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POLISH DGPS SYSTEM — ARCHITECTURE AND INSTALLATION: 1995

ABSTRACT

The idea of setting up the Polish DGPS system was originated by the Polish maritime administration in 1993 in the Polish Hydrographic Bureau in Gdynia. In December 1994 technical equipment and software for local monitoring by two reference stations was ordered, i.e. a central station together with communication software together with measuring and navigation receivers. In 1995 the equipment manufactured by the firm, Maggnavox arrived in Gdynia where it was installed, and commenced operating in conjunction with two radio beacons, one located in Rozewie and the second in Dziwnów. This is the third article in the series dedicated to the implementation of the DGPS system in the maritime regions of the Republic of Poland, and it presents the organizational, legal and technical aspects relating to the installation of the equipment. It contains, among other things, the hitherto unpublished results of the investigations concerned with geodesy-based determination of coordinates for the Rozewie and Dziwnów DGPS reference antennas in the ETRF '89 coordinate system. It also discusses the influence of changes in the law in place at that time regarding the functioning and organization of the Polish DGPS system.

Key words:
Polish DGPS system, navigation, architecture, installation.

THE ORGANIZATIONAL STRUCTURE OF THE SYSTEM

Between 1991 and 1995 very few countries in the world made efforts to install a differential DGPS system dedicated to marine navigation. For this reason

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the main problem faced by the team responsible for implementing this system in the Polish maritime regions was the lack of experience relating to installation, calibration and testing of this kind of systems. Singular scientific publications available at that time — American [8, 9, 11, 12, 14, 20], British [21] and Scandinavian [1, 23], proved that until that time no uniform rules and procedures for the functioning of national DGPS systems had been developed. There were also only singular standardization documents issued by available international organizations [3, 4].

However, there was no doubt that the two reference stations (Rozewie and Dziwnów) should be controlled from a central (control) station and also that in order for the system to ensure capability to transmit to users signals relating to reliability (RTCM16 message) it should be equipped with monitoring stations [10, 15]. Each of these stations should monitor, in real time, one DGPS reference station, maintaing a telecommunication-based connection with the central station [11]. Following this assumption the initial organization of the Polish DGPS network, which is presented in figure 1, was adopted. In addition a proposal was put forward to establish a GPS Information Center at a National level — a state-owned central institution responsible for coordinating national efforts concerned with investments in the sector of satellite navigation and geodesy, which was inevitable. This initiative, however, has never been realized. Especially today, it cannot go unnoticed that on 25 July, 2014 the Polish Parliament during its 71st session passed a Bill on the Establishment of the Polish Space Agency (POLSA) which will also be responsible for coordinating National efforts relating to satellite-based marine navigation. In a way POLSA, set up in 2015, is a realization of solutions recommended in 1994. The proposed organizational concept also included the necessity to connect the system with the Nautical Information Center, responsible for transmitting navigational warnings concerned with the functioning of the system. The Center was to be an organizational element of the then Hydrographic Bureau of the Republic of Poland.

In December 1994 technical equipment and software were ordered for two reference stations with local monitoring by a central station with communication software, as well as measuring and navigational receivers. In 1995 the equipment was installed in two radio beacons: Rozewie and Dziwnów. Soon the trial emission and the central station in the Maritime Authority Office with makeshift cable connections were started. Out of the newly planned structure, its basic elements in the form of maritime reference stations in Dziwnów and Rozewie and the central station in Gdynia (Maritime Authority Office) were established. From the formal point of view the system was working in the test phase, from which, after meeting world technical and navigational requirements it could be transformed into operational status.

