AEGIR – Asynchronous Radiolocation System

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Abstract— **Humans have always wanted to determine position in an unknown environment. At the beginning methods were simple. They were based on the observation of characteristic points, in the case of shipping additional observations of the coastline. Then came navigation based on astronomical methods (astronavigation). At the beginning of the XX-century a new way of determining the current location was developed. It has used radiowave signals. First came radio-beacons. Then ground-based systems came. Currently satellite systems are being used. At present, the most popular one is Global Positioning System (GPS). This system is fully controlled by the Department of Defense, and only the U.S. forces and their closest allies have been guaranteed accuracy offered by the system. Armies of other countries can only use the civilian version. This situation has engendered the need for an independent radiolocation system. This article describes the construction and operation of such a technology demonstrator that was developed at Gdansk University of Technology. It was named AEGIR (according to Norse mythology: god of the seas and oceans). The main advantage of the system is managing without the chain organization of the reference stations, which work now with each other asynchronously. This article demonstrates the functionality of such system. It also presents results and analysis of its effectiveness.**

Keywords- navigation; hyperbolic systems; radiolocation; AEGIR; TDOA.

I. INTRODUCTION

Global Navigation Satellite System (GNSS) is seen by terrorists or hostile countries as a high value target. Volpe Center report contains the following statement [1]: “During the course of its development for military use and more recent extension to many civilian uses, vulnerabilities of Global Navigation Satellite Systems (GNSS) – in the United States the Global Positioning System (GPS) – have become apparent. The vulnerabilities arise from natural, intentional, and unintentional sources. Increasing civilian and military reliance on GNSS brings with it a vital need to identify the critical vulnerabilities to civilian users, and to develop a plan to mitigate these vulnerabilities.”. GNSS can also be targeted by more common criminals - computer hackers and virus writers. Therefore, there is a need for maintenance and continued development of independent radionavigation and radiolocation systems.

Based on many years of experience in the field of modern radiocommunication systems in the Department of Radiocommunication Systems and Networks at Gdansk University of Technology, in cooperation with the OBR Marine Technology Centre in Gdynia and with the support of the Hydrographic Office of Polish Navy a ground-based radiolocation system, which was named AEGIR has been developed, built and tested in real environment. In this system, all reference stations are working in an asynchronous way, so each station uses a local generator to transmit a message location and can receive signals from neighboring stations. On the basis of the received signals reference station determines the time difference between its own rhythm of work, and the neighboring reference stations. The measurement results are periodically placed in the localization message. The receiver on the basis of self-measurements and measurements from the reference stations estimates its location. Compared to existing solutions like Loran-C (Long Range Navigation - C) [2], the AEGIR system resigns chain relationship between reference stations. In the proposed system, there are no supervision centers for maintenance which reduces operating costs and increases system reliability. With this approach, our system has gained new features and new functionality compared to traditional solutions.

This paper at the beginning will present basics of the TDOA method. Then principle of asynchronous system will be described. The next section describes hardware implementation of the presented system. The last two describes investigation results and a brief summary.

II. HYPERBOLIC SYSTEMS – TDOA METHOD

As mentioned before, the AEGIR system is a ground based radiolocation system. Therefore a measurement method of Time Difference Of Arrival (TDOA) was chosen to estimate the position of a localizer. Suppose there are N ground stations, the coordinates for the i-th station are $S_i = (x_{Si}, y_{Si})$, where i = 1, ..., N, and the search object's coordinates are $M = (x_M, y_M)$.

If you define a signal propagation time between the i-th station and the searched position in the point M as T_i, so the distance between the i-th station and the point M is as follow:

$$d_i = T_i \cdot c = \sqrt{(x_{Si} - x_M)^2 + (y_{Si} - y_M)^2}, \quad (1)$$

where:

c - velocity of wave propagation ($3 * 10^8$ m / s)
T_i - the propagation delay between the i-th station and the point M,
d_i - distance between i-th station and the point M.

Timing differences between the i-th station and the first one, can be written as:

$$T_{i1} = T_i - T_1, , \quad (2)$$

Differences in the distances between those stations, can be described by the following relationship:

$$d_{i1} = T_{i1} \cdot c = d_i - d_1, \quad (3)$$

After putting equation (1) in equation (3) we obtain hyperbolic equation:

$$d_{i1} = \sqrt{(x_{Si} - x_M)^2 + (y_{Si} - y_M)^2} - \sqrt{(x_{S1} - x_M)^2 + (y_{S1} - y_M)^2}. \quad (4)$$

Equation 4 presents the difference in distance between the first and i-th station.

