Procedures and Deck Officer Training in Cases of Intentional Radar System Jamming and Deception

Procedure i obuka palubnih časnika u slučajevima namjernog ometanja sustava i obmane

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Summary

This study analyses the procedures of radar system users in cases of intentional radar jamming and deception, with particular emphasis on safe navigation. Along with the procedure analysis, the study also deals with training methods of deck officers for jamming countermeasures to maintain certain accuracy of surveillance and safe navigation. The article also defines a decision tree – safe navigation which offers the radar operator the possibility of choosing "the course of action" based on the type of interference, assessed threat and the activities necessary to ensure safe navigation. Such research is of extreme importance for educating and training of maritime officers, especially deck officers, in thematic units relating to accuracy and reliability of the radar system exposed, in this case, to intentional interference.

KEY WORDS
marine radar
interference (jamming)
detection
safe navigation

Sažetak

Ova studija analizira procedure radarskih korisnika u slučajevima namjernog zagušenja i obmane, s posebnim naglaskom na sigurnu plovidbe. Skupa s analizom procedure, studija se također bavi metodama koje časnici palube koriste i protumjerama da bi se održala određena preciznost i nadzor sigurne plovidbe. Članak također opisuje stablo odluka - sigurnu navigaciju koje nudi radarskom operatoru mogućnost odabira «tijeka djelovanja» temeljenog na tipu interferencije, procijenjenoj opasnosti i aktivnostima potrebnima za sigurnu navigaciju. Takvo istraživanje je od iznimne važnosti zbog obrazovanja i obuke pomorskih časnika, posebno palubnih časnika, prigodom tematskih jedinica koje se odnose na točnost i pouzdanost izloženog radarskog sustava, a u ovom slučaju namjerna ometanja.

KLJUČNE RIJEČI
pomorski radar
interferencija (ometanje)
praćenje
sigurna plovidba

INTRODUCTION / *Uvod*

It is a well-known fact that interference with the radar system can endanger safe navigation. It is therefore essential to identify radar limitations in real usage conditions when exposed to intentional types of jamming. Intentional radar interferences are very rarely to hardly ever analysed in seafarer training, even though they exist and are widely applied. Previous research has shown that the awareness of intentional jamming on the radar display is insufficient which directly endangers safe navigation, thus adding value to this approach.

The situation in navigation has, in this sense, become even more complicated due to an increased number of pirate attacks and decreased prices of electronic jammers. The development of contemporary radar systems is taking into account the resistance to intentional jamming, but efforts are nevertheless insufficient because there is a human factor at the end of the decision chain. Therefore, there is a problem of correct directing, accuracy and timely reactions of the deck crew members.

Namely, the question is how to avoid erroneous reactions which are very likely due to insufficient know-how as to overcoming momentary conditions of the radar system because of, for example, intentional interference, when the radar is functioning correctly but giving a false image of the actual surrounding. Research efforts and the knowledge of the effect of intentional radar interference on safe navigation must be directed at finding *standard operative procedures* which would help avoid erroneous activities (mostly due to a false image of the actual surrounding) and thus enable safe navigation.

Starting from the above stated, *the study problem* is defined as the level of training of systems operators for safe navigation under intentional (selective) jamming to which both the technical system and man are exposed to. The study subject is the level of knowledge and reaction of deck officers, i.e. operators of the marine radar system in interpreting "radar images" under jamming, for proper decision-making. Wrong decision can lead to far-reaching consequences which could result in ship collision, sinking, grounding, etc. *The study objec*t is an operative procedure of the radar system operator (deck officer) and the protocol by which the latter has to operate while identifying intentional (selective) jamming , all for the purpose of ensuring safe navigation. The correct course of action according to the operative procedure and protocol should always answer to two questions:

1. Is there intentional (selective) jamming ? and
2. If there is, how and what actions should be taken to ensure safe navigation?

Unlike unintentional interference impacts, the impact of intentional (selective) jamming on the correct and reliable performance of the radar system is insufficiently researched (bibliographic units detailing intentional jamming are very few), so the purpose of the study was to broaden the knowledge of the problem and to improve the identification of jamming and ensure, through sufficient training, increased safe navigation. The study's hypothesis is that an improved and more precise processing of received information of the navigational radar system under intentional (selective) jamming and a high quality training of deck officers can enable better navigational safety under contemporary threats posed by intentional jamming.

The first part of the study focuses attention on defining the procedure methodology under radar jamming, whereas the second part suggests ways of enabling deck officers to identify and counteract the impact of intentional jamming.