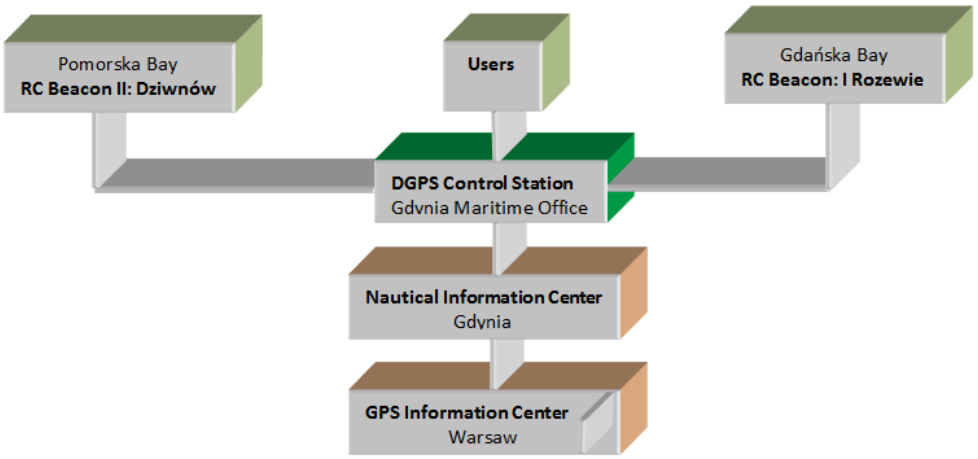

Fig. 1. The Organizational structure of the Polish DGPSS network in 1995 [15]

However, it was not technical problems or technological sophistication of the equipment that decided about the functioning of the Polish DGPS system over the next few years. The strongest influence on the reorganization of the system was legislative activities of the government and local administration. The Act of Law as of 17 November, 1994 on changes in maritime regions of the Republic of Poland and maritime administration [25] closed the Hydrographic Bureau of the Republic of Poland, and the missions of the state maritime hydrographic and navigational marking service concerning maritime hydrography and cartography were taken over by the Hydrographic Bureau of the Polish Navy. At the same time the personnel, material and financial means of the Hydrographic Bureau of the Republic of Poland were transferred to maritime offices within three months of the Act becoming effective.

As a result of the changes in law the infrastructure of the DGPS system had to be transferred to the maritime offices, but one fact was overlooked which was that the DGPS system is national and (not local) and its elements were located in the areas administered by two maritime authority offices: in Szczecin (Dziwnów DGPS reference station) and Gdynia (Rozewie DGPS reference station and also the Central station). For this reason an additional legislative act was passed which divided this system into two parts. Following the regulation by the Minister of Transport and Maritime Industry as of 8 August, 1995 changing the regulation on establishing maritime offices, appointing their locations and territorial responsibility held by directors of maritime offices [17] a decision was made that with respect to navigational marking the directors of maritime offices were held responsible for the areas separated by the meridian through 016°30': East (Maritime Office Gdynia) and

West (Maritime Office Szczecin). Following this regulation the Dziwnów DGPS nautical station was promptly handed over to the Maritime Office in Szczecin and it began to handle technical matters for this station.

Both from the perspective of the 1990s and the present day the then proposed and executed changes must be criticized with regard to safety in navigation, and an evaluation should be made, especially, of the following:

- failure to realize by the state authorities, the significance of national-level navigational systems (independent of local administrations and the location of the meridian through 016°30' E), which resulted in the absence of systemic solutions (legal and organizational) concerned with management and control exercised over them (including location-related decisions — such as DGPS), and especially failure to understand the necessity of centralization and uniform international representation;
- the architecture of the DGPS system was divided, as far as administration was concerned, into two parts, depriving the Dziwnów DGPS reference system of current reliability estimation (absence of connection with the central system station), which had a negative effect on the navigation safety in the Pomeranian Bay and the approach to the port of Szczecin;
- control of the Dziwnów DGPS reference station was possibile only directly from the Dziwnów Nautical Station;
- the Maritime Office in Szczecin had to take immediate actions aimed at starting the second central station controlling the singular Dziwnów DGPS station.