Determination of the distance difference between another pair of base stations generates more hyperbolas and a point of their intersection gives us a position. There are many algorithms [3-6], which allow to determine the coordinates. For the purpose of the system the Chan method was chosen [3], because it gives results without iterative calculations and additionally it is simple to implement.

III. ASYNCHRONOUS SYSTEM

As mentioned in the introduction, the AEGIR system is fully asynchronous. The principle of asynchronous method can be illustrated as follows. Assume that we have three reference stations positioned as in Fig. 1.

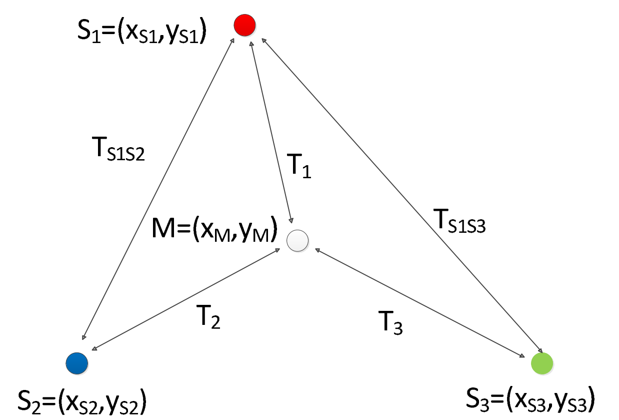

Fig. 1. Deployment of ground stations to illustrate the method of TDOA

Propagation time from the stations S_1, S_2 and S_3 to desired position in the point M (localizer) is respectively T_1, T_2 and T_3. Each station has coordinates as follows: $S_1=(x_{S1}, y_{S1})$, $S_2=(x_{S2}, y_{S2})$ and $S_3=(x_{S3}, y_{S3})$. Stations transmit a reference signal, for simplicity, as an impulse, but time of broadcasting these impulses, as shown in Fig. 2a, is random. The stations have the ability to "listen to" neighboring stations. This is illustrated in Fig. 2b. Reference station designated as S1 receives signal from other two stations: S2 and S3, and calculates the time difference between its own and these stations' signals (nT_{21} and nT_{31}). These time differences are then sent to the localizer. The localizer (at point M) (pictured in Fig. 2c) sets its own time difference between the received impulses from the reference station (dT_{21} and dT_{31}).

Additionally, each ground station sends to the localizer its own coordinates (respectively x_{S1}, y_{S1} - the coordinates of the first station; x_{S2}, y_{S2} - coordinates of the second station; x_{S3} and y_{S3} - coordinates of the third station), so that the localizer calculates the propagation time between the reference stations (T_{S1S2}, T_{S1S3}).

Taking into account all sent data, the localizer (at point M) calculates a real difference in time propagation between stations, which present the following equation:

$$\begin{aligned} T_{21} &= nT_{21} - dT_{21} - T_{S1S2} \\ T_{31} &= nT_{31} - dT_{31} - T_{S1S3} \end{aligned}, \quad (5)$$

The time differences defined in this manner allow to determine coordinates of searched object M using one of the algorithms [3-6].

