Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2012, 29(101) pp. 158–163

2012, 29(101) s. 158–163

Comparative analysis of the pulse and FMCW radars detection possibilities

Analiza porównawcza możliwości detekcyjnych radaru impulsowego i FMCW

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Key words: pulse radar, FMCW radar, detection possibility

Abstract
The paper describes frequency modulated continuous wave (FMCW) radar constructed by Przemysłowy Instytut Telekomunikacji SA and installed in Gdynia Maritime University and results of its detection possibility tests conducted in real propagation conditions. Outcomes from the tests were compared with detection distances of pulse radar Raytheon NSC34 with antenna located a few meters from the investigated FMCW radar scanner position.

Słowa kluczowe: radar impulsowy, radar FMCW, możliwości wykrywcze

Abstrakt
Referat opisuje radar pracujący na fali ciągłej z modulacją częstotliwościową (FMCW), skonstruowany przez Przemysłowy Instytut Telekomunikacji SA i zainstalowany w Akademii Morskiej w Gdyni oraz wyniki testów jego możliwości wykrywczych przeprowadzonych w rzeczywistych warunkach propagacyjnych. Wyniki te zostały porównane z odległościami wykrycia radaru impulsowego Raytheon NSC34, którego antena jest usytuowana kilka metrów od anteny badanego radaru FMCW.

Introduction

The paper presents CRM-203 type frequency modulated continuous wave (FMCW) radar and results of the tests of its detection possibility conducted in real propagation conditions in order to check compliance of this radar with recommendations and standards for detection possibilities of ship's radar and shore based radar used as a source of data for Vessel Traffic Service (VTS) introduced adequately by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), International Electrotechnical Commission (IEC) and International Maritime Organisation (IMO) [1, 2, 3, 4]. Described radar was constructed by Przemysłowy Instytut Telekomunikacji SA Gdańsk Division and installed in the radar laboratory of Gdynia Maritime University as a sensor of data about sea surface objects for Integrated Vessel Traffic Control System designed and constructed in the scope of the research work financed by the Polish Ministry of Science and Higher Education as developmental project No. OR00002606. Its antenna is located nearby the south entrance to the Gdynia Harbour on the roof of the university building at the height of about 25 meters above sea level.

Operational tests of the radar were conducted in winter 2010/2011 and in spring and summer 2011. Its detection possibility and clutters resistance were checked during measurements in real hydrometeorological conditions. Results were compared with information about positions, courses and speeds transmitted by Automatic Identification Systems (AIS) installed on board of detected and

tracked ships and data about these vessels received at the same time from ship pulse radar Raytheon NSC-34 with ARPA function installed in the same laboratory. Radar NSC34 is approved by Recognise Organisations (RO) as ship's radar and has "Wheelmark".

Radars description

Prime function of the CRM-203 type FMCW radar is detection and estimation of planar co-ordinates for sea surface targets and automatic tracking of the selected objects to perform the coastal surveillance tasks. Radar presents current positions of detected objects and calculates the future situation to accomplish the automated radar plotting aids. It consists of the antennas integrated with FMCW transceiver, antennas motor drive, Signal Processing &Radar Control Unit (SPCU) and radar display unit (Fig. 1). The main functions performed by the radar are:

- Selection of the operative mode (local or remote), reception of all controls, commands and selections needed for full operation capability. In case of control line failure all controls are automatically put in a default condition in order to guarantee the antenna rotation, the radar emission and the automatic acquisition and tracking of the targets.
- Processing of the radar video, compression and transmission of the digitised video to the local or remote radar display unit.
- Automatic or on-demand acquisition of targets falling inside predefined automatic acquisition zones or acquired manually by the operator.