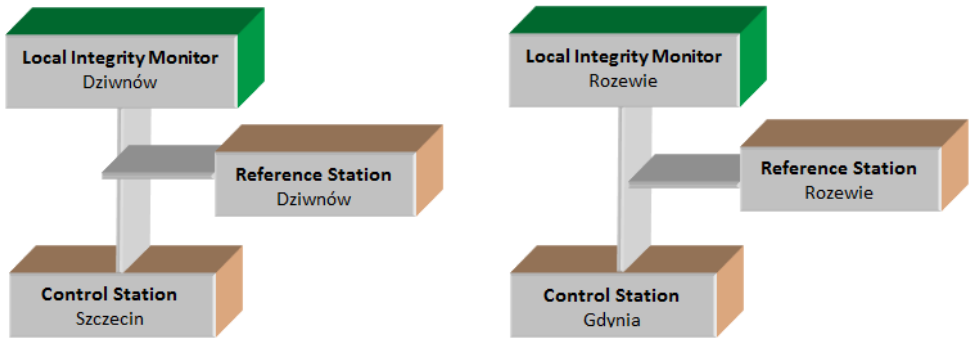

Fig. 2. The configuration of the Polish DGPS system in 1996–2001

It was not until 2002 that, as a result of an agreement between the maritime offices, a decision was made to hand over the technical infrastructure of the Dziwnów reference station to the Maritime Office in Gdynia. As a result, the system is controlled by one control station in Gdynia, just like it was at its start-up phase in 1995.

THE SYSTEM ARCHITECTURE

In order to start new radio emissions (DGPS) on the Polish seacoast new agreements with IMO and IALA relating to navigational marking were necessary. In 1950–1997 major work was done concerned with modernization of radio beacons (RC) and implementation of reference stations in the satellite DGPS system. Efforts made in this field were focused on changes in the organization, location, ranges, and radio emission methods. Both the location and assignment of working frequencies (and other emission features) were subject to international coordination through IALA, and after obtaining the proper recommendation through the Country Management of the State Radio Agency (SRA) in Warsaw. As a result the necessary acceptance was given by the International Telecommunication Union Radio-communication Sector in Geneva and a provisional approval was obtained from the Country Management of SRA to start the emission. As a result of the efforts taken:

- use of radio beacons RC in the so called chains, which involved successive emissions of radio beacon signals within the same chain and at the same frequency (two chains by the end of 1994), were abandoned;
- continuous work mode was adopted for the radio beacon with A1A modulation;
- each radio beacon was assigned an individual frequency (until then two frequencies were used for both chains);
- two radio beacons RC (Krynica Morska and Kołobrzeg) were shut down;
- the number of direction finding radio beacons was reduced from seven to five and calibration radio beacons from four to two;
- two DGPS reference stations were set up in Dziwnów and Rozewie;
- type approval measurements of receivers were carried out;
- type approval up to 2005 was granted.

The equipment installed in the two reference stations is identical and consists of the following elements listed in table 1.

Table 1. The equipment in the Polish DGPS reference station (Dziwnów/Rozewie) in 1995–2008

No.	Type of equipment	Number
1	Reference receiver MX 9112	2
2	Modulator MSK MX 50	2
3	Transmitter Amplidan type 015771	2
4	Lane selector switch	1

No.	Type of equipment	Number
5	Antenna Tunig Unit ATU	1
6	Power supply buffer type ELMECH (24V/20A) (with batteries 80Ah)	1
7	Integrity Monitor MX 9212 + MX 51R	1
8	PC Compaq 486DX-60MHz (HDD-0,5 Mb, FD, 4kb RAM)	1
9	Uninterruptible Power Supply UPS type APC-250	1
10	Software IM 406 version 4.06	1
11	Telephone modem Multitech 9600	1

Most of the appliances (except the computer and transmission antenna) were doubled. The redundancy allows for meeting very high requirements set for a DGPS system with respect to availability (min. 99.7%) as the main radio navigational marking system in port approaches and in coastal navigation.