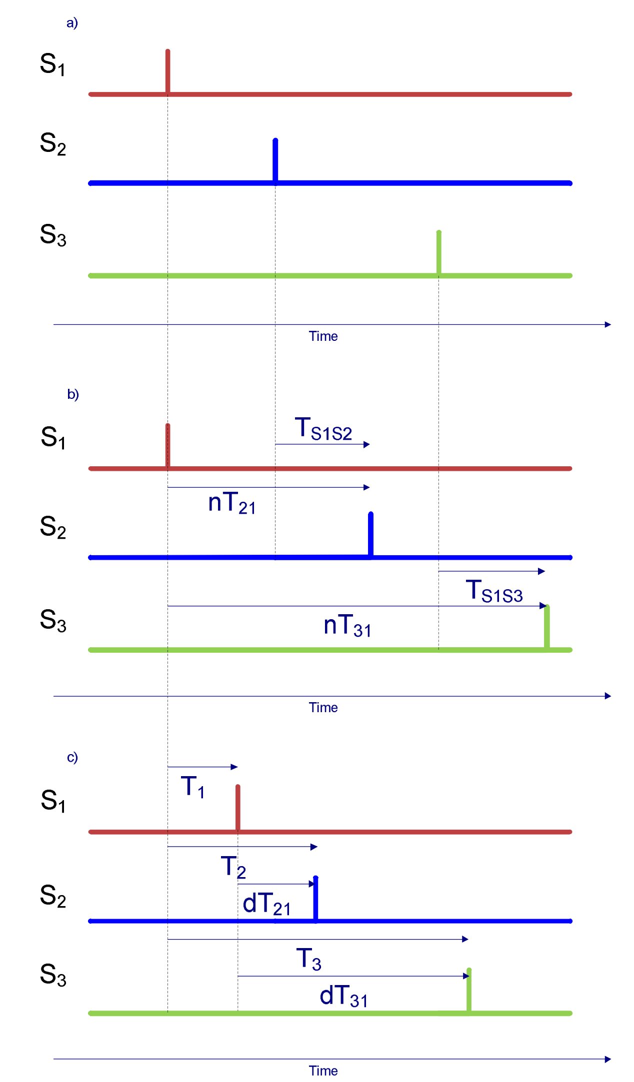

Fig. 2. Timing between signals broadcasted by base stations in an asynchronous system, a) the moment of broadcasting impulses by the stations b) the time of receipt of impulses by S_1 station c) the time of receipt of impulses by the localizer in point M [8,9]

IV. HARDWARE IMPLEMENTATION

The AEGIR system has been built as a demonstrator of technology. The system consists of a localizer and three reference stations.

The block diagram of a localizer is presented in Fig. 3.

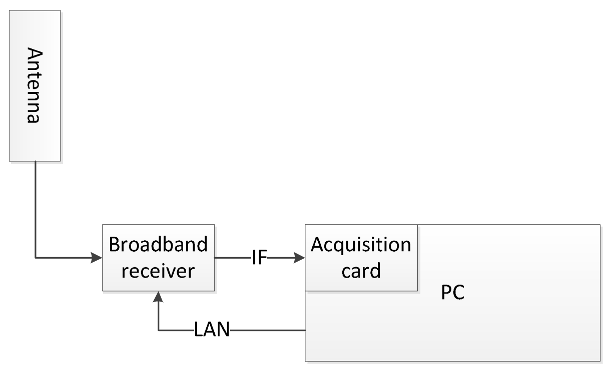

Fig. 3. Block diagram of a localizer.

The localizer has been made in the technology of Software Defined Radio [7]. It consists of: an antenna, a broadband receiver, an analog to digital converter (in the form of data acquisition card) and a digital signal processor (in form of PC). This approach allows to shape flexibly functionality of the localizer.

Ground stations, as it was mentioned before, have the ability to "listen to" neighboring stations. It is assumed that the system should consists only of such stations (Master ones). However, for demonstrable purposes only one Master station is required. Therefore, two types of ground stations were created: broadcasting stations (Slave type) and broadcasting and listening ones (Master type).

The block diagram of a Slave station is shown in Fig 4.

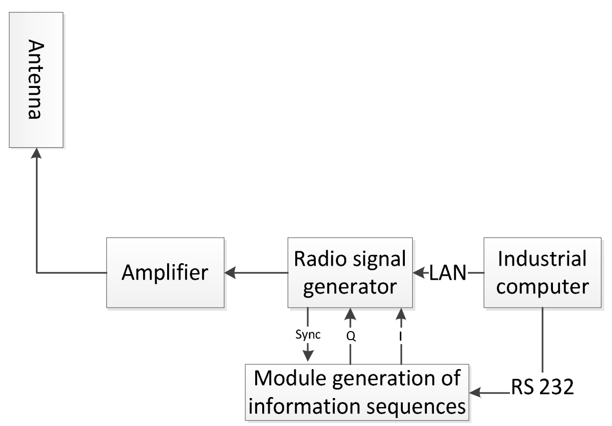

Fig. 4. Block diagram of a Slave station

The main element of the station is a radio signal generator, whose task is to broadcast modulated signal with data that are generated by industrial computer.

The block diagram of the last element of the described system - Master station – is shown in Fig. 5.