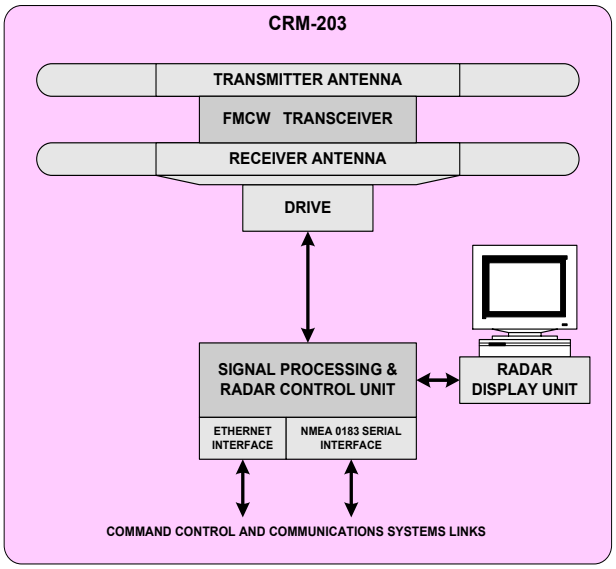

Fig. 1. Radar FMCW CRM-203 functional diagram [1]
Rys. 1. Schemat funkcjonalny radaru FMCW CRM-203 [1]

- Automatic tracking of acquired targets.
- Transmission to the control unit, once per antenna revolution, of status and alarms from the sensor (BITE) and tracked targets data (position, speed and course).

Display units of described radars, location of their scanners and visibility sectors from antennas positions are shown in figures 2–6. Figure 7 presents radar FMCW CRM-203Signal Processing & Radar Control Unit (SPCU).Basic technical parameters of both radars are listed in tables 1 and 2. Their more detailed description may be found in [5].

Fig. 2. Radar FM-CW CRM-203 display unit
Rys. 2. Wskaźnik radaru FMCW CRM-203

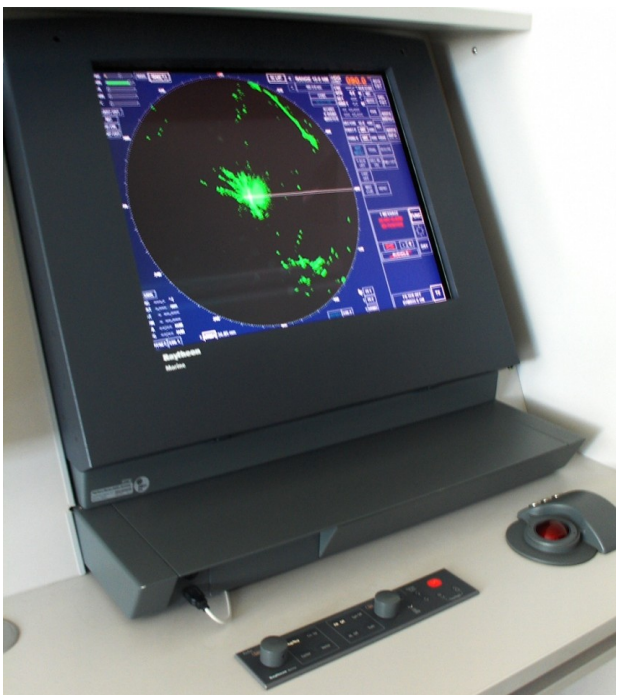

Fig. 3. Pulse radar Raytheon NSC-34 display unit
Rys. 3. Wskaźnik radaru impulsowego Raytheon NSC-34

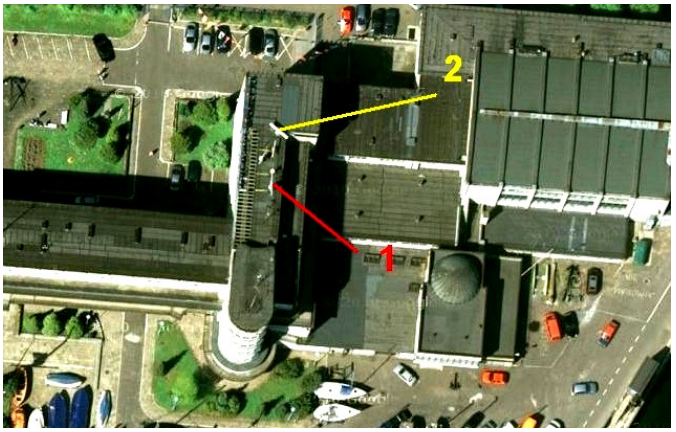

Fig. 4. Raytheon NSC-34 (No 1) and FMCW CRM-203 (No 2) radars scanners location
Rys. 4. Rozmieszczenie anten radarów Raytheon NSC-34 (Nr 1) i FMCW CRM-203 (Nr 2)