1. DECK OFFICER'S PROCEDURES IN THE CASE OF INTENTIONAL JAMMING / *Postupci palubnog časnika u slučaju namjernog ometanja*

Today, safe navigation is increasingly reliant upon the radar system (e.g. ARPA radar) in various navigation areas and in determining the position of the navigating vessel. It is therefore necessary to define procedures in case of intentional jamming.

Procedures suggested in case of identification and existence of intentional jamming with the radar system can be divided into:

- threat assessment,
- procedures optimization,
- change in navigation plan and
- increased surveillance.

The necessary procedures are:

- usage of the alternative radar system, or new operating frequency of the radar
- determining the current vessel position with other electronic devices
- radio contact with nearby vessels and port authorities and reporting on the current state.

In accordance with the above stated, the following decisions are possible:

a. continue navigation,
b. continue navigation with increased surveillance,
c. reroute and
d. stop navigation.

Besides the above stated, it is also necessary to make a record of the incident , which will later be used for the analysis of the procedures undertaken. In accordance with the author's experience and research of intentional jamming and the fact that thus far literature has not methodologically detailed the documentation of such events, it is suggested the notes contain the following elements

- Chronology of events, as shown in Table 1. (research has shown that the most dominant shadow sector is in the direction connecting the radar jammer and the jammed radar).

- Description of the area where the jamming occurred - determine the jamming direction based on the most dominant shadow sector of the radar screen.

c. A list of engaged devices and procedures undertaken to prevent intentional interference:

- which other devices were used and what the operating radar frequency was used
- what information about the situation in the environment of the existing vessels and navigation

Table 1. Chronology of incident
Tablica 1. Kronologija nezgode

Time	Procedure undertaken
T1 + 1 min	switch to a radar system operating in a different frequency band
T + 2 min	switch from automatic to manual vessel control
T + 4 min	verify the current position of surrounding vessels with alternative radar systems (VTMIS, radar systems of surrounding ships)
T + 5min	increase the number of the crew members on the bridge of the ship
T+5 min	decrease the cruising speed to a safety speed
T+10 min	compare the established position with the position obtained from other electronic devices (AIS, GPS, ECDIS) (AIS, GPS, ECDIS)[2]
T+ 10 min	make the change of the navigation plan
T+ ……	continue navigation according to a new navigation plan, with increased surveillance and usage of other methods of determining the position

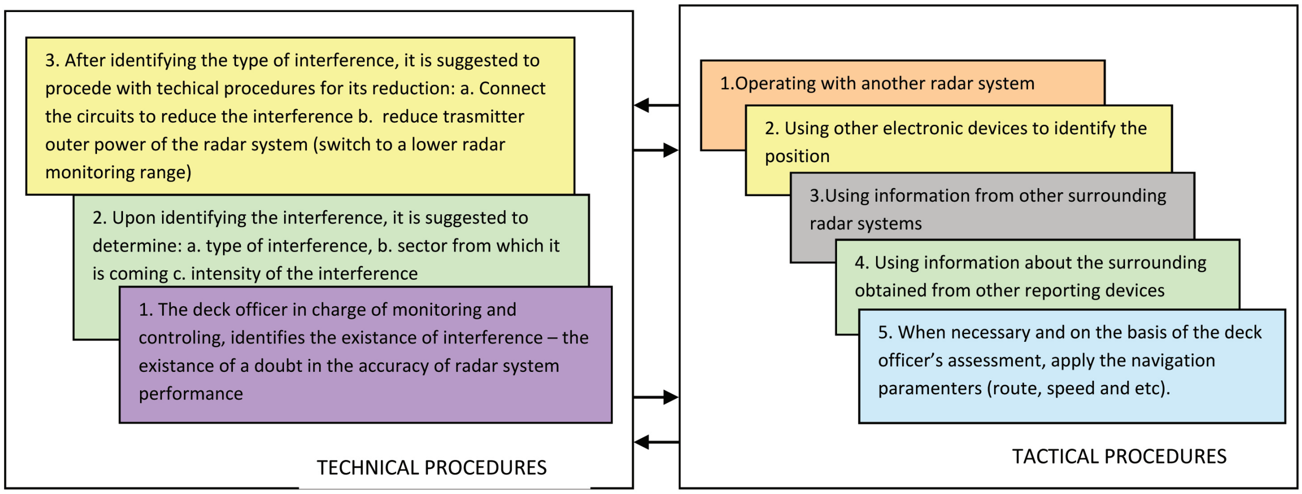


Figure 1. Procedures of the radar system operator in case of intentional jamming 4

Slika 1. Postupci operatora radarskog sustava u slučaju namjernog ometanja 4

features was obtained from AIS subsystem,

- ECDIS comparison of the current position with the situation on the map
- The results of procedures undertaken which reduced the effect of intentional jamming and protected safe navigation.

