Signal Definition of QZSS IMES and its Analysis

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BIOGRAPHY

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Kazuki Okano is a chief engineer at GNSS Technologies Inc. He is involved in hardware design and development for Pseudolites and IMES.

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Masahiro Asako is a director of engineering department and supervises software and hardware development. He has more than 25 years of experience in the GNSS related technologies and applications.

Hideyuki Torimoto is a president of GNSS Technologies Inc. He is one of the pioneers of satellite navigation related application businesses such as car navigation, earthquake monitoring, marine and air navigation, cell-phone based timing in Japan. He established Trimble Japan in 1986. In 2002, he founded GNSS Technologies Inc. to promote R&D as well as marketing in the field of GNSS in Japan. He is managing GNSS R&D including IMES for the global promotion of the technology. He served as Satellite Division Member of ION for 2003-04.

Satoshi Kogure is an associate senior engineer of JAXA. He received MS in aerospace engineering from University of Colorado in 2001. He has been working for satellite positioning system as a satellite systems engineer since 2001. He is one of the members to design and develop IMES.

Hiroaki Maeda is the founder and managing director of Lighthouse Technology and Consulting Co., Ltd (LHTC). He received Ph. D from the Tokyo University of Marine Science and Technology in 2008. Since 2003 he has been a technical lead of the Japanese satellite navigation system, QZSS. He is one of the members to design and develop IMES.

ABSTRACT

Seamless navigation and position has become one of the most important requirements for many commercial applications related with location as well as services like E911. The implementation of E911 or similar services in Japan, USA and many other countries demand cellular phones to be capable of delivering position data with specified accuracy both indoor and outdoor locations. However, the current GNSS technology is still unable to provide accurate and reliable position services in indoor areas like underground stations or other deep indoor locations. Though, there are weak signal processing capable receivers, they do need information about the satellite orbits and/or time which are normally provided by some external means. There are also positioning systems that are based on the combination of GPS and cellular phone networks. However, they still do lag in providing correct 3D information and may need infrastructure setup in the existing cellular networks which are not always possible. The accuracy that can be achieved by these systems varies based on location environment and assist data quality. The accuracy varies from few tens of meters to few hundreds of meters.

In order to overcome these problems a new signal has been defined in QZSS IS document which is known as IMES (Indoor Messaging System). IMES has been jointly developed by GNSS Technologies and JAXA. Ten PRN codes ranging from PRN ID 173-182 has been allocated for QZSS IMES use from the US government.

The signal definition of IMES is done in such a way that the current GPS receivers can process IMES signal by modifying navigation message bit decoding algorithms.
only. In this paper we present IMES signal processing using similar algorithms as for GPS signal processing (acquisition and tracking) to show that standard GPS receivers can process IMES signal. The navigation bit decoding algorithms are based on IMES message structure. The decoding of navigation message bits provides position and other related database. It does not need estimation of pseudorange since the position data are directly transmitted by the transmitter to the receiver.

INTRODUCTION

The main objective of IMES is to provide seamless position and navigation to the user with good accuracy along with related attribute data of the location where the user belongs at that particular time. In the case of emergency, how do we know that whether the victim is in the 50th Floor, room number 510 or room number 512? Or how do we know that whether the victim is in the 5th Floor below the basement in room number 110? The key point here is to identify precisely the location of the victim without any mistakes. IMES possesses these capabilities to identify the location of the user without mistake. IMES signal is designed in such a way that existing GPS receiver can use IMES signal only by modifying the firmware for decoding navigation message. This makes the same receiver to be capable of working both outdoors using GPS/QZSS signal and indoors using IMES signal leading to seamless navigation.

SIGNAL STRUCTURE

The signal structure of IMES is similar to the signal structure of GPS or QZSS. IMES uses L1C/A signal type. The only difference is in the navigation message contents. In GPS or QZSS, ephemeris, almanac, clock and other satellite related data are transmitted whereas in the case of IMES, position data are transmitted directly inside the message. The following points were considered during the signal design of IMES:

- Same hardware will be used for both indoor and outdoor positioning with minimum modifications on the firmware in the GPS chipset.
- High precision like sub-meter order is not required. Precision of position around 10m seems to be enough for users to know where they are per moderate room size, each shop or portion in shopping complex. Accuracy of such order at any time is more important than higher precision.
- Low power consumption is required for cell phone use. Smooth switching of indoor/outdoor continuous positioning is one of the key issues to decrease additional power consumption.
- Low cost transmitter is essential as well as low cost installation and maintenance of it.
- Compatibility with GPS, QZSS and other GNSS is an essential requirement. IMES signal must not cause harmful interference with other GNSS signals.

