TRANSNAV
International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 3
Number 3
September 2009

CRM-203 Type Frequency Modulated Continuous Wave (FM CW) Radar

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ABSTRACT: Paper presents description of the principle of work, structure and basic technical parameters of the Maritime Coastal Surveillance Frequency Modulated Continuous Wave (FMCW) Radar CRM-203 type constructed by Telecommunication Research Institute Ltd. in Gdańsk. Results of its tests in real conditions and comparison with pulse ship radars with scanners installed in the same place will be presented during the conference.

1 INTRODUCTION

The CRM-203 type Coastal Surveillance Radar is solid state Frequency Modulated Continuous Wave (FMCW) sensor with low transmission power. One of the most significant parameters of this coastal application is small targets detection possibility in heavy sea clutter conditions and high range resolution. The requirements perform FMCW technology, which is rapidly advancing recently. Fully solid-state transmitter design (due to the low radiated power) ensures excellent Mean Time Between Failure (MTBF) and practical without service continuous operation.

FMCW transmitter produces a constant amplitude linear frequency modulated signal. The principle of FMCW radar is presented on Figure 1.

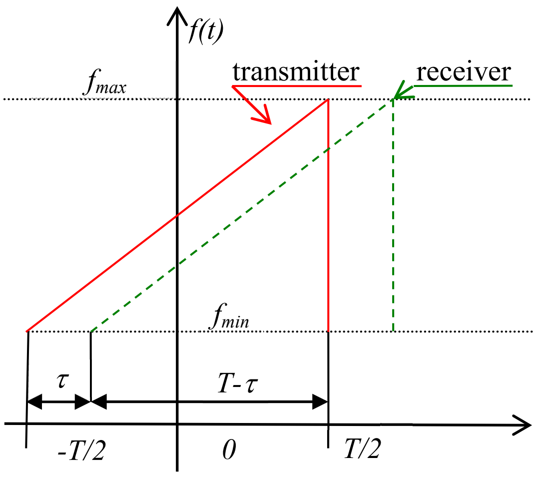

Figure 1. Principle of FMCW radar

Radar signal is transmitted, reflected by the surface of the target and then received after a delay time τ:

$$\tau = 2R / c \quad (1)$$

where: c = speed of light; and R = distance.

The difference between the transmitting and receiving frequency f_R is directly proportional to the distance and is used to further FFT processing (Wawruch & Stupak 2008):

$$f_R = 2R\Delta f / cT \quad (2)$$

where: Δf = frequency deviation; and T = modulation period.

Frequency Modulated Continuous Wave technology offers low probability of intercept feature because of the low peak power and frequency modulation.

2 RADAR GENERAL DESCRIPTION

The prime function of CRM-203 is detection and estimation of planar co-ordinates for sea surface targets and automated tracking the selected ones to perform the coastal surveillance tasks. The radar sensor gives a presentation of the current sea situation and calculates the future situation to accomplish the automated radar plotting aids.

Functional diagram of described radar is presented on Figure 2. Radar sensor basically includes the antennas integrated with FMCW transceiver, antennas motor drive and Signal Processing & Control Unit (SPCU) also including local interface and control circuitry. Each radar transceiver is controlled by the SPCU which is connected to the Operations Centre (OC).

The main functions performed by radar are:

- selection of the operative mode (local or remote); reception from the OC of all controls/ commands and selections needed for complete operation capability; in case of control line failure all the 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 targets;
- processing of the radar video; compression and transmission to the OC of the digitised video;
- automatic or on-demand acquisition of targets falling inside predefined automatic acquisition zones or acquired by the operator;
- automatic tracking of targets falling inside predefined automatic tracking areas; and
- transmission to the OC, once per antenna revolution, of status and alarms from the sensor (BITE), track data (position, speed/course) of targets under tracking.

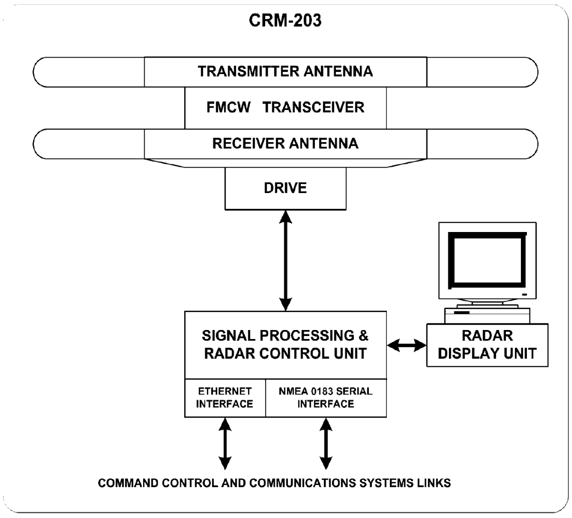

Figure 2. CRM-203 functional diagram

3 ANTENNAS

CRM-203 in the coastal surveillance application has typical requirements as small target detection in weather and sea clutters and high angular resolution. To provide good angular resolution a narrow azimuth beam is required. A narrow azimuth beam is desirable to reduce resolution cell size for three main reasons:

- to provide accurate bearing information on the target;
- to differentiate between targets which are close together; and
- to reduce clutter returns.