Records are made by the deck officer on call and approved by the ship commander. As a contribution to the study, Table 1 suggests procedures for radar system operators in cases of intentional jamming. The procedure is shown in Figure 1. and is divided into two units: technical and tactical.

Figure 1. shows procedures of the radar system operator in case of intentional jamming . The procedure is divided into two units: technical and tactical procedures.

Considering how the defined sub processes have not yet been detailed in the literature available, Table 2. offers the possibility of better understanding of the jamming process as well as procedures suggested.

The most important step is assessing and determining the degree of threat because this creates prerequisites for a high quality choice of tactical and technical procedures.

Tactical measures suggest rerouting (changing navigation plans) in a way that would avoid running aground or colliding with the objects in the navigating aquatorium.

Technical measures ensure the choice of alternative technical devices, thus ensuring an accurate position and vessel route.

Based on previously mentioned, upon completion of procedures in case of intentional jamming, and taking into account the applied technical and tactical procedures, the following data is present:

- chronology of incident during procedures undertaken
- the area where the jamming occurred
- engaged devices and procedures undertaken
- results of the procedures undertaken to reduce jamming

Mentioned data are entered into the database and can serve to develop simulation models in the deck officer training process.

It is also noticed that there are seven sub-processes, described in Table 2., which are conducted during intentional jamming.

Every sub-procedure is actually a sum of actions that is

Table 2. Sub-processes in case of jamming 4

Tablica 2. Podpostupak u slučaju ometanja 4

NAME OF SUBPROCESS	DESCRIPTION OF THE SUBPROCESS
Detection of jamming	After the start of jamming, the officer identifies the situation on the radar screen which is not in accordance with the expected one.
Identification of jamming	Considering the situation, he tries to diagnose jamming elements: type, area where it is originating from, intensity and severity of the impact on data
Normal continuation of navigation despite jamming	Unless impact on the data is dominant, navigation proceeds with increased caution.
Technical procedures to reduce the impact of amming	Undertake action that involves using and connecting system circuits to reduce the impact of jamming.
Tactical procedures to reduce the impact of jamming	Undertake action and procedures which imply the use of tactical procedures to reduce the impact of jamming (operating on other radar systems, use of data obtained from other electronic devices, rerouting the vessel and etc.)
Continue navigation after exiting the area affected by jamming	Continue navigation after the end of jamming.
Records	Make a record of the undertaken and executed activities and procedures.