Fig. 5. Visibility sector from the radar FMCW CRM-203 scanner position
Rys. 5. Sektor widzialności z pozycji anteny radaru FMCW CRM-203

Fig. 6. Visibility sector from the radar Raytheon NSC-34 scanner position
Rys. 6. Sektor widzialności z pozycji anteny radaru Raytheon NSC-34

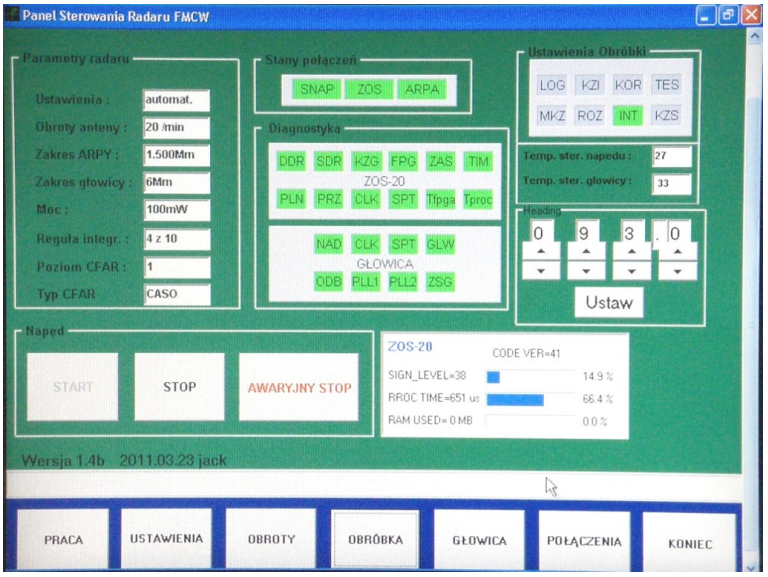

Fig. 7. Radar FMCW CRM-203 Signal Processing & Radar Control Unit (SPCU)
Rys. 7. Panel przetwarzania sygnału i sterownia radaru FMCW CRM-203 (SPCU)

Table 1. Radar FMCW CRM-203 – basic technical data [1]
Tabela 1. Radar FMCW CRM-203 – podstawowe dane techniczne [1]

Parameter	Value
Transceiver	
Output power	1 mW–2 W (switched)
Carrier frequency	9.3 – 9.5 GHz
Frequency deviation	Switched according to the required scale range: –54 MHz at 6 NM –27 MHz at 12 NM –13.5 MHz at 24 NM
Range scales	0.25 NM – 48 NM
Modulation	DDS based linear FMCW
Sweep repetition period	1 ms
IF bandwidth	4 MHz
Noise factor	2 dB
Maximum gain	120 dB
Frequency curve slope of IF amplifier	6 dB/oct; 12 dB/oct; 18 dB/oct.
Antennas	
Antenna length	3.6 m
Beam width (3 dB) horizontal/vertical	0.70°/22°
Polarisation	Horizontal
Gain	32 dB
Rotation speed min/max.	12/30 rpm
Drive motor	1.5 kW
Signal processing	
FFT signal processing	8192-points FFT
Sampling frequency	8 MHz
Number of range cells	4096
Signal threshold	CFAR
Signal integration	Binary, number of detections dependent on antennarotation speed
Sea clutter reduction	Signal correlation from 2 antenna rotations
Display unit	
Display size	22 inch
Resolution	1280 × 1024 pixels
Acquisition	Automatic up to 100 targets
Tracking	Automatic of all acquired targets
Zones	2 guard zones
Target information	Target: number, range and bearing from radar position,course
Options	ARPA anti-collision functions
Range and angle measurements	
Scale range	12 NM / 24 NM / 48 NM
Range cell size	5.6 m / 11 m / 22 m
Range measurement accuracy	1% of selected range or 50 m (whichever is greater)
Angle resolution	0.1°
Bearing accuracy	0.7°
Environmental conditions	
Wind operational	30 m/s
Wind survival	50 m/s
Humidity	98% at temperature 25°C
Temperature operational	From –10°C to +50°C (inside operating room) and from –30°C to +50°C (outside operating room)
Temperature survival	From –40°C to +65°C