In order to share the same RF front-end as GPS and QZSS, IMES uses L1 center frequency, 1575.42 MHz and BPSK modulation, 1.023MHz Gold code family as GPS/QZSS C/A signal which is defined in IS-GPS-200D [3] and the Interface Specification for QZSS Users (IS-QZSS) [2] respectively. Table 1 shows the signal properties of IMES.

Table 1: Signal properties of IMES

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Centre Frequency</td>
<td>1575.42Mhz</td>
</tr>
<tr>
<td>PRN Code Rate</td>
<td>1.023Mhz</td>
</tr>
<tr>
<td>PRN Code Length</td>
<td>1ms</td>
</tr>
<tr>
<td>PRN ID</td>
<td>173 – 182</td>
</tr>
<tr>
<td>Navigation Message Rate</td>
<td>50bps</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Polarization</td>
<td>RHCP</td>
</tr>
</tbody>
</table>

PRN CODE

PRN codes 173-182 are assigned for ground based IMES transmitters by US government. The code table is available at [1]. These PRN numbers are designated solely for low-power terrestrial regional applications and may be simultaneously assigned to multiple regions. The generation of PRN codes for IMES is similar to GPS PRN codes. Table 2 shows the initial settings and chip delays for G2 registers to generate IMES PRN codes. G1 settings are the same as GPS PRN codes.

Table 2: IMES PRN Code Table

<table>
<thead>
<tr>
<th>PRN Signal Number</th>
<th>G2 Delay (Chips)</th>
<th>Initial G2 Setting (Octet)</th>
<th>First 10 Chips (Octet)</th>
<th>PRN Allocations</th>
<th>Orbital Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>173</td>
<td>150</td>
<td>1362</td>
<td>415</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>174</td>
<td>210</td>
<td>1654</td>
<td>123</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>175</td>
<td>345</td>
<td>510</td>
<td>1267</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>176</td>
<td>848</td>
<td>242</td>
<td>1535</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>177</td>
<td>796</td>
<td>1142</td>
<td>835</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>178</td>
<td>599</td>
<td>1017</td>
<td>750</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>179</td>
<td>350</td>
<td>1070</td>
<td>707</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>180</td>
<td>996</td>
<td>501</td>
<td>1276</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>181</td>
<td>877</td>
<td>465</td>
<td>1302</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
<tr>
<td>182</td>
<td>112</td>
<td>1568</td>
<td>211</td>
<td>O2SS-IMES</td>
<td>Ground</td>
</tr>
</tbody>
</table>

The characteristics of the IMES PRN codes are the same as GPS PRN codes. Figure 1 shows the auto-correlation of IMES PRN ID 173 with a chip delay of 512. The auto-correlation characteristics are the same as GPS PRN code. The correlation values are either +1023, +63, -65 or -1 as shown in Figure 1. Figure 2 shows cross-correlation between PRN ID 173 and 174. The correlation values are +63, -65 or -1 which are the same as in GPS PRN codes.
IMES SIGNAL

IMES signal is logged by a software receiver front-end device. The front-end logs data at 16.3676 MHz sampling frequency, 4.1304 MHz IF and four bit A/D bit resolution. Figure 3 shows IF data, power spectrum and histogram of IMES signal logged by the front-end device. The IF data looks like simply noise since GPS signal is always below the noise floor level which is the characteristics of spread spectrum. Information is not available from this signal unless the signal is de-spread or demodulated. The power spectrum plot is similar to a plot of random noise. Had there been interference from strong CW signal, there would have been a sharp peak in the plot. The histogram plot shows the spreading of bit values from -8 to +7 (four bit A/D resolution).