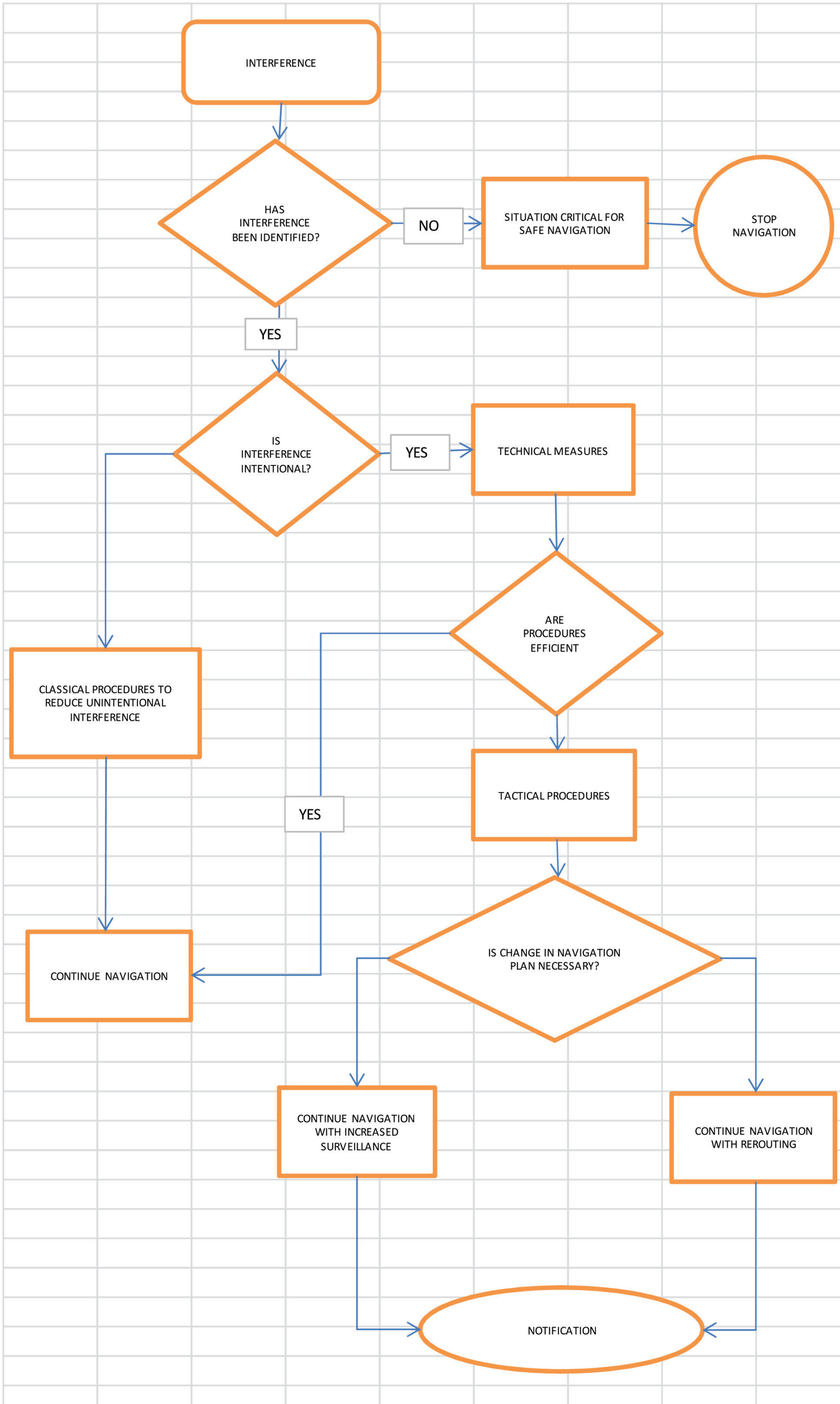


Figure 2. Decision tree – safe navigation 4
Slika 2. Stablo odluke - sigurna navigacija 4

directly carried out by the deck officer.

The decision tree for protecting safe navigation is shown in Figure 2.

The decision three shown in Figure 2. whose aim is to enable safe navigation, is the direct result of the knowledge gained and procedures suggested in the previous section of the study and represents an original contribution to safe navigation.

The decision tree is in the shape of an algorithm and offers the radar operator the possibility of deciding on “a decision path”,depending on the type of jamming, threat assessment and activities necessary to undertake for safe navigation.

The choice of the decision path, depending on the information collected, is divided into two units:

a. when the assessed threat of intentional interference can be reduced to an acceptable level and is not critical for safe navigation (continuation of navigation with increased surveillance) and

b. when the assessed threat is unacceptable and critical for safe navigation (re-routing or stopping navigation).

The suggested and standard operative procedures shown enable effective protection of safe navigation in cases of intentional jamming with radar systems. They are to be elaborated in detail for each case: vessel, platform, monitoring station and etc.

Along with the defined actions and standard operative procedures, it is also necessary to conduct adequate deck officer training for confronting intentional jamming through the educational system at Maritime colleges. This type of training will be outlined in the following unit.

2. DECK OFFICER TRAINING TO COUNTER INTENTIONAL JAMMING / *Obuka palubnog časnika da se suoči s namjernim ometanjem*

Deck officer training to counter international jamming should be carried out through the education process and a suitable training. The curriculum and syllabus of such training should combine various explanations of the radar image.

Radar image is different from the natural panoramic image of the human eye for the following reasons:

- different wavelength of light and radar waves,
- reflections of individual objects are neither in size nor shape proportional to natural ones,
- depending on the direction and distance separation, close objects merge,
- existence of radar shadows,
- existence of false reflections and interferences,
- existence of blind sectors and etc.

2.1. IMPACT OF INTENTIONAL JAMMING ON THE RADAR SCREEN / *Utjecaj namjernog ometanja na radarskom zaslonu*

Due to the existing differences in radar images it is necessary to show the trainees, through simulator training, the various images on the radar screen when exposed to different interferences. Those impacts can be:

- Object distortion – it is reflected in relatively enlarged dimensions in relation to real ones. Directional object distortion is caused by horizontal beam width and is reflected in angular object enlargement. Longitudinal object distortion is caused by the impulse width while radar shadows represent dark places which appear due to the shape of obstacles, their position and the inability of EM waves to reflect against geometrically occluded areas.
- False and interfering reflections – these are the reflections whose position on the radar display does not correspond to the real one, giving erroneous (false) information on objects. The cause of this is mostly multiple reflections, reflections due to side lobes, reflections against parts of its ship, secondary reflections and etc.
- Intentional interference - detailed in the author’s PhD thesis.

During the training process it is of pivotal importance to approach interpretation of the radar image in cold waters in high latitudes due to sub - refraction and possible icebergs whose smooth and bent surface can be detected from a relatively small range.