Table 2. Radar Raytheon NSC34 – basic technical parameters
Tabela 2. Radar Raytheon NSC34 – podstawowe parametry techniczne

Parameter	Value
Transceiver	
Output peak power	25 kW
Carrier frequency	9410 ± 30 MHz
Pulse length Pulse repetition frequency IF bandwidth	0,06 μs 0,25 μs 3000 Hz 2000 Hz 20 MHz 6 MHz
Range scales	0.25 NM – 96 NM
Antenna	
Antenna length	2.1336 m
Beam width (3 dB) horizontal/vertical	1.0°/23°
Polarisation	Horizontal
Gain	29 dB
Rotation speed	22/26 rpm
Signal processing	
Processor	Motorola 68EC030
Memory	EPROM
Display unit	
Display size	28 inch
Resolution	1600 × 1200 pixels
Acquisition	Automatic up to 70 targets
Tracking	Automatic of all acquired targets
Acquisition zone and tracking range	3 types of zones: sector, polygon, circle, 0.1 NM – 24 NM
Target information	RNG, BRG, CRS, SPD, CPA, TCPA,BCR, BCT
Range and angle measurements	
Range discrimination	0.3% of selected range or 3.6 m (whichever is greater)
Range measurement accuracy	0.3% of selected range or 3.6 m (whichever is greater)
Angle resolution	0.3°
Bearing accuracy	1.0°

Description of measurements

According to the IMO Resolution MSC.192(79) "Adoption of the Revised Performance Standards for Radar Equipment" ship borne radar detection possibility shall be checked for an antenna height of 15 m above sea level in normal propagation conditions, in the absence of sea clutter, precipitation and evaporation duct [4]. IEC standard 62388 "Maritime navigation and radiocommunication equipment and systems – Ship borne radar – Performance requirements, methods of testing and required test results" [3] does not introduce any additional requirements for radar detection possibility. Alike,

IALA recommendations listed in the bibliography [1, 2] define required radar accuracy and discrimination basing on type of capability (basic, standard, advanced) only.

Minimum detection ranges in clutter-free conditions according to the IMO Resolution MSC.192 (79) are presented in table 3 [4].

Table 3. Minimum detection ranges in clutter-free conditions [4]
Tabela 3. Minimalne odległości wykrycia w warunkach braku zakłóceń [4]

Target description	Target height above sea level [m]	Detection range in NM	
		X Band	S Band
Shorelines	Rising to 60	20	20
Shorelines	Rising to 6	8	8
Shorelines	Rising to 3	6	6
SOLAS vessel (> 5000 gt)	10	11	11
SOLAS vessel (> 500 gt)	5.0	8	8
Small vessel with radar reflector meeting IMO performance standards	4.0	5.0	3.7
Navigation buoy with corner reflector	3.5	4.9	3.6
Typical navigation buoy	3.5	4.6	3.0
Small vessel of length 10 m without radar reflector	2.0	3.4	3.0

There were conducted six series of measurements: two in winter 2010/2011 and four in spring and summer 2011 to check the detection possibility of the investigated FMCW radar. All of them were realized in good weather without snowfall and rainfall in normal refraction conditions. According to information received from Vessel Traffic Service "Zatoka Gdańska" during all tests wind was variable from NE to SE directions with mean speed 1.0 to 3.2 m/s. Sea state was assumed as 1°–3° in Douglas scale. Both radars (FMCW CRM-203 and Raytheon NSC34) were working on the same ranges. Quality of radar image (resolution, contrast and legibility) and detection possibility were assessed by five experienced radar observers and service workers. During tests were checked detection ranges for coast line, buoys, ships and small vessels like RIB and yachts with radar reflector and without it. Measurements were conducted for different values of radar FMCW transmitted power, scanner rotation speed and signal processing parameters (type of CFAR algorithm and level of its activity and integration, correlation and differentiation rules). Results were compared with information about positions, courses and speeds transmitted by Automatic Identification Systems (AIS) installed on board of detected and tracked ships and documented using photo cameras.

