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Input paper for the following Committee(s): check as appropriate Purpose of paper:

**□** ARM  ENG **□** PAP **□** Input

**□** ENAV **□** VTS **□** Information

Agenda item [[2]](#footnote-2) 3.1

Technical Domain / Task Number 2 …………………………………

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PROPOSALS ON THE KEY ISSUES IN THE IMPLEMENTATION OF THE VHF R-MODE

# summary

This proposal gives suggestions on the key technical issues of the implementation of the R-Mode in the VHF band, including: the synchronization scheme of the R-Mode base station, the ranging message and its format, and the transmission slot map of the ranging signal. This proposal describes the specific design of the synchronization solution of the R-Mode base station, analyses its characteristics. And gives preliminary test results in the annex. This proposal explains the specific format of the ASM navigation message. And tests ranging performance of the ASM training sequence and parameter of the transmitter delay in the navigation message in the annex. This proposal also discusses the synchronous transmission and asynchronous transmission of the ranging signal, compares their advantages and disadvantages. And tests weak signal shielding due to adjacent channel interference of the synchronous transmission in the annex. The committee is invited to review the suggestions given in this document and discuss whether to adopt them.

# Purpose of the document

The purpose of this proposal is to give suggestions on key technical issues such as R-Mode base station synchronization, navigation messages and their transmission strategies, and to provide support for the writing of the *DRAFT on Implementation of R-Mode on MF and VHF frequencies* document.

# Background

In order to reduce the impact of GNSS service interruption on maritime navigation and ensure the safety of ships, ships should be equipped with space-based and land-based dual backup ship positioning and navigation systems. R-Mode is a low-cost land-based positioning and navigation system that utilizes the existing maritime radio communication infrastructure.

The "AIS Ship Autonomous Navigation System" AAPS project in China (2012-2015) initially realized the positioning function of the AIS R-Mode system, and conducted theoretical research on the VDES R-Mode in 2016-2017. Based on the above researches, the Project of VDES R-Mode Testbed (2018-2020) has built an R-Mode testbed in the Yellow and Bohai Sea. At present, the project has completed laboratory and ranging and positioning experiments on land, furthermore, R-Mode base station equipment has been deployed, and maritime experiments are being deployed.

This article is based on the research results of the VDES R-Mode Testbed Project, and gives suggestions on the key technical issues of the implementation of the VHF band R-Mode.

# discussion

## R-Mode base station synchronization solution

R-Mode base station synchronization is an important prerequisite for realizing R-Mode autonomous positioning. Base station synchronization error would directly affect the accuracy of autonomous positioning. This proposal provides a solution for R-Mode base station synchronization, including: 1. Synchronize with UTC time when GNSS is valid; 2. Use rubidium clock to maintain UTC synchronization when GNSS fails for a short time; 3. When GNSS fails for a long time, synchronize with wireless reference base station. This solution has strong self-healing properties and is not subject to regional restrictions and influences. Compared with the R-Mode global time synchronization solution, although this solution cannot achieve high-precision time synchronization for all base stations, the synchronization accuracy of adjacent base stations is relatively high, and the construction cost is low. In addition, ships in the AIS/VDES system can only receive signals from adjacent base stations in a limited area.

### Overall Design

Based on the scheme figure given in section 3.3 PHYSICAL R-MODE ARCHITECTURE of *DRAFT on Implementation of R-Mode on MF and VHF frequencies,* the design of three R-Mode stations has been realized.



*Figure1 Physical system architecture*

It is recommended to change the “R-Mode Transmitter” in the schematic diagram to “R-Mode Transceiver”, which indicates the device can not only transmit R-Mode navigation messages, but also receive navigation messages from other base stations, to realize functions such as reference station synchronization. In addition, in order to maintain the validity of the 1PPS signal in the case of GNSS failure, the data flow direction between the Timing device and the R-Mode Transceiver is changed to bidirectional, so that the received time information of other base stations can be used to synchronize with reference station, adjusting the 1PPS pulse phase of the Timing device.

The working process of the R-Mode base station synchronization system is shown in Figure 2. The specific process is as follows:

（1）Determine whether the GNSS is valid: if it is valid, the UTC synchronization mode will be performed. Otherwise, it will determine the invalid duration of GNSS.