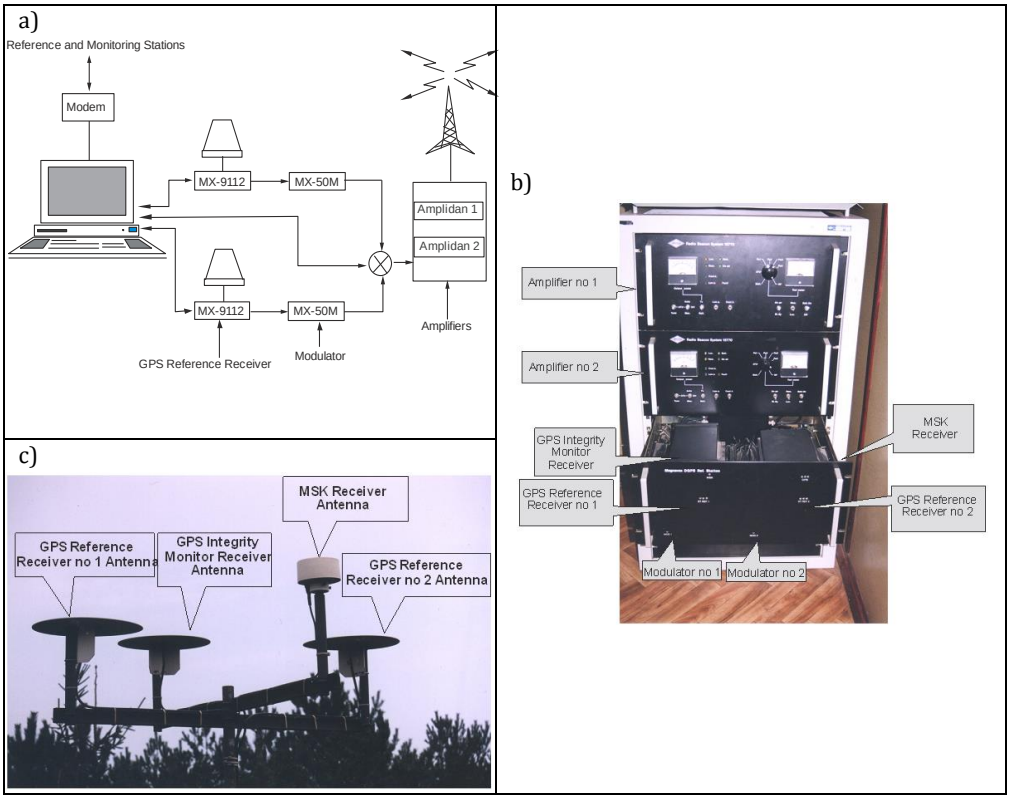

Fig. 3. The functional diagram of the DGPS reference station Rozewie/Dziwnów (a); the set of appliances in the Rozewie DGPS reference station (b); the receiver antennas in the Dziwnów reference station(c); photos by C. Specht

CALIBRATION

Calibration of a radio-navigation system includes several actions taken by a hydrographic service, mutually correlated with respect to the purpose, place and time which are intended to generate a grid of positions compatible with the theoretical one. The calibration process can be divided into three stages [15]: preparatory, executive and control, and report. In 1995 together with the process of installing the appliances of the DGPS station two important calibration tasks were performed: the antenna system calibration involving preliminary determination of Effective Radiated Power (ERP) for both of the stations Rozewie and Dziwnów and the antenna coordinates for the reference stations and monitoring networks were determined.

The calibration of the antenna stations

The Rozewie and Dziwnów DGPS reference stations in principle differ from each other with respect to technical solutions in their transmission antennas. The transmitter in the Rozewie station has a doublet long wire dipole antenna, whereas the Dziwnów DGPS station has a vertical antenna. Type 'T' antennas are often used in DGPS stations. They are recommended by the 'Geneva Frequency Plan' for long and short waves. The basic radiating element in such an antenna is a vertical wire having over 10 m and less than 20 m in length. The basic task of a horizontal wire, having up to 50 m in length, is to change the current distribution in time in the vertical wire, which causes an increase in the 'effective height'. The doublet antenna as compared to the T type antenna has better parameters, especially the effective height. A system of this type was used in the Rozewie DGPS reference station until 2000. The horizontal wire of this antenna was suspended between the lighthouse and the mast of the Rozewie DGPS reference station's antennas. The vertical wire is at the height of the nautical station building (fig. 4).

The Dziwnów reference station is equipped with a vertical self-supporting mast antenna STA 150 NDB which can be used in several fixed Omni-directional radio beacons. It replaces the expensive wire antenna installations which require a lot of space and can be installed in places having limited space. Owing to the fact that it does not require much space it can also be installed in mobile radio beacons (aboard light vessels, off-shore rigs, etc.). The standard height (14.5 m) can, in case of need, be reduced to 11.5 m. The mast antenna supports the top assembly integrated in one system consisting of 5 load rods (four installed in the tilted position and one installed vertically) and a loading coil with the air core. This induction set

is placed in a watertight pipe-shaped frame. It also reduces the voltage magnitudes around the antenna, which causes it to be less sensitive to ambient changes. The top assembly ensures favorable voltage distribution along this not long antenna. The antenna under consideration is non directional. Standard antennas of this type are made for frequencies 250–580 kHz. This beam is sufficient with respect to DGPS service requirements in European water regions.