The used system features 12 feet, X-band antennas with horizontal polarisation and the following electrical parameters:

- 3dB horizontal beam width = 0.7°;
- 3dB vertical beam width = 22°; and
- gain = 32 dB.

Each antennas group consists of a pedestal supporting the rotating unit. The pedestal contains the drive mechanism, the rotary joint and an 4096 pulses encoder for transmission of antenna position data. The power rating for motor controller is 1.5 kW. Antennas rotating speed is selectable between 12 and 30 rpm. The antennas group is designed to withstand severe marine environmental conditions such as salt spray, sun light, sand, etc.

4 TRANSCEIVER

Functional diagram of the transceiver unit is shown on Figure 3. Direct Digital Synthesizer (DDS) produces a synthesized “chirp” (linear frequency modulated) signal. Next this signal is up-converted by multiplier. The last stage of transmitter circuit is solid state power amplifier (PA), which feeds X-band / 10W FMCW signal to antenna. The receiver consists of a low noise amplifier (LNA), image rejection mixer and intermediate frequency amplifier (IFA).

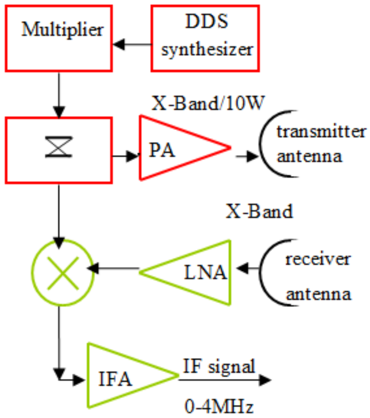

Figure 3. Functional diagram of transceiver unit

The DDS advantages include very fast switching (typically sub microseconds), excellent phase noise, transient-free (phase continuous) frequency changes, extraordinary flexibility as a modulator, and small size, among others. Frequency changes look like those of a Voltage Controlled Oscillator (VCO) – smooth and without phase discontinuity sweep across a defined frequency range with synthesizer accuracy, but without the glitches and transient produced by any other synthesizer technique. Because of the synthesis techniques, this characteristic is unique to the DDS and enables it to produce a synthesized “chirp”. It is very important in FMCW applications because frequency modulation accuracy is directly influencing on accuracy of distance measurements and frequency modulation non-linearity decreases targets detection.

The proposed transceivers have some additional features which make them specially suited for coastal applications:

- sector blanking: emission can be inhibited within an adjustable sector, so as to avoid undesired returns (e.g. land clutter);
- 12 dB/okt. frequency curve slope of IFA amplifier ensures equal intermediate frequency (IF) output signals for targets in different ranges; and
- digital automatic receiver gain control function ensures optimal IF signal output level, independently of under detection target radar cross section.

5 SIGNAL PROCESSING AND CONTROL UNIT

5.1 *Functional diagram*

Functional diagram of the signal processing is shown in Figure 4.

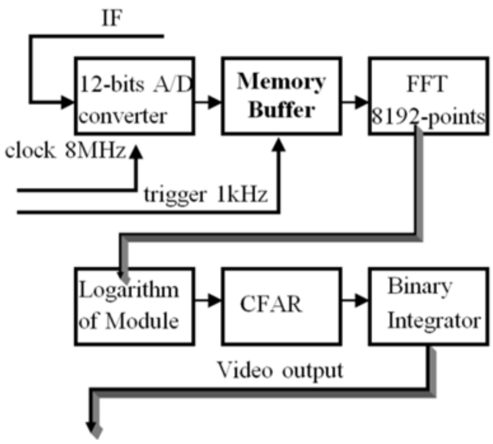

Figure 4. Functional diagram of signal processing

The frequency measurement performed to obtain the range measurement is made digitally using the Fast Fourier Transformation (FFT). So the IF signal is digitised and sent to the spectrum analyser that performs FFT. On the input of the signal processing an analog-to-digital converter samples the IF signal with 8 MHz frequency and 12-bit resolution. Next the spectrum analysis of the digitised IF signal is performed on the base of 8192-point FFT. At the output of the spectrum analyser a periodogramm presenting 4096 range cells is obtained. Range cell size is 5.6 m for radar scale range 12 NM.

The signal after the frequency analysis can be best referred as the video signal. The signal is indeed an exact analogue of the video of pulse radar. The range data output from the spectrum analyser is further processed like in pulse radar: CFAR (Constant False Alarm Ratio) thresholding and binary integration during the dwell time on a target are performed.