When studying these radar reflections it is necessary to point out the fact that they differ according to:

- size (related to gain)
- detection range,
- shape,
- fluctuation,
- acuity,
- mobility.

The main characteristics of the reflection based on the object features are:

for ground objects:

- objects appear in expected positions, according to its location on the map,
- reflections do not have movements of their own,
- reciprocal positions of these reflections do not change,
- reflections are most often big and “dense”

for vessels:

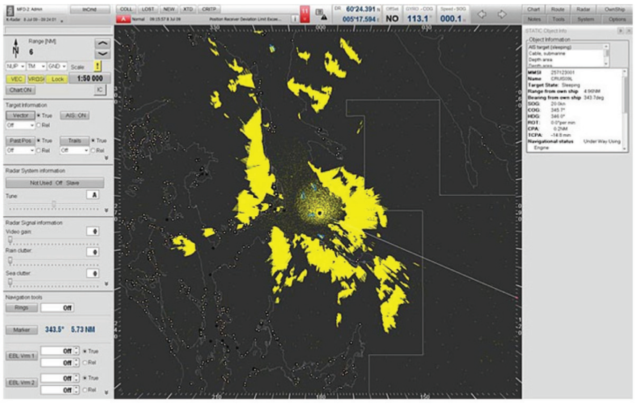
- reflections are not expected according to the map,
- they have their own movements,
- they fluctuate, but do not disappear (they appear whenever a EM wave passes through)
- they are narrow (in relation to the radial line)
- they appear at a medium range (which depends on the size of the vessel, material and route),

for boats, buoys and other small objects:

- they appear at small ranges,
- their fluctuation is prominent, with disappearances in certain EM beam passages in wavy sea)
- reflections are stronger than individual reflection (dot) of interferences.

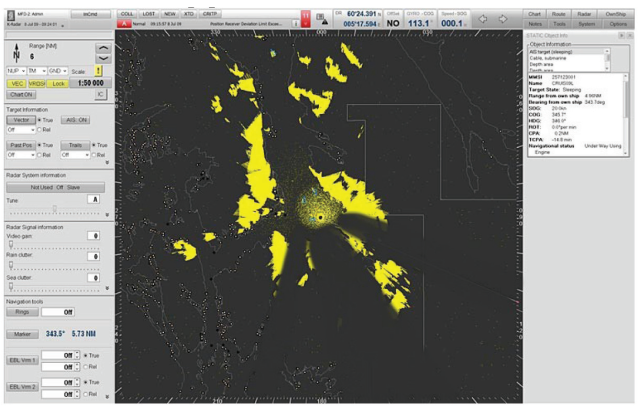
The visual aspect is extremely important in the learning process of beginners. It is therefore essential to use electronic methods to show radar images which can identify interferences.

In the following pages we will show what interferences look like on the Konsberg Maritime K-Bridge ARPA radar screen. (Figure 3. a,b,c,d)



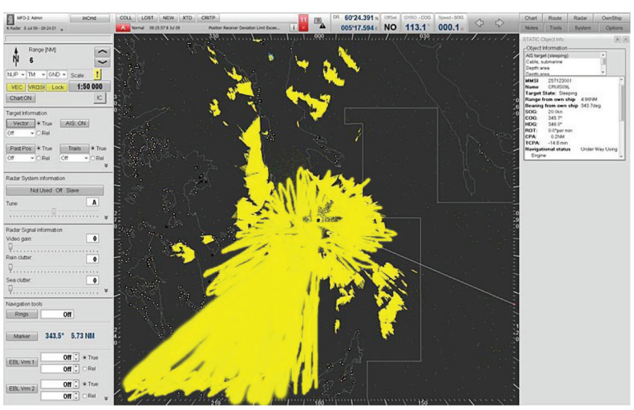
3. a. Radar display without the impact of intentional interferences 9

3. a. Radarski zaslon bez utjecaja namjernih interferencija 9



3. b. Radar receiver in saturation in the 160^0 sector 4

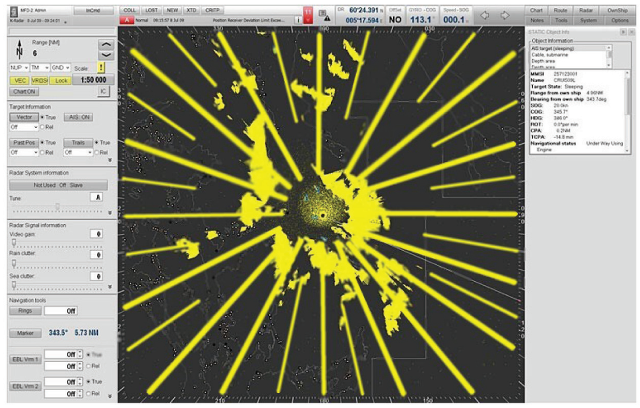
3. b. Radarski prijamnik u zasićenju kod 160^0 sektor 4