（2）If the invalid duration exceeds a certain time, it will enter the wireless reference station autonomous synchronization mode; if the GNSS invalid duration is within the set range, use the disciplined rubidium clock to maintain the UTC synchronization mode.



*Figure2 The workflow of the synchronization system*

### GNSS is Valid

When the GNSS signal is valid, the base station synchronization system mainly completes the following tasks:

(1) The rubidium clock disciplined equipment uses the UTC time provided by the GNSS system to discipline the rubidium clock to obtain a more stable PPS signal. At the same time, it also obtains a higher stability of the rubidium clock 10MHz output clock for R-Mode base station equipment.

(2) R-Mode base station records the received ranging value of other shore-based equipment, and calculates the system delay error generated in the transmitter and receiver equipment based on the known distance information for Ranging correction in autonomous synchronization mode.

### GNSS is Short-Term Invalid

During the short-term failure phase of GNSS signals, the rubidium clock can be used to maintain UTC time synchronization. In this process, the synchronization accuracy will gradually become worse.

### GNSS is Long-Term Invalid

If GNSS is invalid for a long time, start the wireless reference station autonomous synchronization mode. R-Mode base station receives the signal from the wireless reference station, obtains the ranging information and the timing of the reference station, and then with the known distance between base stations to correct the timing, and realize the synchronization with the reference station eventually.

The base station that cannot directly receive the signal of the wireless reference station will synchronize with the reference station indirectly. Although the high-precision synchronization of the whole system base station cannot be guaranteed, the synchronization precision of the adjacent base station is relatively high, which can meet the requirements of the ship's autonomous positioning.

## Ranging Message

It is recommended to use ASM message 10 to schedule broadcast message transmission ranging messages. Its training sequence can be used to obtain ranging values. The specific format of message is suggested as shown in Table 1.

Table-1 ASM message 10 format

|  |  |  |
| --- | --- | --- |
| Parameter | Length(bit) | Comment |
| Message ID | 4 | Identifier for Message 10;  always 10 |
| Source ID | 32 | MMSI number of source station |
| Reserved | 4 | Set to 0 |
| Shore station longitude | 32 | Longitude in 1/10 000 min |
| Shore station latitude | 32 | Latitude in 1/10 000 min |
| UTC year | 14 | 1-9999 |
| UTC month | 4 | 1-12 |
| UTC day | 5 | 1-31 |
| UTC hour | 5 | 0-23 |
| UTC minute | 6 | 0-59 |
| UTC second | 6 | 0-59 |
| Synchronization States | 2 | 0.GNSS valid；  1.GNSS short-term invalid；  2. GNSS long-term invalid，synchronized with reference station；  3. GNSS long-term invalid and is not synchronized with the reference station。 |
| Slot number /Communication status | TBD | TBD |
| Differential correction parameter | TBD | Set to 0 |
| Reserved | TBD | Set to 0 |
| Total | 352 |  |

## Transmission slot map of ranging signal

### Synchronous Transmission of Ranging Signals

1. ASM message

When only the ASM signal is used for positioning, the transmission rule of the base station ranging signal will be carried out in the manner shown in Figure 3. The transmission modes of all base stations are divided into three types: A, B and C:

* Class A base stations continuously transmit two slots on channel 1, and then stop one slot;
* Class B base station transmits one slot on channel 2 first, and after a slot interval, transmits one slot on channel 1;
* Class C base stations stop for one slot, and then continuously transmit two slots on channel 2.

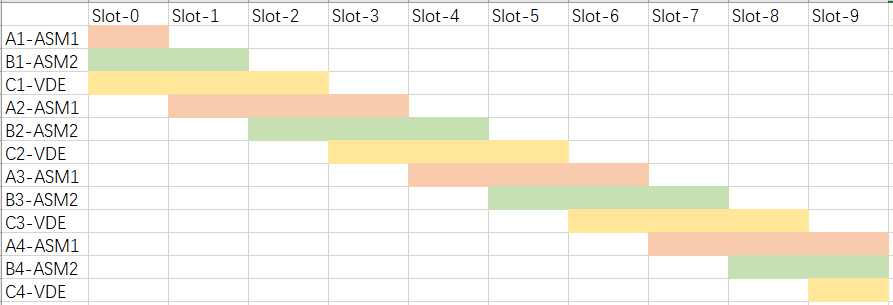
The base station management system first defines the base station as A1, B1, C1; A2, B2, C2. At the beginning of the transmission period (for example 6s), transmit ASM ranging signals in order of A1 B1 C1; B1 C1 A2, C1 A2 B2, A2 B2 C2....