Fig. 4. The transmission antennas in the Rozewie (left side) and Dziwnów (right side) DGPS reference stations in 1995; in the photo of the Rozewie DGPS reference station the shape of its two wires (vertical and horizontal) are drawn with the white line; photos: C. Specht

It must be noted that the power of the transmitters (100W) in these two stations was divided into two emissions: radio direction finding (A1A) and transmission of DGPS corrections (G1D) in the proportion 50/50. As there were no measurements relating to the efficiency (accuracy, availability, reliability, etc.) of the two antenna systems available, it was necessary to determine the real performance zone of each of the stations. To this end measurement tests were carried out during which the electromagnetic wave strength of the signals in the DGPS station were measured. The tests were as follows:

- a cruise by the SV Zodiak: 20–22 April, 1995;
- summer yacht training for the Naval Academy Cadets in 1995;
- measurements carried out between 12–14 April, 1995 and 26–27 May, 1995.

A graphics method was used with the Szulejkin-Van der Pol equation (fig. 5) to elaborate the results

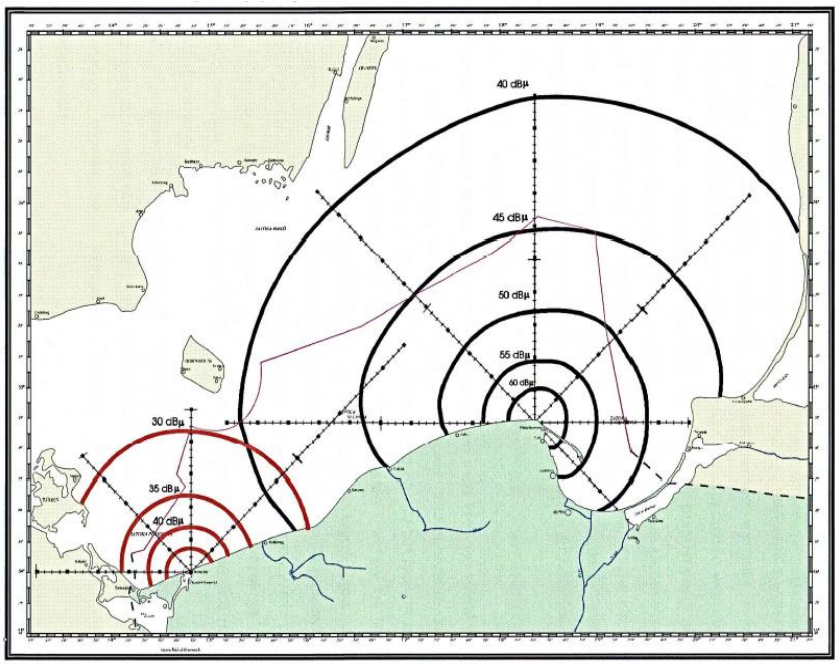

Fig. 5. The operation zones of the Rozewie and Dziwnów DGPS reference stations in 1995 [24]

The measurements carried out allowed for estimating the ERP magnitudes for both transmission systems. They are presented in table 2.

Table 2. Energy-related parameters of the reference stations in the Polish DGPS systems

Parameter	Rozewie	Dziwnów
Type	2T	rod, vertical
Length\height	55 m\20 m	16 m
Efficiency	0.8%	0.2%
Effective Radiated Power (ERP)	approx 0.4W	approx 0.1 W

As a result of the tests it was found that both antennas have Omni-directional radiation characteristics. The antenna in the Dziwnów station has less efficiency than was originally assumed and for this reason its ranges are shorter than in Rozewie, especially in directions when the signal runs partially on land, i.e. over the Piastowski Channel and the Order River in the proximity of Szczecin. In the direction

'towards the sea' the station reaches the range of 55 km at 50 μV/m (34 dBμV). The Rozewie DGPS reference station reached the assumed in [15] range of 90 km.