3. c. Noise generated for sector 210^0 4

3. c. Buka koja je proizvedena za sektor 210^0 4

Based on the ARPA radar features and possible errors in its correct functioning, seafearer training must emphasise that mistakes can also be triggered by intentional (selective) jamming using certain jamming modes. It is of pivotal importance to point out that there are two key areas in which intentional



3. d. Amplitude modulated interference 4

3. d. Interferencija 4 prilagođene amplitude

(selective) jamming can manifest iteself in ARPA radars:

a) while monitoring objects and danger assessment and

b) exchange of navigating vessels and imitating them by emitting false alarms, imitating channels and narrow passages and imitating search and rescue actions

Regarding the navigation safety, such jamming can often be applied in the presence of high speed vessels and in locations of dense traffic, when, for example, the radar operator fails to interpret the minimum bypassing distance and navigation time to the minimal bypassing distance correctly, i.e. leading to interruption of object monitoring because it has simply vanished from the screen because the echo of one of the navigating vessels was artificially increased in relation to the other so the computer continued to monitor the vessel with the stronger echo rather than the one with the higher priority.

Table 3 shows some of the jamming modes and their manifestations on the ARPA radar. The table unites error manifestations in ARPA radars and the effect such jamming can have on navigation safety.

In accordance with Table 3, the following will show dependency between radar ranges in relation to reflective surface of the target for the given detection coefficient. Table 3 shows dependency of the radar range on the radar reflective surface (σ).

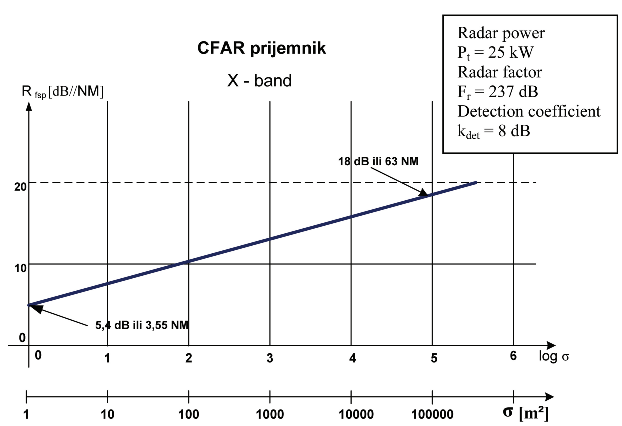


Figure 3. Diagram shows dependency of the radar range on the reflective surface of the target 4

Slika 3. Dijagram prikazuje ovisnost radarskog dometa na površinu koja reflektira cilja br. 4

Table 3. The effect and manifestation of jamming modes in ARPA radars 4

Tablica 3. Efekt i manifestacija načina ometanja kod ARPA radara 4

Jamming modes	Jamming effect	Manifestation on the ARPA radar
SPOT-NOISE JAMMING - bandwidth noise jamming	Inability to detect the aim (high noise density within the reciever bandwidth)	Reflection disappearance (island and objects) in the area where the jamming originated from
REPETITIVE REPEATER	Generating false objects	Appearance of objects on unexpected locations
PSEUDORANDOM SEQUENCING JAMMING	Inhibits object monitoring i.e. determining aim coordinates	Detecting objects with false coordinates, incorrect bypass course calculations
SCAN FREQUENCY JAMMING – generating gate speed error	Generating gate speed error (false Doppler aims)	Appearance of moving objects with false speeds
RGWO- Range Gate Walk-Off DELTA JAMMING AGC JAMMING - AGC(Automatic Gain Control)	Range time gate walk off from the aim Error in tracking the angle Error in tracking the angle Angle error	Detecting objects with false coordinates and speeds
BARAGE NOISE	Masking the expected reciever radar signal	Light fans on the radar screen that cover object and land refletions – inability to detect objects

Correspondingly, we are analyzing different object detection (detection targets) at sea and their possible masking in noise. Table 4 shows examples of parameters of civil radars used in navigation.

On the basis of Table 4, calculations are made for detection coefficients of known detection threshold (SNRmin, Signal-to-Noise Ratio at which reliable detection occurs) from 12, 5 dB for specific types of radars (A-E) and radar range in relation to specific types of navigating vessels (Table 5) representative by the size of radar reflective surface.

In accordance with the stated in Table 5, various diagrams for those types of radar have been made.