*Figure3. ASM ranging signal synchronous transmission slot diagram*

1. ASM+VDE message

When the ASM and VDE signals are both used for positioning, the transmission rule of the base station ranging signal will be carried out in the manner shown in Figure 4. The transmission modes of all base stations are also divided into three types: A, B and C mode, and the ranging signals are transmitted on the ASM1, ASM2 and VDE channels respectively. The management system first numbers the base stations according to the relationship of geographic location as A1, B1, C1, A2, B2, C2, A3, B3, C3.... At the beginning of the transmission period (for example, 6s), the ranging signals are transmitted sequentially in the order of A1, B1, C1; B1 C1 A2; C1, A2, B2...



*Figure4 ASM+VDE ranging signal synchronization transmission slot diagram*

### Asynchronous transmission of ranging signals

The asynchronous transmission rule of the base station ranging signal can be as shown in Figure 5. The base station management system firstly numbers the base stations according to the position as No1, 2, 3, 4, 5, 6..... At the beginning of the transmission period (e.g. 6s), the ranging signal is transmitted on the same channel (e.g. the ASM1 or ASM2 or VDE channel) in sequence in the order of numbers.



*Figure5 ASM ranging signal asynchronous transmission slot map*

### Comparison of synchronous and asynchronous transmission of ranging signals

Compare the methods of synchronously and asynchronously transmitting ranging signals, as shown in Table 2. It shows that the synchronous transmission of ranging signals will reduce the error of the receiver clock jitter and the error of time different of arrival (TDOA) caused by ship motion. However the complexity of synchronous transmission is higher and the signal strength received by the receiver in the same slot should be similar; otherwise, the ranging performance of weak signals would be affected.

Table-2 Comparison of synchronous and asynchronous transmission of ranging signals

|  |  |  |
| --- | --- | --- |
| **Performance** | **Synchronous** | **Asynchronous** |
| The complexity of the receiver system | Complex | Simple |
| The complexity of the shore station monitor | Complex | Simple |
| The complexity of the shore station transmission system | Complex | Simple |
| The difference of signal strength received by the receiver | The signal strength difference must be less than a certain value, otherwise the weak signal will be sheltered and the ranging value cannot be obtained. | There is no restriction for receiving in different slots. |
| Receiver ranging accuracy | When receiving in the same slot, the errors caused by the clock jitter of the receiver and ship motion are the smallest. (Low cost oscillator like TCXO can be used in receiver.) | When receiving in different slots, errors caused by the clock jitter of the receiver and ship motion are larger. (High cost Oscillator like OCXO should be used in receiver.) |

# Action requested

The ENG committee is invited to review the information of this paper and provide comments.

1. Relevant design instructions and test results
2. background

GNSS has inherent vulnerability. In order to ensure the navigation safety of ships, IMO recommends that ships should be equipped with both space-based and land-based ship positioning and navigation systems. R-Mode is a land-based positioning and navigation system that uses the existing maritime radio communication infrastructure to transmit synchronized ranging signals for distance measurement and positioning. It can reduce the impact of GNSS service interruption on maritime navigation and make full use of the existing shore equipment to minimize the cost of infrastructure. IALA's application for R-Mode technology has been passed at the ITU Conference, and it is planned to issue R-Mode technical standards in 2023.

Countries are actively carrying out R-Mode technology research. The European ACCSEAS project (2012-2015) demonstrated the feasibility of R-Mode technology, and the R-Mode Baltic project (2017-2020) will build R-Mode testbeds in the Baltic Sea. "AIS Ship Autonomous Navigation System" AAPS project in China (2012-2015) initially realized the positioning function of the AIS R-Mode system, and conducted theoretical research on the VDES R-Mode in 2016-2017. Based on the above researches, the Project of VDES R-Mode Testbed (2018-2020) has built an R-Mode testbed in the Yellow and Bohai Sea, mainly focusing on: (1) shipborne terminal without Rubidium clock; (2) Long-term autonomous synchronization of multiple base stations; (3) Specific VDES navigation messages.