Spectrum analysis

The IF signal is analysed using FFT transform. The analysis is carried out in real time. The analysed signal can be modelled as a sum of sinusoids embedded in noise and clutter. In FMCW processing scatters at different ranges appear as different constant frequency components at the IF output. The FFT response to a sinusoidal input reveals a main lobe and side lobes. The width of the main lobe indicates Fourier Domain Resolution, which for CRM-203 application is very narrow and equal 1 kHz. This Fourier Domain Resolution or differently bandwidth of FFT frequency cell is very important parameter of FMCW radar, because of detection performance. Probability of detection depends on the ratio of the target received signal level to the sum of clutter and noise. FMCW transceiver noise power N_i is function of the FFT frequency cell bandwidth:

$$N_i = kT_eB_{FFT} \qquad (3)$$

where: k = Boltzman's constant; T_e = effective noise temperature; and B_{FFT} = FFT frequency cell bandwidth.

This relationship explains excellent CRM-203 radar noise properties allowing low transmitter power.

5.2 *CFAR thresholding*

The radar must detect a target against a changing background of clutter and noise. The clutter reflectivity and statistics will generally vary with range and direction. The problem is how to set a threshold to provide an acceptable probability of false alarm P_{fd} whilst maximising the probability of detection P_d. Standard detection strategy is to fix the P_{fd}. In CRM-203 application an automatic CFAR detector is used. To control of the false alarms, the detector must be able to estimate the parameters of the probability density function of the clutter and noise returns. A well known method of estimating the clutter mean level is the cell-averaging CFAR circuit. The mean level of the cell under test is obtained from the average of a number of surrounding clutter cells. A gap between the cell under test and the surrounding cells is method to ensure that a distant relative strong target does not contaminate the clutter estimates. In CRM-203 radar smallest off CFAR window is taken to calculate threshold. This strategy helps to detect small targets in neighbourhood of strong clutter region. Size of CFAR window is small so a threshold can follow the local clutter mean and can give a much better performance in detection in our case. After CFAR the binary integrator is used with the "M-of-N" rule in accordance with formulas valid for Gaussian noise.

The Signal Processing & Control Unit includes a local display facility, in order to allow local maintenance and set-up operations. All radar controls are available on the local panel. Moreover SPCU feeds video signal to Radar Display Unit, which accomplish:

- video acquisition and processing;
- plot extraction; and
- tracking.

Track data are sent to the OC for further processing. Also plot information can be routed through the same communications channel. All the radar controls, including those available at the local panel, can be also sent by the OC via the remote interface. The radar continuously sends the status information to the OC, together with target data.

6 TECHNICAL DATA

Basic technical are presented in Tables 1-7.

Table 1. Transmitter

Parameter	Value
Output power	1mW-2W (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 – 48NM
Modulation	DDS based linear FMCW
Sweep repetition period	1 ms

Table 2. Receiver

Parameter	Value
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.

Table 3. Antennas

Parameter	Value
Antenna length	3.6 m
Beamwidth (3 dB) horizontal/vertical	0.70°/22°
Polarisation	Horizontal
Gain	32 dBi
Rotation speed min/max.	12/30 rpm
Drive motor	1.5 kW

Table 4. Signal processing

Parameter	Value
FFT signal processing	8192-points FFT
Sampling frequency	8 MHz
Number of range cells	4096
Signal thresholding	CFAR
Signal integration	binary, number of detections dependent on antenna rotation speed
Sea clutter reduction	signal correlation from 2 antenna rotations.

Table 5. Display unit

Parameter	Value
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, target range and bearing from radar position, target course
Options	ARPA anti-collision functions

Table 6. Range and angle measurements

Parameter	Value
Scale range [NM]	12 / 24 / 48
Range cell size [m]	5.6 / 11 / 22
Range measurement accuracy	1% of selected range or 50 m (whichever is greater)
Angle resolution	0.1°
Bearing accuracy	0.7°

Table 7. Environmental conditions

Parameter	Value
Wind operational	30 m/s
Wind survival	50 m/s
Humidity	98 %, 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

7 RECAPITULATION

Described radar was installed in the radar laboratory of the Gdynia Maritime University this year. Its antenna is located on the roof of the university building nearby the south entrance to the Gdynia Harbour. Operational tests of the radar will be conducted in December 2008. Its detection possibilities, accuracies and clutters resistance will be checked during measurements in real hydro-meteorological conditions. Results will be compared with information about positions, courses and speeds received from Automatic Identification Systems (AIS) installed on board detected and tracked objects and data about these objects received at the same time from four different ship pulse radars installed in the same laboratory. Results of these tests will be presented on the conference.

REFERENCES

Wawruch R. & Stupak T. 2008. Charakterystyka radaru na falę ciągłą. Prace Wydziału Nawigacyjnego Akademii Morskiej w Gdyni No. 21, p.120-130.