Figure 4 clearly shows how radar range increases with the increase of radar power i.e. the fishing vessel of the radar reflective surface 6 m2 is at the end of radar visibily whose power is Pt=2,2 kW. Also noticeable is that radars stronger than

Table 4. Typical examples of civil radar parameters for navigational purposes in X-range (Gallman P.) 11

Tablica 4. Tipični primjerci parametara civilnog radara za navigacione svrhe kod X-dometa (Gallman P.) 11

Example	A	B	C	D	E
R (NMi) - radar range	16	48	96	120	120
P_t (kW) - radar power	2.2	4	12	25	50
θ_H (º) – bandwidth horizontally	6.2	2.4	1.8	1.23	0.95
θ_V (º) – bandwidth vertically	25	27	25	20	20
G_t (dB) – antenna gain	21	25	26	29	30
F_n (dB) – noise factor	10	6	6	6	6
B_n (MHz) - width of the frequency noise band	7	3	3	3	3
F_r (dB) – radar factor	201	219	227	235	241

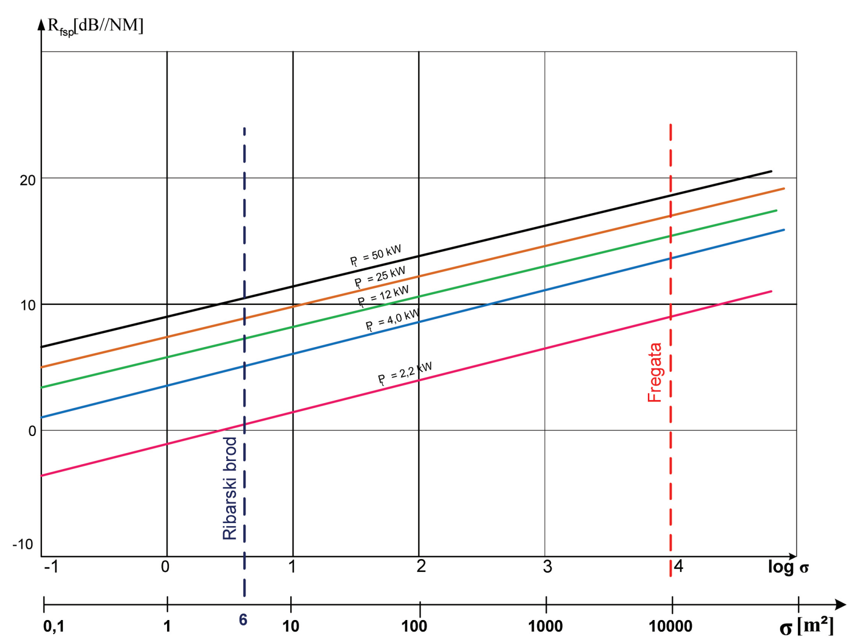


Figure 4. Diagram showing dependance of radar range on the reflective surface of the target for different radars 4

Slika 4. Dijagram koji pokazuje ovisnost radarskog dometa o površini cilja koji reflektira za različite radare 4

Table 5. Calculations of the detection coefficient and range for specific types of radar and navigating vessels 4

Tablica 5. Kalkulacije koeficijenta praćenja i dometa za specifične tipove radara i brodove koji plove 4

	P_t^5 (kW)=2,2	P_t (kW)=4	P_t(kW)=12	P_t (kW)=25	P_t (kW)=50
k_{det} (dB)	**-1.0**	**3.51**	**5.51**	**7.51**	**9.01**
R_{fsp}[6](NM) (Fishing vessel σ ~ 6m2)	1.2	4.62	8.22	11.22	13.45
R_{fsp} (NM) (Fishing vessel σ ~ 1000 m^2)	4.46	17.41	30.97	41.68	50.58
R_{fsp} (NM) (Bulk carrier σ ~ 5.000 m^2)	6.66	26.00	46.23	63.09	75.50
R_{fsp} (NM) (Warship σ ~ 50.000 m^2)	11.85	46.23	82.22	112.20	134.28
R_{fsp} (NM) (Tanker σ ~ 1.000.000 m^2)	25.00	97.94	174.18	237.68	284.44