1. system framework

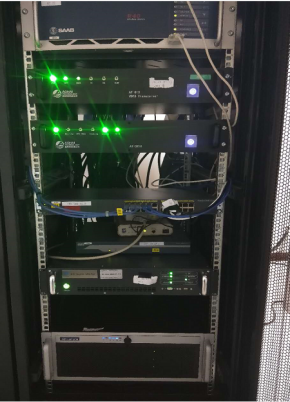
The system framework of the VDES R-Mode Testbed Project is shown in Figure 1. The system mainly includes a base station synchronization system, AIS/VDES R-Mode autonomous positioning system, integrity monitoring system, and VHF wireless channel measurement and correction system.



Figure1 System framework of VDES R-Mode Testbed Project

1. construction status

At present, the Project of VDES R-Mode Testbed has completed ranging and positioning tests in laboratory condition and terrestrial condition. And R-Mode base station devices have been installed in 3 locations, as shown in Figure 2. Tests at sea are currently being deployed.



|  |  |  |
| --- | --- | --- |
| (a)Huangbaizui | (b)Beihuangcheng | (c)Laotieshan |

Figure2 Construction status of VDES R-Mode Testbed Project

1. Test results
   1. Base Station Synchronization
      1. Design description

Based on the scheme figure given in section 3.3.PHYSICAL R-MODE ARCHITECTURE of *DRAFT on Implementation of R-Mode on MF and VHF frequencies*, the design realizes three R-Mode stations.

* + 1. Test results

Test method：Three Timing devices are connected to GNSS antennas. After the GNSS is normally positioned, use an oscilloscope to observe the phase difference of the three 1PPS signals. After removing the GNSS antennas of the three Timing devices, the oscilloscope continued to observe the phase difference of the three 1PPS signals.

Test environment: normal temperature: 15℃～35℃; relative humidity: 20%～75%.

Test result: When GNSS is valid, the phase difference of the three 1PPS signals is less than 20ns. Within 1 hour after removing the GNSS antenna, the phase difference of the three 1PPS signals remained less than 100ns.

* 1. Ranging of training sequence in the navigation message
     1. Design description

There are 27-symbol training sequences in the ASM signal specified by the ITU-2092-0 standard, and the distance measurement value is obtained by using the correlation of the Barker code.