It is worth mentioning that towards the end of the 1990s a decision was made to increase the ranges of the DGPS reference stations through abandoning A1A emission. At the same time the two Polish stations were equipped with new transmission antennas. In 2000 a new antenna commenced operation in Rozewie and in Dziwnów in 2001.

Determining antenna positions for reference and monitoring stations

As for the accuracy in determining position coordinates by a user in a DPS system precise (geodetic) determination of coordinates for chase centers of all the GPS satellite stations both reference and monitoring is very important. The studies on accuracy in position determining were preceded by determining coordinates for antennas of reference and monitoring stations in ETRF '89 by a team from the Agriculture and Technology Academy in Olsztyn headed by prof. Stanisław Oszczak [2, 18, 19].

The Rozewie DGPS reference station. The reference network designed in Rozewie for attaching the antennas of the Rozewie DGPS reference station to the European Terrestrial Reference Frame 1989 (ETRF '89) was made using the GPS relative measurement method and classical tachometric measurements. At points (fig. 6a) 301: GPS, 5402, AMW1 static GPS measurements were carried out. Point 301 belongs to the EUREF-POL zero order network and has coordinates published in ETRF '89, with the accuracy of 1 cm. All the GPS measurement calculations were based on the ETRF '89 coordinates for this point. The GPS point was selected at the distance of approx 430 m away from point 301, creating this way a good base for the classical measurements. Point 5402 belongs to the POLREF first order network. It was attached to the reference network in order to ensure control of the reliability of fixes.

The Dziwnów DGPS reference station. The reference network designed in Dziwnów for attaching the antennas of the Dziwnów DGPS reference station to the European Terrestrial Reference Frame 1989 (ETRF '89) was made using the GPS relative measurement method and classical tachometric measurements. During the second measurement session the following points were measured (fig. 6b): point GPS of the marigraph in Świnoujście marked as ŚWIN, two points referred to as GPS1 and GPS2 stabilized at the area of the Nautical Station in Dziwnów, in proximity of the DGPS antennas and point EUREF-POL 304 in Czarnków.

The ETRF ’89 coordinates are available withan accuracy of 1 cm. This point was measured in order to ensure the accuracy control of fixes. The network of reference points designed this way was attached to ETRF ’89 using the coordinates of the ŚWIN marigraph. The adjustment of the coordinates showed that the accuracy of fixing the coordinates for points GPS1 and GPS2 can be estimated to be at the level of 20 m.

The GPS measurements carried out at the points of the discussed network were synchronized with the measurements of the permanent GPS station in the Satellite Observatory in Lamówek. This station lies at the distance of 180 km away from Rozewie. At the points of the network above two static sessions were carried out using 5 receivers Ashtech MD XII. The coordinates for vectors of the GPS network were adjusted using GeoLab software. The analysis of the GPS network accuracy showed that the semi-major-axes of error ellipses relating to point positions, at the 95% confidence region, did not exceed 7 cm.

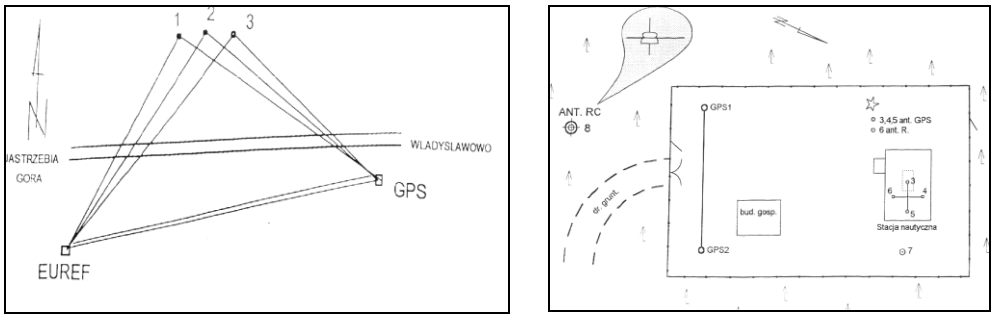

Fig. 6. Situational outlines of the Polish DGPS reference stations used to determine locations of the GPS reference antennas: Rozewie (left side), Dziwnów (right side: *bud. gosp.* — utility buildings; *stacja nautyczna* — nautical station)