Results of measurements and conclusions

Tested radar scanners are installed at height of about 25 meters above sea level, other than height of radar antenna used for calculation of detection ranges presented in table 3. It is possible for pulse radars, utilizing program CARPET 2, to calculate detection ranges for antenna height other than that used during tests. But there are not tools to do this calculation for FMCW radar. Due to that detection possibility of investigated FMCW radar was estimated by comparison with detection possibility of pulse radar Raytheon NSC-34. This radar has "Wheelmark" and is approved by recognized organizations as ship's radar fulfilling requirements of IEC standard and recommendations of IMO resolutions.

Low intensity of traffic at the approaches to Polish ports in the Gulf of Gdańsk caused that number of measurements conducted for vessels with approximately the same radar cross sections (RCS) depending on ship's type, displacement, aspect, loading condition, etc. is too small to make any statistical analysis.

Following conclusions may be formulated on the base of conducted measurements:

1. Radar FMCW, due to the higher resistance to disturbances than compared pulse radar, has better small target detection possibility visible mainly on ranges up to 6 nautical miles (NM). It may be observed in figures 8 and 9.
2. Both radars have similar detection possibilities of point objects (ships) and shoreline rising to 6 meters on medium and big ranges (bigger than 6 NM). Largest observed distance to detected ship was equal to 19.2 NM (ship behind Peninsula Hel in figures 10 and 11).
3. FMCW radar detects high shore objects at smaller distances than radar Raytheon. It may be seen in figure 12 presenting radar image on range 48 NM. Pulse radar shows in distinct manner echoes from this kind of unidentified objects in Elbląg region at distance of 34.85 NM. On FMCW radar display unit this targets are completely imperceptible. Due to the lack of possibility of objects identification, it is impossible to appreciate whether tested FMCW radar fulfil recommendation for minimal detection distance of shoreline rising to 60 meters.
4. Comparison of detection possibilities of both investigated radars allows making final conclusion that CRM-203 type FMCW radar fulfils IMO recommendations regarding radar detection possibility other than detection possibility for shoreline rising to 60 meters. This recom-

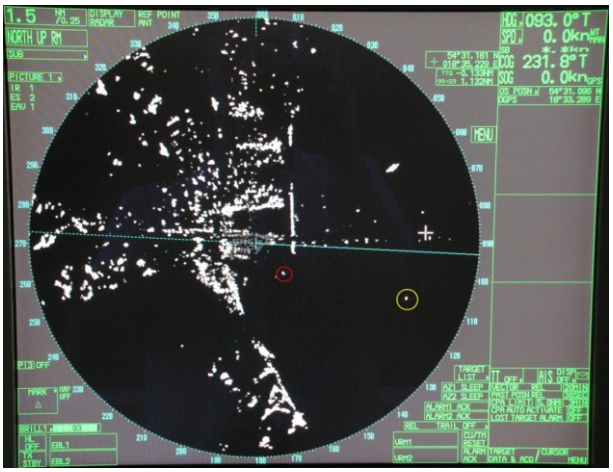

Fig. 8. Radar CRM-203. Image on range 1.5 NM. Circles mark buoys "GS" (red, left) and "GP" (yellow, right)
Rys. 8. Radar CRM-203. Zobrazowanie na zakresie 1.5 NM. Okręgi oznaczają pławy „GS" (czerwony) and „GP" (żółty)

