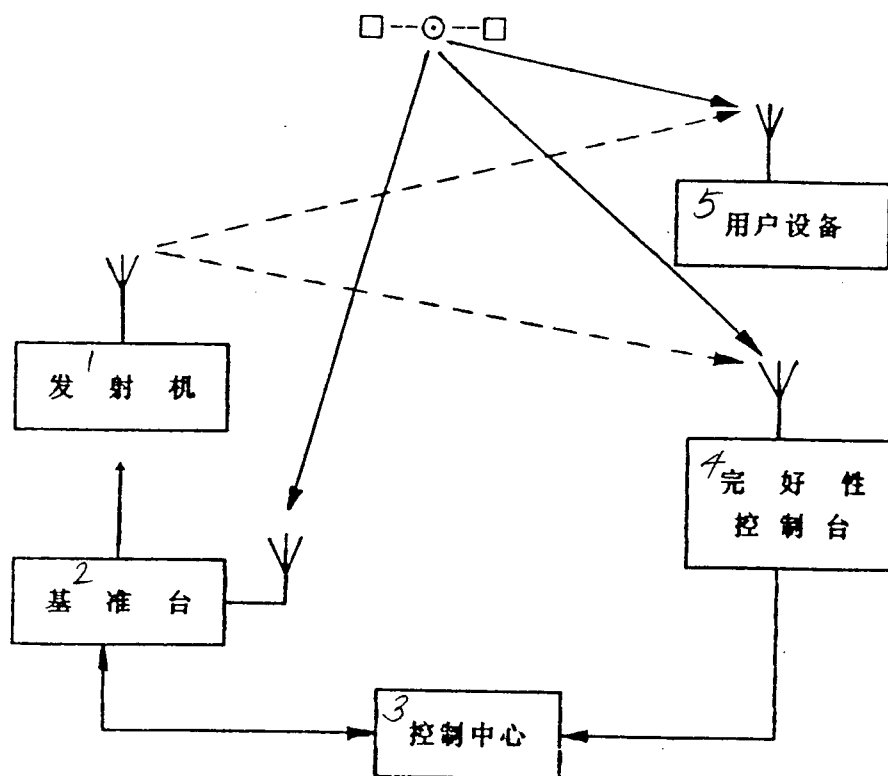


Fig. 2. Differential GPS system  
 KEY: 1. Transmitter 2. Beacon station 3. Control center 4. Ideal control station 5. User's equipment

(6) Ideal monitoring and control station -- with coordination of the beacon station control center, the station

monitors the ideality of the GPS signals and differential GPS signals.

(7) Control center -- it is composed of a set of equipment with computer control capability to manage the entire system. The control center should have the operating capability of managing the entire system in emergencies. A control center is to be established in Shanghai so that the center can control and manage the operations of the entire differential GPS system network along China's coasts.

(8) Data communications -- By using special or conventional cable connections, data communications are conducted among beacon stations, monitoring and control stations, transmitting stations, and control center.

(9) User's equipment -- user's equipment installed on board a ship not only can receive GPS signals, but can also receive the differential GPS revised signals.

#### IV. Differential GPS Data Telegrams

The format of differential GPS data telegrams should adopt such data telegram format as recommended by the RTCM-SC-104. There are three format types: standard telegram, supplementary telegram, and special telegram.

The standard telegram provides the data of pseudo-distance and revised variation rate of pseudo-distance, the status of satellite and ground stations, and the data transmission time. The supplementary telegram provides the data on ground station sites, operational status with the aid of constellations, parameters of ionospheric and tropospheric models, and the revised value of revising the additional distance for satellite telegram variation. The special telegram is used for prospecting, providing high-precision Doppler counts obtained by using carrier phase surveying.

The conventional telegram format is similar to the GPS navigation guidance telegram. The main distinctions between the telegram format types are that there are fixed lengths of various

subframes of the GPS telegram format, but the differential GPS telegram will employ the variable-length format.

No speed is specified in this data telegram format; however, it is suggested at 50bits per second, the same as for the GPS. By using this speed, a precision of better than 5m can be ensured even when two continuous sets of telegrams are lost. If once the SA policy is changed and this artificial error is eliminated, the requirements on data transmission speed can be lowered by more than one order of magnitude.