In the next step, using an electronic tacheometer WILD TC 1000, classical measurements were undertaken with reference to the base points in ETRF’89. The coordinates for the antennas in ETRF ’89 were determined in the following stages:

- transforming ETRF ’89 3D coordinates for GPS points onto the Mercator transverse plane projection;
- calculating 2D coordinates for the antennas onto the TM plane using the intersection method;
- calculating the heights of the antennas above the projection plane;
- transforming the computed TM coordinates to the ETRF ’89 again;
- the average error value of the determined coordinates for the antennas was 30 mm.

The measurement results in the form of coordinates for particular points with respect to both places: Rozewie and Dziwnów are presented in the table below.

Table 3. The coordinates for the GPS points and antennas in ETRF'89 for the Rozewie and Dziwnów stations

	GEODETIC DATUM			
	Name of point	B	L	h [m]
Rozewie DGPS Station	**0301 EUREF**	54° 49' 39.01589''N	18° 19' 35.36004''E	70.807
	AMW1	54° 32' 35.09902''N	18° 32' 44.86720''E	51.778
	GPS1	54° 49' 34.21404''N	18°19' 58.06466''E	66.590
	antenna 1	54° 49'50.24671''N	18° 20' 7.68138''E	102.820
	antenna 2	54° 49'50.21754''N	18° 20' 7.63408''E	102.820
	antenna 3	54° 49'50.18583''N	18° 20' 7.58716''E	102.820
Dziwnów DGPS Station	**SWI1**	53° 54' 28.399370''N	14° 15' 45.9541000''E	37.882
	SWIN	53° 54' 29.735180''N	14° 15' 50.929450''E	37.876
	GPS1	54° 01' 18.541640''N	14° 43' 50.317450''E	39.549
	GPS2	54° 01'18.940580''N	14° 43' 51.116230''E	39.534
	3	54° 01'19.203068''N	14° 43' 49.988254''E	46.308
	4	54° 01'19.223467''N	14° 43' 49.987606''E	46.377
	5	54° 01'19.224295''N	14° 43' 50.021825''E	46.332
	6	54° 01'19.202508''N	14° 43' 50.024638''E	46.407
	7	54° 01'19.308890''N	14° 43' 50.434791''E	50.233
	8	54° 01'18.255764''N	14° 43' 51.419380''E	49.253
	9	54° 01'19.892168''N	14° 43' 50.705665''E	50.106

Determining positions for the monitoring station in Jarosławiec

A special feature of the equipment installed in both of the reference stations is connection of the hardware and software in a monitoring station in a reference station. This means that the monitoring station has to be installed in the same place as the reference station. In the 1990s this view did not raise any doubts, as most often the reference station was placed in the center of a water region (harbor complexes), which was covered by DGPS signals. The monitoring station should also be placed in the center of the water region covered by the GPS system so that system fitness status should be estimated. In the Polish solution for the Gdańsk Bay, the Rozewie DGPS station is located a few dozen kilometers away from the Gdańsk — Gdynia harbor complex. There would be nothing unusual about it if it were not for

the fact that it is impossible to separate hardware and software equipment installed in the Rozewie DGPS reference station from that installed in the station monitoring the Rozewie DGPS reference station. This monitoring station should have been located in Gdynia or Gdańsk but because of the above it was located in Rozewie. Noticing this problem, practically since the moment the Polish DGPS system was set to work the necessity of (rationale behind) establishing the so called distant monitoring in Jasłowiec has been discussed. It must be remembered that this idea was put into practice in 2014.

Taking into account possible locations of the stations monitoring both of the reference stations in one place, in Jarosławiec, as early as in 1995 coordinates were determined for the antenna mast which could be used for installing monitoring station antennas in ETRF'89. The reference grid would contain the following points:

- BSL (Baltic Sea Level) point located near the marigraph in Ustaka; this point was attached to the ETRF '89 during GPS campaigns of measuring the Baltic Sea level; the working name of this point was adopted as USTK;
- two points selected in Jarosławiec; line of sight propagation was secured between the antenna mast being determined and the two GPS points as well as between the points; the two points selected in Jarosławiec named GPS1 and GPS2; these points were attached to the ETRF '89 and they constituted the base for classical measurements;
- point belonging to the zero network of EUREF-POL order situated near Czarnków bearing number 304.