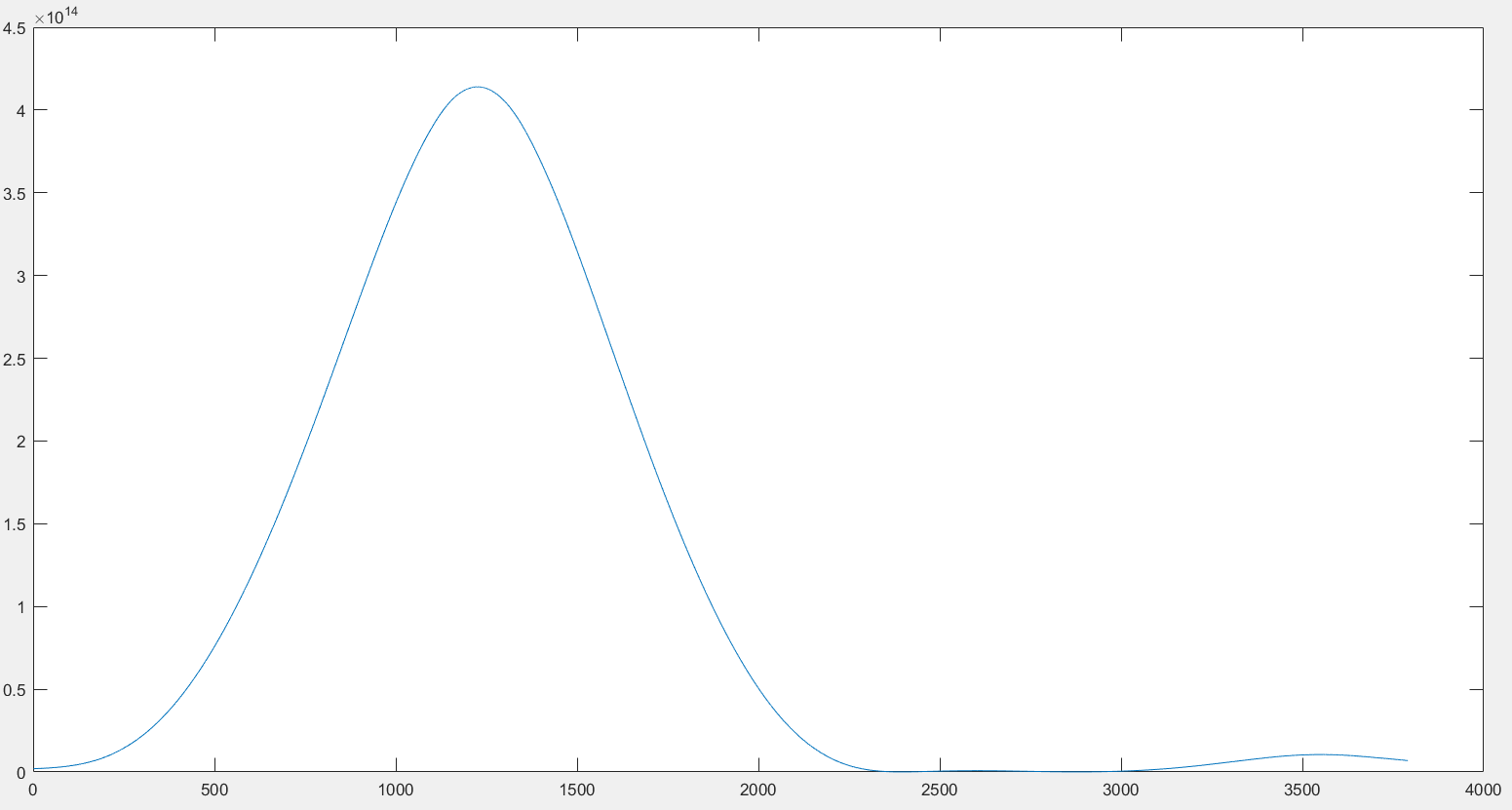
* + 1. Test results

Test method: The transmitter generates and transmits the ASM ranging message, the receiver receives and stores the signal of the training sequence part to make correction calculation.

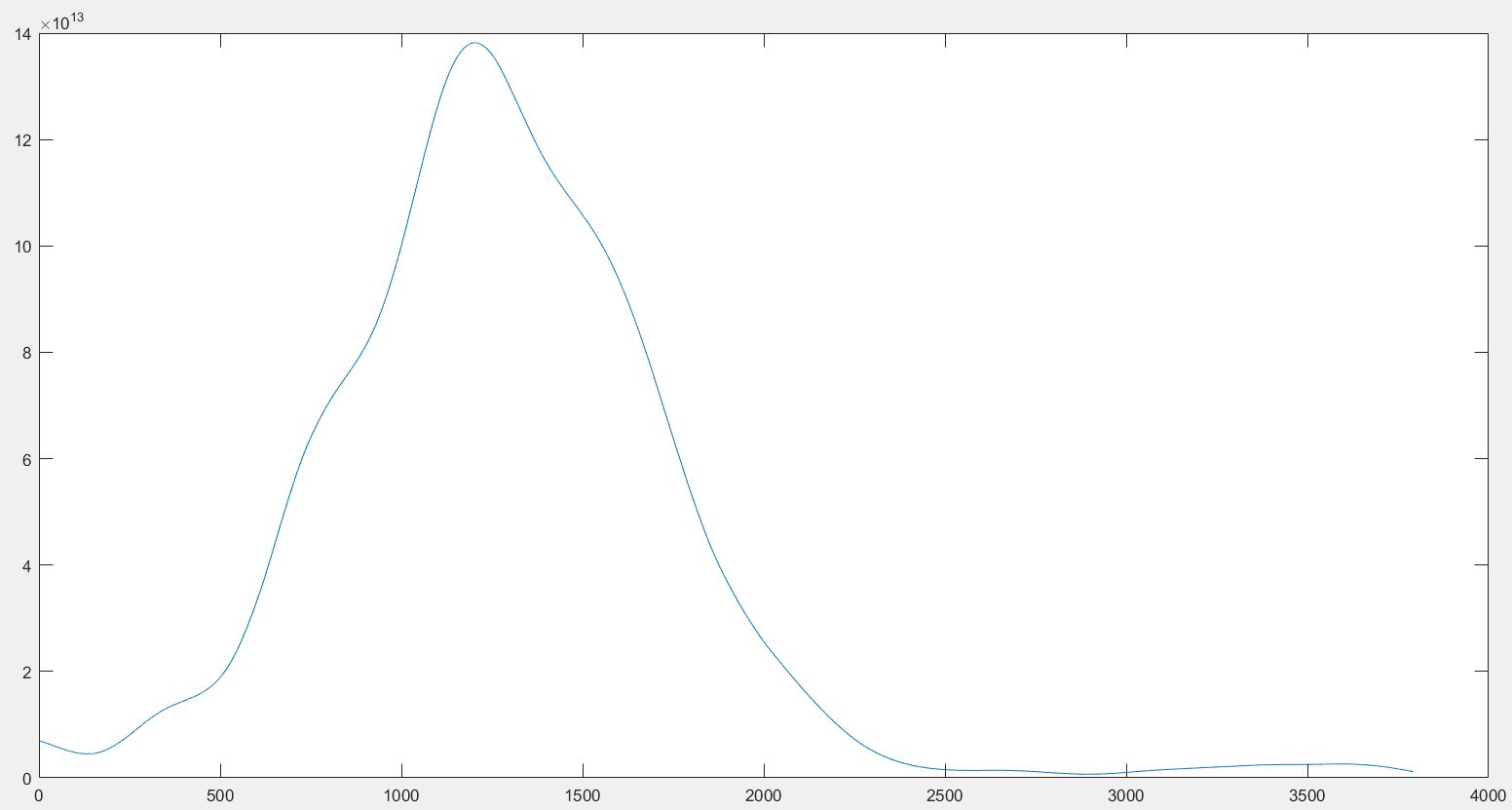
Test environment: normal temperature: 15℃～35℃; relative humidity: 20%～75%.