Fig. 3 shows the format of a conventional telegram. Each telegram frame is composed of words of several sets of 300bits. In addition, every set begins with two standard words. The following information should be included:

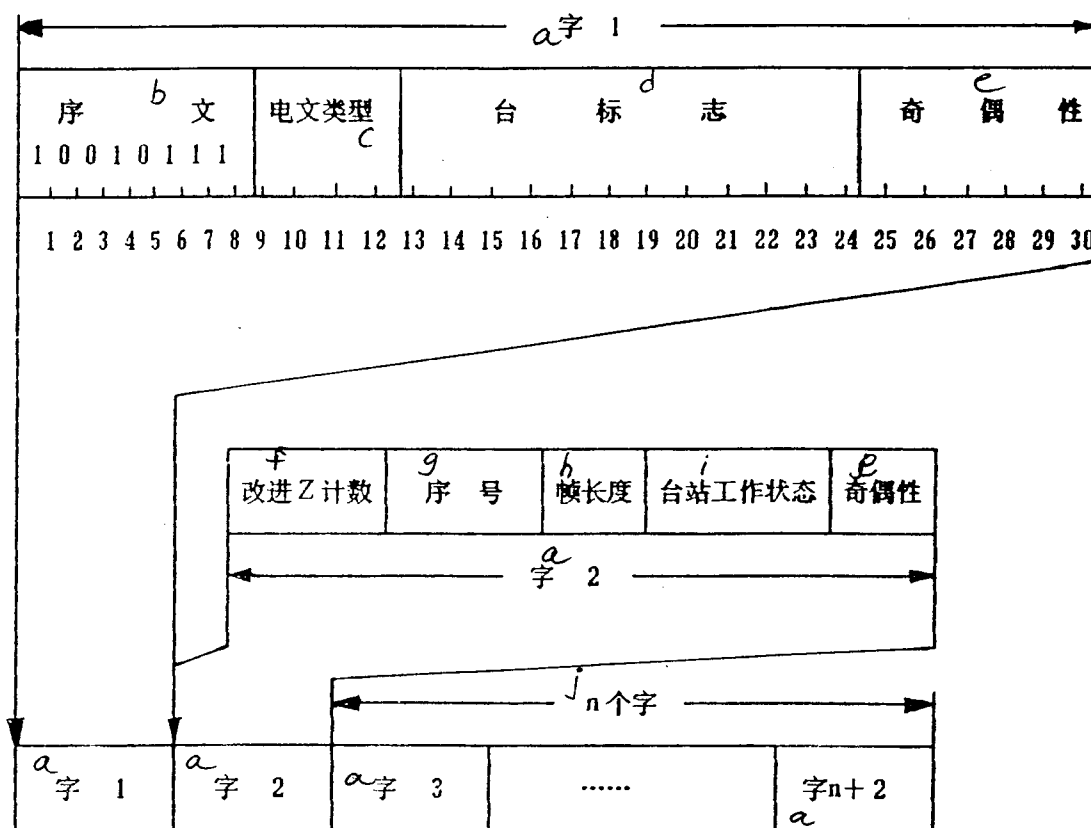


Fig. 3. Conventional telegram format:

KEY: a. Word b. Digit sequence c. Telegram types  
 d. Station beacon e. Parity f. Improved Z count  
 g. Sequence number h. Frame length i. Operational  
 status of station j.  $n$  words

1. Routine telegram;
2. Discrimination marks of telegram types;
3. Discrimination marks of stations;
4. Timing data;
5. Length of telegram frames; and
6. Information of station operational status.

#### V. Several Problems for Consideration

##### (A) Problem of coordinate conversion

Sea charts in China use the 1954 Beijing Coordinate System; however, the GPS system employs the WGS-84 Earth Center Coordinate System. There are major differences between these two systems. To adapt GPS to China, the WGS-84 should be converted to the Beijing-54 Coordinate System.

(B) The differential GPS system to be built in China should conform to the future international standards. In waters of all differential GPS systems in the world, all user equipment units with differential GPS capability should be able to receive and utilize differential GPS information for navigation guidance and positioning.

(C) Considering the economic strength of China at the present time, building of the system can proceed according to plans by steps. First, the differential GPS system can be built along waters of important function and significance in the current economic development, such as Bohai Gulf, Yangtze River Estuary, Taiwan Straits, and the Pearl River Estuary, among others, in order to solve the problems of port traffic jams and blocking in future growth.

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- [2] Collected Papers at the 1992 Annual Meeting of Communication and Navigation Guidance Technology of China Maritime Society.
- [3]

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