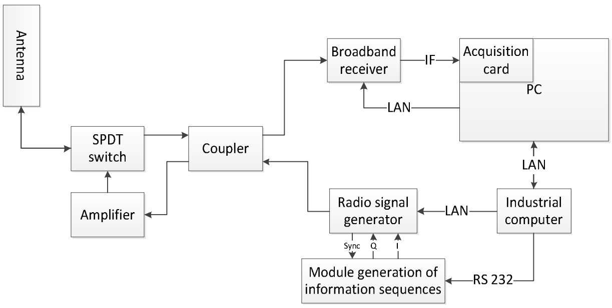

Fig. 5. Block diagram of a Master station

Master station is a combination of a localizer and a Slave station. The task of the receiver is to listen to a nearby station and to determine difference in synchronization between reference signal and signals from the neighboring stations. To enable listening to neighboring stations, Master one has been equipped with a coupler and a SPDT switch, which periodically changes transmitting antenna into a receiving one.

All devices are based on a universal radiocommunication equipment. The entire system functionality is provided by software installed on computers.

V. RADIO PARAMETERS

Analysing the bandwidth VHF / UHF (Very High Frequen-cy / Ultra High Frequency) among resources available for civil use, it was decided to build system using DS-CDMA technology (Direct Sequence Code Division Multiple Access) in the band 430 MHz, with the following parameters:

- Carrier frequency 431.5 MHz system,
- bandwidth of the transmission channel - 1 MHz (4 MHz)
- Sampling frequency baseband signal - 4 MHz (16 MHz),
- the location information transmission rate - 1 kb / s,
- QPSK modulation (Quadrature Phase Shift Keying).

VI. TESTS AND RESULTS

At the moment there were 4 large test sessions carried out in real conditions. Two sessions were carried out in 2010, in April and October. Then next two in 2011, in June and October. The last test was performed on board a survey ship of the Polish Navy.

The AEGIR system has been tested three times in the Bay of Gdańsk and once - along the coast line of the Baltic Sea. During field tests a position from a satellite navigation system was recorded with the use of a Javad Alpha receiver, which enables simultaneous reception from both American (GPS) and Russian (GLONASS) systems. During the test performed on board of the Navy vessel, two geodetic DGPS receivers have been used (Leica VIVA GS15). They have been installed along the axis of the vessel and the AEGIR antenna has been placed between them.

The effects of our tests performed in October 2010 are illustrated by the visualization shown in Fig. 6, created with use of Google Earth software. The dotted line represents the path of positions received from the satellite systems GPS/GLONASS, and the dots represent the calculated positions of the ground-based system.

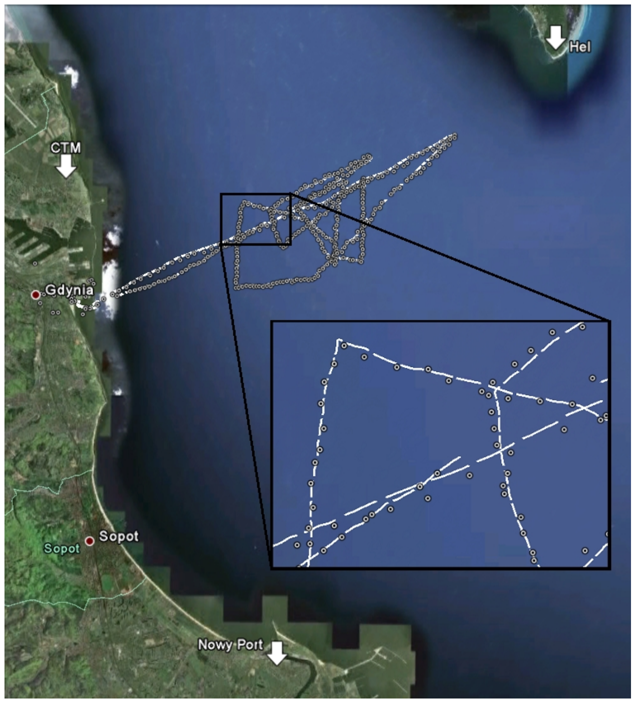

Fig. 6. Deployment of ground stations (arrows) and a path of GPS and GLONASS positions (dotted line) and readings of autonomous AEGIR system (dots)

Analyzing the visualization shown in Fig. 6 it can be observed how accurate the route travelled by the vessel was reconstructed by points calculated by the autonomous localization system – AEGIR.

After completing the measurements, average error (relative to the position shown by the GPS / GLONASS) was obtained at 46m. Distribution and histogram of all results are illustrated in Fig. 7 and Fig. 8.