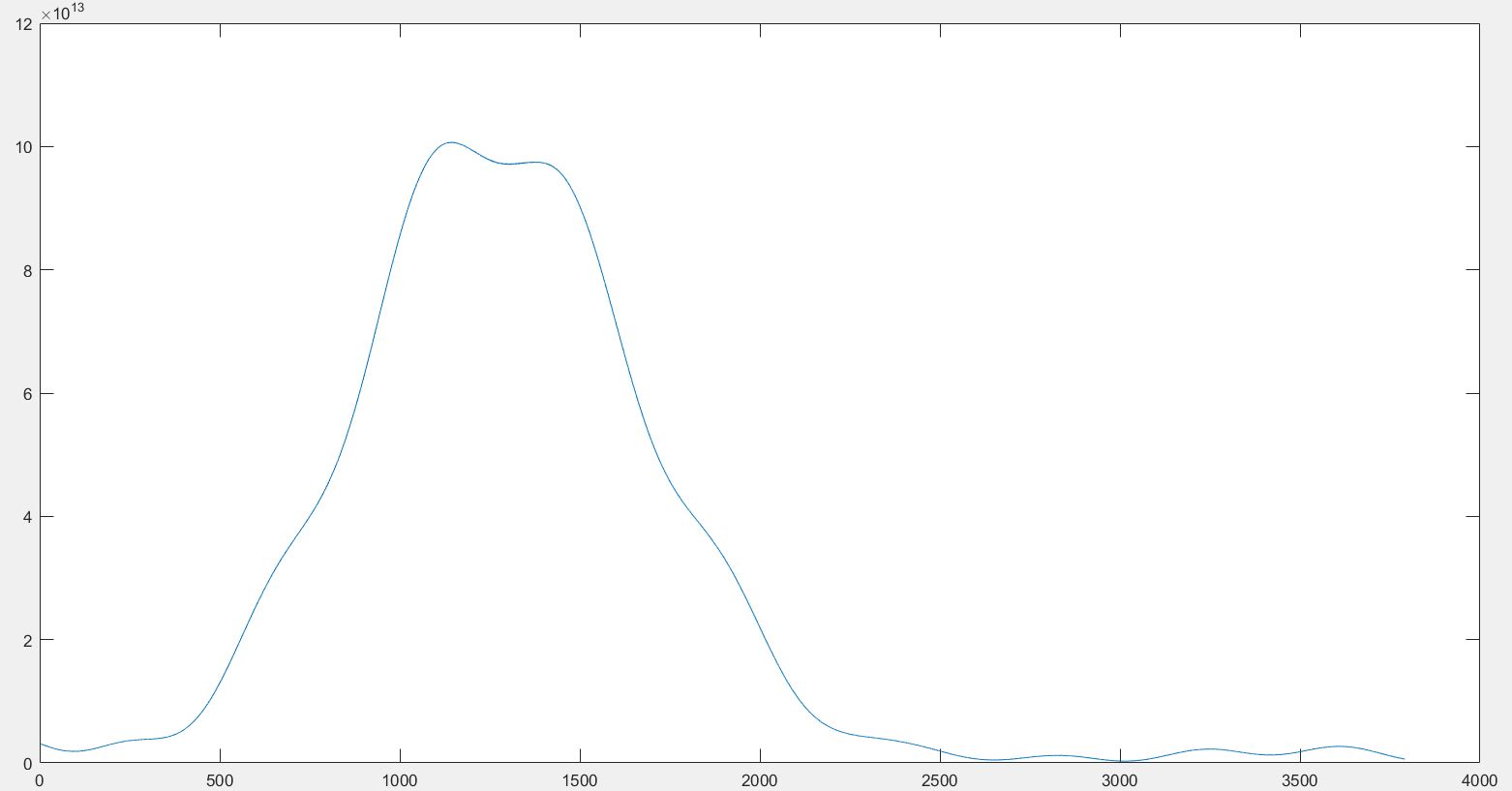
Test data: According to the ASM signal format specified in the ITU-2092-0 standard, the transmitter generates and transmits standard ASM test signals.