Tablica 6. Syllabus of the necessary training

Tablica 6. Silabus potrebne obuke

<table>
<tr><td></td><td colspan="2">Title</td></tr>
<tr><td></td><td colspan="2">ANALYSIS OF THE RADAR IMAGE</td></tr>
<tr><td rowspan="2">Lectures organization</td><td>Lectures</td><td></td></tr>
<tr><td>10</td><td>10</td></tr>
<tr><td>Ensuring quality lecture performance</td><td colspan="2">Report on lectures and exercises held</td></tr>
<tr><td rowspan="2">Training content:</td><td colspan="2">Unit:</td></tr>
<tr><td colspan="2">The starting point of the training: STCW 78/95 Convention
Training components:
• Description of radar systems used on SOLAS vessels
• Familiarization with the problem of electronic jamming with radar system and aspects of electornic countermeasures applicable on SOLAS vessels
• Familiarization with tactical and technical procedures applicable during intentional jamming with the radar system
• Assessment and risk analysis in cases of intentional jamming
• Monitoring, surveillance and navigation in cases of intentional jamming
• Documentation and files management
• Reporting in cases of intentional jamming
Purpose:
• Familiarize students with the process and methodology of procedures in cases of intentional jamming.
Competencies and understanding:
• Understanding and identifying intentional radar jamming
• Navigational training during intentional jamming
Knowledge and skills:
• Identifying intentional radar jamming
• Quality equipment for executing work assignments
Types of training:
• lectures
• work on the simulator</td></tr>
<tr><td>Student responsabilites</td><td colspan="2">Regular attendance at lectures, practical training and exercises on the navigation simulator</td></tr>
</table>

Outcomes	• Explain and apply the knowledge on radar system of SOLAS vessels • Explain and define the impact of intentional jamming to safe navigation • Explain and use the knowledge of intentional electronic jamming • Explain and use technical procedures to protect against jamming • Explain and use tactical procedures to protect against jamming • Explain and apply ways of reporting in cases of jamming • Apply the acquired knowledge to maintaining safe navigation under intentional jamming

Evaluation of the acquired knowledge and skills	
NOTE: The final grade will be based on the success achieved in all marking elements listed. All elements have to be marked with a passing grade.	
Marking elements	**Points**
Activites at lectures	10
Practical work on the simulator	50
	40
Total	**100**
Student obligations	**Attendance (in percentages)**
	Regular students
	50%
	80%
	Forms for recording student attendance
	The professor's signature
	Obligatory for the professor's signature : 1. achieving a sufficient percentage of attendance at exercises, 2. achieving a sufficient percentage of attendance at lectures.

2,2 KW will detect the target of the stated reflective size.

However, if, with such conditions, we generate jamming whose manifestations on the ARPA radar are defined in Table 3. it is obvious that this will inevitably further threaten range, visibility, and accuracy of recieved data directly linked to the type of jamming, sector where it originated from and the jammer power. Experience (of the author while working with operative radar jammers) has proven that the increase of radar power (by increasing radar range) in cases of jammer- responder (jammer analyses and responds to every inward impuls) only achieves the opposite effect i.e. radar reciever is jammed by a stroner jamming signal.

Correspondingly, the following part recommends a training syllabus for deck officers in cases of intentional jamming for the purposes of taking necessary actions in cases of intentional radar jamming.

2.2. SYLLABUS OF THE NECESSARY TRAINING / *Silabus potrebne obuke*

Table 3. shows the outline of the curriculum and syllabus of a sailor in charge of the watch on the ship bridge.

The syllabus is the result of years of work and research conducted in the area of radar jamming, lectures of radar system operators in cases of intentional jamming as well as lectures held at Maritime colleges. Research has practically shown that radar system operators have numerous times failed to recognize radar jamming and have accordingly not been able to take necessary measures.

The number of lectures and exercises can vary depending on the type of simulator and radar device used for the training. If necessary, it is suggested to make the adjustment for the training group in question.

CONCLUSION / *Zaključak*

The results of this study are directy applicable in everyday marine practice. They can directy affect an increased safe navigation because the very application of these results reduces the danger of intentional jamming.

This can be achieved through:

- knowing the models and the corresponding procedures as described in Chapter 1.,
- identifying jamming, as detailed in Chapter 2.1. i.e.
- an appropriate deck officer training in countering intentional jamming, as described in Chapter 2.2.

Worth noting is the contribution to a broader scientific knowledge of the impact of intentional jamming to safe navigation. as a result of years of work on the issue of radar system jamming in a series of articles dealing with radar system jamming 2, 4, 10, 12, 13, 14.

All of the stated has special significance in educating and training marine officers, deck officers, especially in thematic units relating to accuracy and reliability of the radar system exposed, in this case, to intentional jamming. Insufficient research of the impact of intentional jamming on the correct performance of the radar can endanger safe navigation. As mentioned previously, intentional jamming and research into radar system jamming has mainly been conducted in the military structure domain which has made research results unavailable to the broader scientific study and consequently caused insufficient training of deck officers on SOLAS vessels..

It is therefore suggested to continue with permanent research and training in identifying radar limitations in real usage conditions when the radar is exposed to various types of jamming. Also suggested is to keep up to date with the development of radars used on vessels and of systems for intentional jamming and changing and adjusting of the necessary educating and training.

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