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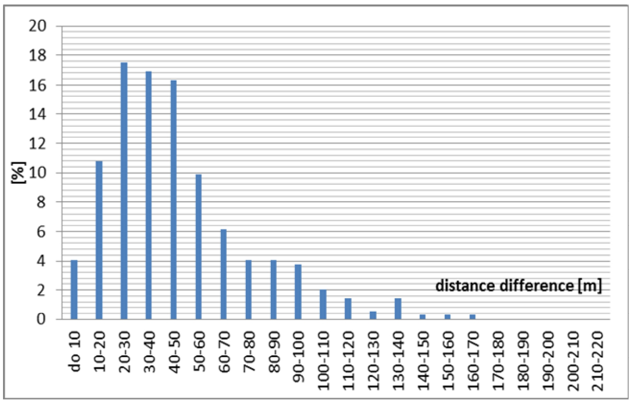

Fig. 7. Histogram of results.

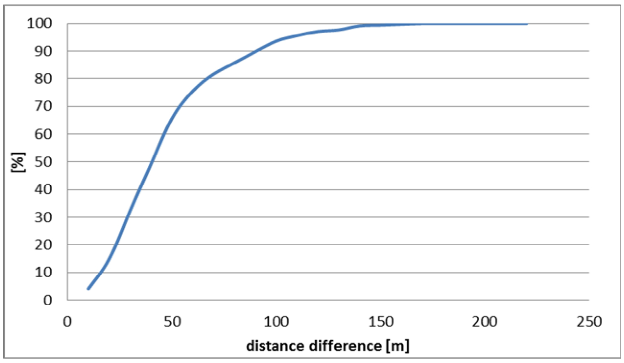

Fig. 8. Distribution of results.

Analyzing the distribution function in Fig. 8 it can be observe, that in 90% of all measured cases the difference distance is bellow 100m.

Test performed in June 2011 was carried out in different configuration. Ground stations were set in a less favorable configuration, along the coastline. Additionally a bandwidth was increased up to 4MHz. It was expected, that because of the unfavorable ground station placement results may worsen comparing to previous ones. However a wider bandwidth would compensate for poor geometry of the system.

Visualization of this configuration is illustrated in Fig. 9.

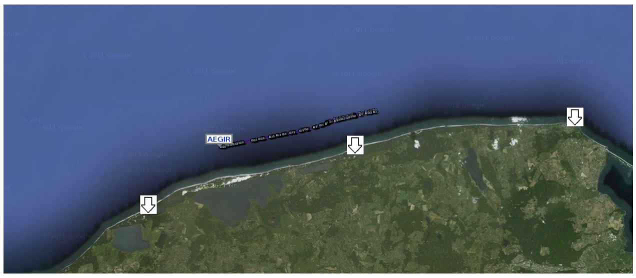

Fig. 9. Visualisation of AEGIR path when ground station are placed along the shore.

As before an average error has been calculated and obtained at 55m. So as predicted increase of bandwidth nearly compensated a poor system geometry.

Distribution and histogram of obtained results are illustrated in Fig. 10 and Fig. 11.

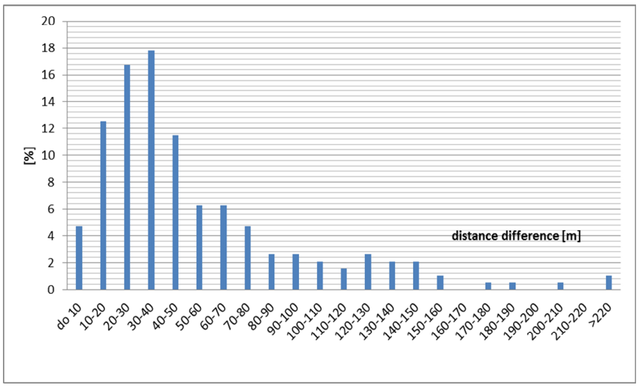

Fig. 10. Histogram of results.

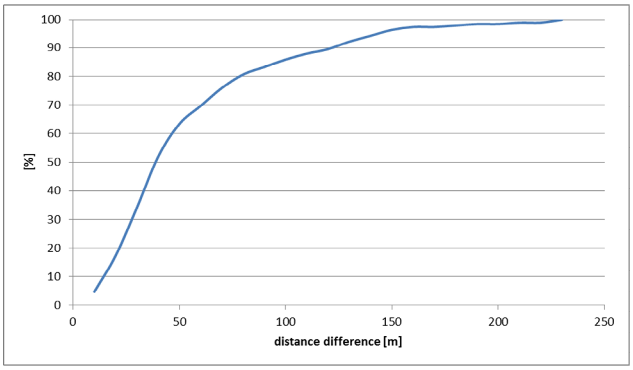

Fig. 11. Distribution of results.