NAVIGATION MESSAGE

The message structure of the IMES is the same as QZSS or GPS L1C/A message structure and is defined in the annex of IS-QZSS. Currently, there are four types of IMES messages defined that are named as type “0”, “1”, “3”, and “4” as shown in the figures 4 to 7 respectively. Message type “0” contains absolute position data using three words of 30 bits each. This is the shortest message length to transmit absolute position data using latitude, longitude and floor data. Message type “1” contains position data using four words of 30 bits each and the resolution is as twice fine as the position transmitted in message type “0”. Since, floor number is considered more important than height (for inside the building data), floor number is given higher priority than height data in the current message type design. Message type “3” and “4” contains only IDs and are one and two words long respectively. It takes 0.6 sec to read one word at 50 bps. Message type “3” and “4” do not contain any position data or coordinates. The position data are retrieved from database server based on the unique ID to get the latitude, longitude, height, floor number as well as other value-added information such as guidance map, advertising and so on. Medium IDs are unique IDs assigned to each operator, for instance, department store, underground mall and etc. Medium ID works for connecting each IMES transmitter to local server established by each operator to provide LBS services to their own customers. Short IDs are defined and maintained by each operator. It is possible to define up to eight different types of message structures.
The messages can be transmitted as required. Currently, absolute position in message type “0” or “1” and unique ID combining message type “3” and “4” are planned to be transmitted with time divided multiplex manner. The absolute position is important for emergency use since user can know their position without server assist. Above procedure requests that absolute position should be broadcasted in some intervals. For example, fraction of message type “0” or “1” may be larger in the public space than commercial area. Commercial area may be more frequently transmitted ID type message for LBS information. The sequence of transmit message can be changed by the IMES operator easily by using the GUI developed for IMES.

One more point to be emphasized is “BD bit” included in the message type “3” and “4”. “BD” stands for boundary and this one bit indicates that the transmitter is located in the boundary between indoor and outdoor locations. When user moves from indoor location to outside, it is more effective in the case that receiver starts searching PRN code for GPS referring this BD bit rather than the case that receiver continues to search satellite signal to acquire them. It can help reduce power consumption of receiver. Low power consumption is significant requirement for cell phone handset.

Figure 4: IMES L1C/A message Type “0” as defined in QZSS IS Document

Figure 5: IMES L1C/A message Type “1” as defined in QZSS IS Document

Figure 6: IMES L1C/A message Type “3” as defined in QZSS IS Document

Figure 7: IMES L1C/A message Type “4” as defined in QZSS IS Document

IMES SIGNAL PROCESSING

IMES signal is transmitted by IMES signal generator and logged by a commercial software receiver front-end device. This signal was processed to study the signal characteristics of IMES signal, its feasibility as a seamless navigation device and interference analysis.

Figure 8 shows acquisition output of IMES signal for PRN ID 173. The acquisition results show a Doppler of about 1300Hz although both transmitter and receiver are stationary. The Doppler appears due to the clock errors of transmitter and receiver and hence this value will vary from device to device (basically receiver). However, this is not a problem as long as the Doppler does not exceed the search range during the acquisition process.

Figure 9 shows tracking results of IMES data. The acquisition and tracking methods used here are the same for GPS signal acquisition and tracking. Hence, the same hardware GPS receiver can also be used to process IMES signal. As in GPS signal processing, the I-channel contains signal that corresponds to navigation data bits.

Figure 8: Acquisition output of IMES signal

Figure 9: Tracking results of IMES data.
and Q-channel contains only noise. I-channel data are used to extract the navigation data bits.

The main difference between GPS and IMES signal processing is that IMES does not need to estimate pseudorange. The position data is embedded into the navigation message. Hence, a simple decoding of navigation data bits provides position data or device ID or other information based on message type. Thus it is necessary to find the message ID in the navigation data first for proper decoding. For example, if the message ID is “0”, then there will be position data that includes latitude, longitude and floor ID. The position data output can be displayed as text coordinates or over a map as shown in Figure 10. In this case, we have used Google Earth data. The output from the IMES further can be linked to external database using its device ID for LBS and other applications.

CONCLUSIONS

The signal definition of IMES is done in such a way to minimize impact on existing GPS receivers. The existing receivers only need to change its navigation message decoding firmware. The analysis of IMES signal shows that the same algorithms used for GPS work well for acquisition and tracking. The only difference is in navigation algorithms.

REFERENCES

[2] Japan Aerospace Exploration Agency, "Interface Specifications for QZSS" (IS-QZSS Ver.1.0) available from the following site: http://qzss.jaxa.jp/is-qzss/index_e.html

Figure 9 : Tracking output of IMES signal

Figure 10 : Display of IMES position data over Google Earth Image