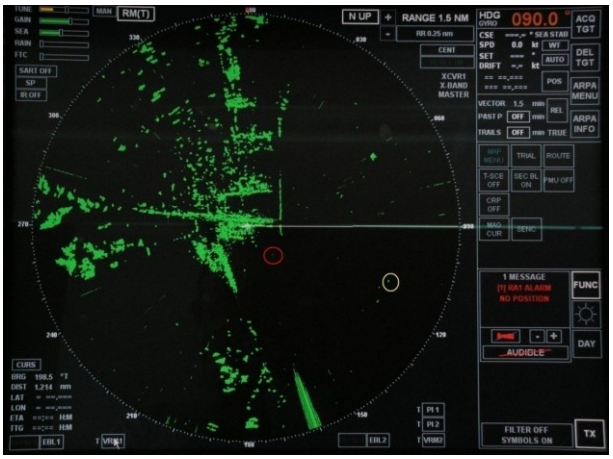

Fig. 9. Radar Raytheon NSC-34. Image on range 1.5 NM. Circles mark buoys "GS" (red, right) and "GP" (yellow, left)
Rys. 9. Radar Raytheon NSC-34. Zobrazowanie na zakresie 1.5 NM. Okręgi oznaczają pławy „GS" (czerwony) and „GP" (żółty)

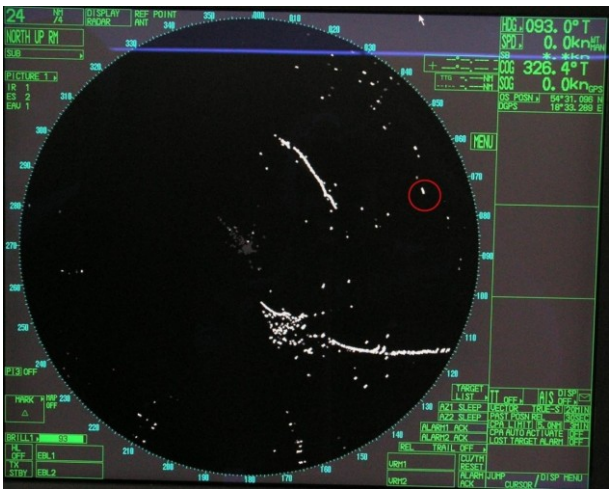

Fig. 10. Radar CRM-203. Image on range 24 NM. Circle marks echo received from ship at distance 19.2 NM
Rys. 10. Radar CRM-203. Zobrazowanie na zakresie 24 NM. Okrąg oznacza echo statku w odległości 19,2 NM

mendation cannot be checked due to the height of coastal objects in the Gulf of Gdańsk.

Fig. 11. Radar Raytheon NSC-34. Image on range 24 NM. Circle marks echo received from ship at 19.2 NM
Rys. 11. Radar Raytheon NSC-34. Zobrazowanie na zakresie 24 NM. Okrąg oznacza echo statku w odległości 19,2 NM

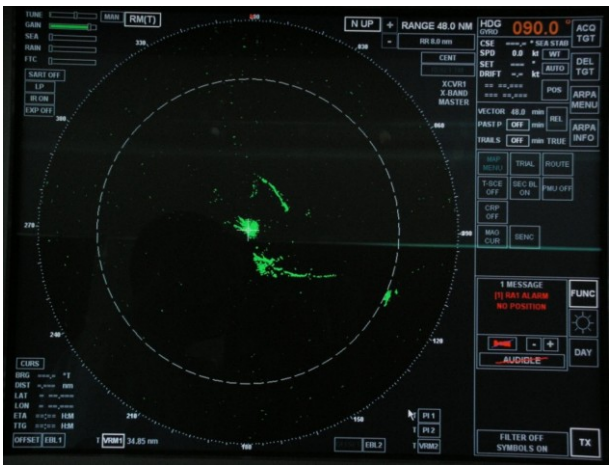

Fig. 12. Radar Raytheon NSC-34. Image on range 48 NM. Visible echo received from coast line at distance 34.85 NM
Rys. 12. Radar Raytheon NSC-34. Zobrazowanie na zakresie 48 NM. Widoczne echo linii brzegowej w odległości 34,85 NM

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