The last test has been carried out in October 2011 with the support of the Hydrographic Office of Polish Navy. The system was tested again in the Bay of Gdansk with the same radio parameters as before. Visualization of travelled route illustrates Fig. 12.

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Fig. 12. A path of GNSS positions and readings of autonomous AEGIR system.

The main objective of the tests was the comparison of the results obtained with the use of bandwidth 1MHz and 4MHz. In addition, the correctness of the system was verified in case of location placed outside the geometry of the system (the triangle designated by the reference ground stations). It was expected the coordinates estimated outside the area of good geometry will worsen (outside of the triangle). Figure 13 presents shift of the estimated position outside of the mentioned area.

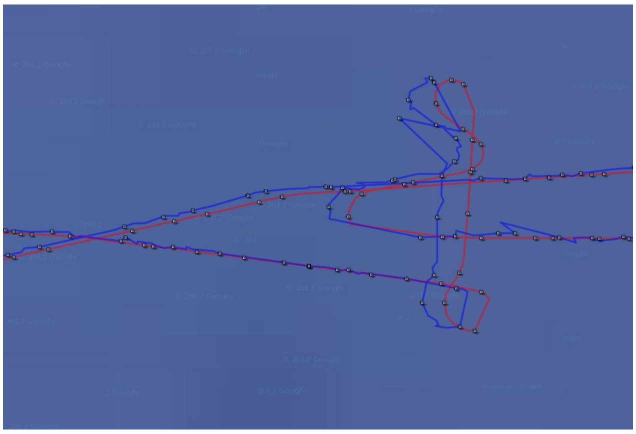

Fig. 13. A path of GNSS positions and readings of autonomous AEGIR system outside of the good geometry of the system

As before an average error has been calculated and obtained at 30m. It should be emphasized that this result also contains the results which have been measured outside the good geometry of the system (outside the triangle).

Distribution of the results is illustrated in Fig. 14.

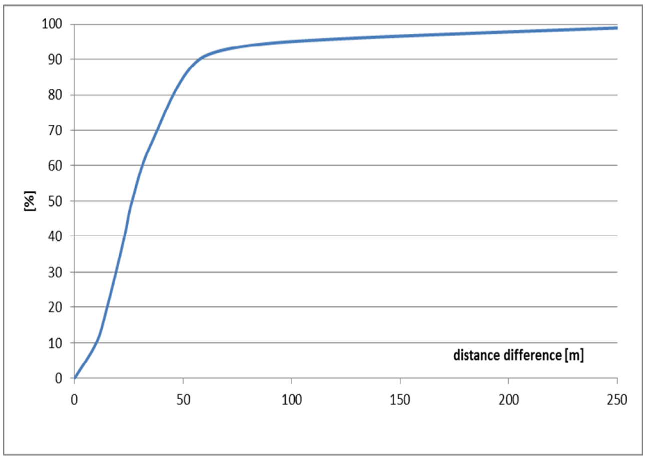

Fig. 14. Distribution of results.

Analyzing the distribution function in Fig. 14 it can be observed, that in 90% of all measured cases the difference distance is bellow 60m.

VII. Conclusion

The AEGIR system is a contribution to the development of ground radiolocation systems. The use of modern technology (developed system is fully digital) guarantees the long term operating of such a system.

An important advantage of the developed system is that in the process of estimating the position of the locator coordinates are determined directly (without the need to assign these coordinates to the so-called line items that are needed in phase systems). Therefore, there is no need for start position locator and counting the excess line items that are repeated periodically in the area of the system, depending on the wavelength of the radio and that can lead to errors in the upright-commercial determination of the geographical coordinates of the locator.

The presented system is fully asynchronous. In case of damage or shutdown of one of the stations, the system is fully functional, the only condition is to receive signals from at least three ground stations.

The AEGIR system has been developed to be very flexible. It allows to use more than three ground-stations. Placing them in areas of known positions, allows to create a grid, which will provide ~~an~~ readings of coordinates independent from satellite systems. Using more than three reference station will also increase precision of calculating position.

The AEGIR works in both kind of ground station configuration (triangle deployment and along coastline as well).

In the course of designing and building the system, the adequacy of the system for water bodies has been focused on. However, the versatility of the proposed solution suggests that the system would work on land as well.

VIII. Acknowledgment

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