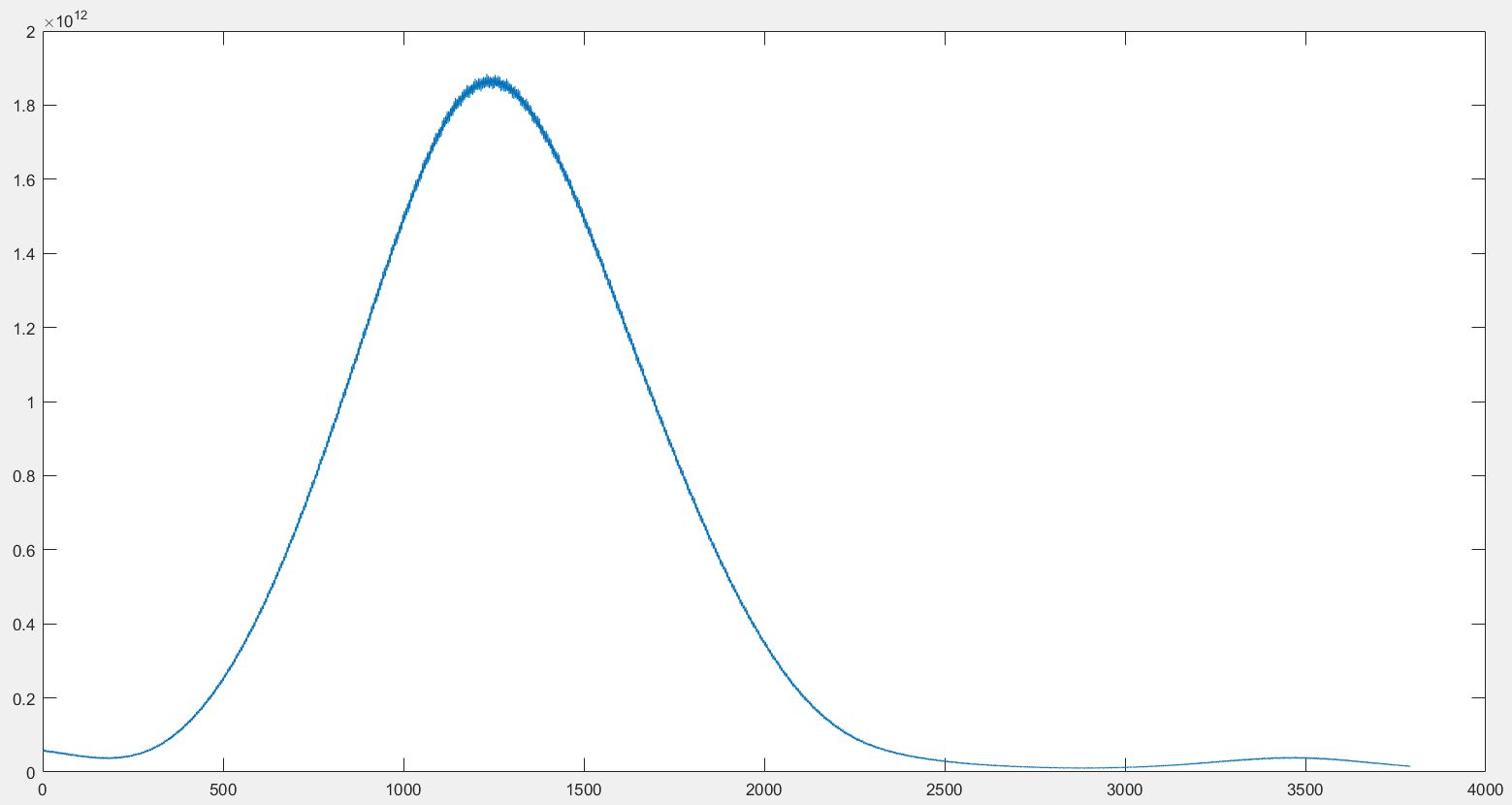
The test result is shown in Figure 3. The maximum value of the correlation value and its fixed correlation curve shape can be used to obtain accurate delay information.