Figure 7 presents the situational outline of the reference points used to determine the position of the monitoring station located in Jarosławiec.

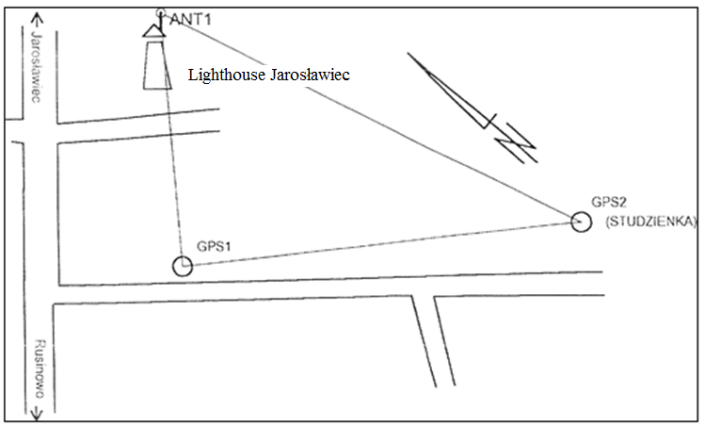

Fig. 7. A situational outline of the monitoring station in Jarosławiec

The coordinates determined are shown in table 4.

Table 4. The coordinates for GPS and antenna points in ETRF '89 — Jarosławiec

GEODETIC DATUM			
Name of point	B	L	h [m]
USTK	54° 35' 15.68214''N	16° 51' 13.87242''E	33.868
GPS1	54° 32' 18.15902''N	16° 32' 23.10944''E	50.114
GPS2	54° 32' 11.41722''N	16° 32' 35.44822''E	39.387
ANT1	54° 01' 19.203068''N	16° 32' 32.4538''E	85.656

CONCLUSIONS

The Polish DGPS system was the first national (country-wise) positioning system to have been implemented. Until that time analogous solutions included navigational structures of local reach (e.g. AD-2, Syledis, Bras), where there was no necessity to coordinate activities taken by state administration of the central level. However, in this case the legislative steps concerned with the DGPS system must be criticized as they led to separating elements of the system and to a lot of problems concerning competencies and international representation for several successive years.

As for the technical aspect of the Polish system the greatest problems were concerned with communications. It affected the current, remote control of its operation. For the rented Gdynia — Rozewie link, at the installation stage, transmission speed at the level of 2400–4800 bods was hard to obtain, and it was accompanied by a high error rate.

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POLSKI SYSTEM DGPS — ARCHITEKTURA I INSTALACJA: 1995

STRESZCZENIE

Idea ustanowienia polskiego systemu DGPS zainicjowana została przez morską administrację w 1993 roku, w ówczesnym Biurze Hydrograficznym RP w Gdyni. W grudniu 1994 roku zamówiono wyposażenie techniczne i oprogramowanie dwóch stacji referencyjnych z lokalnym monitorowaniem, stację centralną z oprogramowaniem komunikacyjnym oraz odbiorniki pomiarowe i nawigacyjne. W 1995 roku sprzęt firmy Magnavox dotarł do Gdyni, po czym został zainstalowany i uruchomiony w obiektach dwóch radiolatarń: Rozewia i Dziwnowa. Artykuł, trzeci z serii dotyczącej wdrożenia na akwenach morskich RP systemu DGPS, prezentuje aspekty organizacyjne, prawne i techniczne instalacji aparatury. Przedstawiono w nim również niepublikowane dotychczas wyniki prac związane z zagadnieniem geodezyjnego wyznaczenia współrzędnych anten stacji referencyjnych DGPS Rozewie i Dziwnów w układzie ETRF '89. Dyskusji poddano wpływ ówczesnych zmian prawnych na funkcjonowanie i organizację polskiego systemu DGPS.

Słowa kluczowe:
polski system DGPS, nawigacja, architektura, instalacja.