1. Received ASM signals without obvious interruption







1. Received ASM signals with obvious interruption

**Figure 3 Ranging by Training sequence correlation curve**

* 1. Transmitter delay in the navigation message
     1. Design description

Transmitter delay refers to the time delay from the slot edge of the base station transmitter to the phase centre of the transmitting antenna. If the delay is sent to the user as a navigation message for correction, it will increase the complexity of the receiver. The number of the receivers is far greater than the number of base stations. Therefore, it is recommended to compensate this delay in the base station to ensure that the time when signal reaches phase centre of the transmitting antenna coincides with the slot edge.

The transmitter delay can be divided into two parts. One is the delay from the slot edge to the output of the power amplifier, that is also the input of antenna. Another is the delay from the antenna input to the phase centre of the transmitting antenna. The latter mainly depends on the length of the antenna feeder. The following tests the first part, that is, the transmitter delay of the transmitted signal at the beginning of the slot to the antenna input.

* + 1. Test results

Test method: Triggered by the slot edge of the transmitter to make the VHF signal change suddenly, and measure the delay when the suddenly changed signal appears at the antenna input.

Test environment: normal temperature: 15℃～35℃; relative humidity: 20%～75%.

Test data: VHF carrier signal.

Test Results:

Table-1 Test results

|  |  |  |
| --- | --- | --- |
| Number | Transmitter | Delay |
| 1 | Transmitter 1 | 1015ns |
| 2 | Transmitter 2 | 974ns |
| 3 | Transmitter 3 | 997ns |

* 1. Synchronous transmission of ranging messages
     1. Design description

According to the slot diagram shown in Figure 3 in the proposal, two different shore stations respectively transmit ASM1 and ASM2 signals in the same slot, and the receiver will receive the signals of the two channels at the same time. When the two received signal strengths are very different, the weak signal will be sheltered and an effective ranging value cannot be obtained.

* + 1. Test results

Test method: The signal generator generates ASM1 and ASM2 signals at the same time, and sets the signal power to different values respectively. The receiver receives two signals at the same time for ranging, and tests the validity of the ranging value.

Test environment: normal temperature: 15℃～35℃; relative humidity: 20%～75%.

Test data: According to the ASM packet format specified in the ITU-2092-0 standard, the transmitter generates and transmits standard ASM test signals.

The test results are as follows:

Table-2 Test results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Number | ASM1 power | ASM2 power | ASM1 ranging value | ASM2 ranging value |
| 1 | -7dBm | -67dBm | Valid | None |
| 2 | -7dBm | -66dBm | Valid | None |
| 3 | -7dBm | -63dBm | Valid | Valid |
| 4 | -7dBm | -60dBm | Valid | Valid |
| 5 | -7dBm | -57dBm | Valid | Valid |
| 6 | -7dBm | -54dBm | Valid | Valid |

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