International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R M.2321-0
(11/2014)

Guidelines for the use of spectrum by oceanographic radars in the frequency range 3 to 50 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

1865 - 2015

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at http://www.itu.int/publ/R-REP/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	**Mobile, radiodetermination, amateur and related satellite services**
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management

Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2015

© ITU 2015

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

REPORT ITU-R M.2321-0

Guidelines for the use of spectrum by oceanographic radars in the frequency range 3 to 50 MHz

(2014)

Table of Contents

Page

1 Introduction 4

2 Frequency administration 5

2.1 Allocations 5

2.2 Frequency management issues 6

2.3 Call-sign identification 7

3 Operational considerations 7

3.1 Oceanographic radar database 7

3.2 Coordination of multiple radars 7

3.3 Emergency management 8

4 Summary and conclusions 8

Annex 1 – Call sign identification 8

Annex 2 – Non-modulation specific coordination techniques 9

Annex 3 – Frequency modulated continuous wave modulation multiplexing coordination techniques 15

Annex 4 – Oceanographic radar sweep factors impacting radar to radar interference 30

Annex 5 – Examples of other radar technologies 34

Annex 6 – Data elements for electronic submission of information related to oceanographic radars 35

Glossary

Abbreviations

BW: Bandwidth

c: Speed of light

DBF: Digital beam forming

DDS: Direct digital synthesis

DF: Direction finding

e.i.r.p.: Equivalent isotropic radiated power

FDM: Frequency division multiplexing

FMCW: Frequency modulated continuous wave
(NOTE – The words “pure FMCW” and “non-gated FMCW” are used in the same sense in Annexes 3 and 4.)

FMICW: Frequency modulated interrupted continuous wave
(NOTE – The word “gated FMCW” is used in the same sense in Annexes 3 and 4.)

GF: Gating frequency

GPS: Global positioning system

IW: Information width

MM: Modulation multiplexing, sweep MM

NS: Nominal slot

NSO: Nominal slot offset

PT: Propagation time

RL: Range limit

SD: Sweep directions (multiplexing)

SN: Slot number

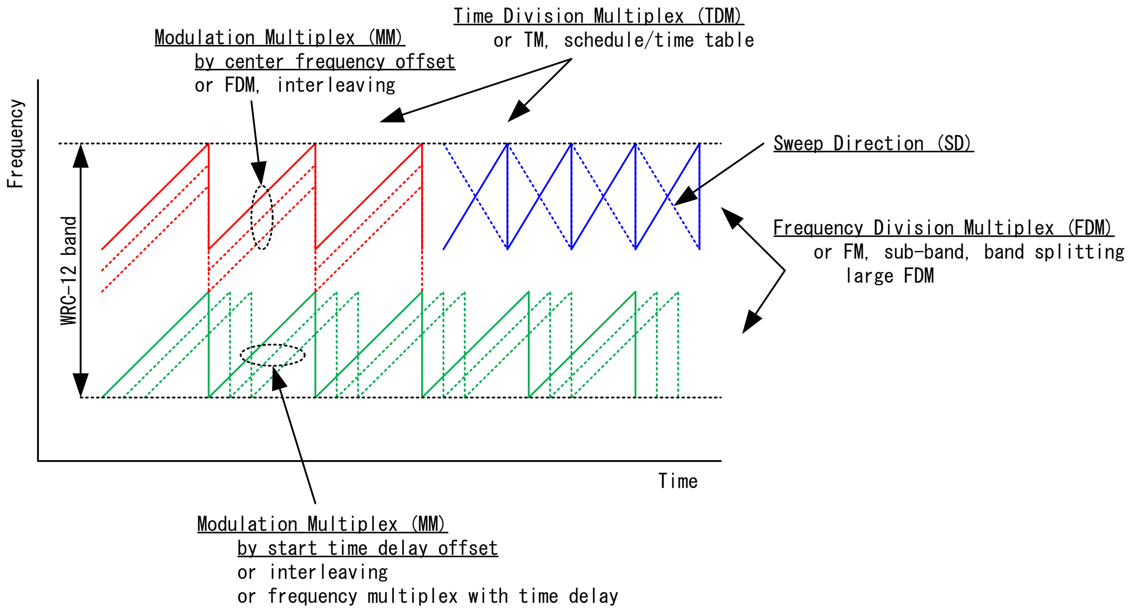
SRF: Sweep repetition frequency

SR: Sweep rate

TDM: Time division multiplexing

FIGURE 1

Illustration of Glossary Terms



1 Introduction

The 2012 World Radiocommunication Conference (WRC-12) allocated a number of frequency bands in the frequency range 3 to 50 MHz to the radiolocation service to be used for oceanographic radar applications as outlined in Resolution **612 (Rev.WRC-12)**. In addition to the coordination of oceanographic radar operations, Resolution **612 (Rev.WRC-12)** outlines requirements that oceanographic radar operators must meet to ensure that if cases of interference do occur, they can be easily mitigated.

Each administration has the right to manage the use of spectrum within their borders. The information contained in this Report can be used by administrations, oceanographic radar operators, and regional radar operator groups, for the most effective use of the allocated frequency bands. Efficient use of the radio spectrum by oceanographic radars also requires coordination between administrations operating oceanographic radars.

This Report addresses technical characteristics for efficient spectrum use by oceanographic radars operating in the frequency range 3 to 50 MHz based on the following views:

– The existing oceanographic radars have been implemented and operated all over the world based on the technical characteristics described in the latest version of Recommendation ITU-R M.1874.

– This Report should facilitate the exchange of technical and operational information for a wide range of oceanographic radars described in the latest version of Recommendation ITU-R M.1874, but may also apply to developmental radars that meet the requirements of Resolution **612 (Rev.WRC-12)** but are not yet included in Recommendation ITU-R M.1874.

– Operational coordination of the oceanographic radars should be implemented under Resolution **612 (Rev.WRC-12)** and Report ITU-R M.2234. Further implementation of a detailed coordination procedure should be maintained on a region by region basis or related administrations basis between the oceanographic radars.

It is important to take into account that various system and operational designs may use different signal generation, stability, wave forms, antenna techniques, frequencies of operation, and bandwidth. Additional factors include the number of radars, their distance from one another, the nature and geometry of paths (sea, land, mixed) between them, the required timeliness and duration period of radar output data, their mode of operation (whether or not multi-static operations among neighbouring radars is planned), required multi-function capability, intended application(s) of the oceanographic radar network, the spatial resolution needed to achieve intended application goals, the signal parameters of nearby radars that have already been assigned a frequency and the need to mitigate other-source interference within allocated bands. All of these factors affect the frequency sharing conditions

Oceanographic radars may require coordination and use of sharing techniques outlined in this report when they have separation distances less than 920 km while operating at frequencies near 5 MHz, 670 km while operating at frequencies near 9 MHz, 520 km while operating in the 13 to 17 MHz range, and 320 km above 20 MHz.

The coordination technique used for each radar should be selected or defined regarding its operation, frequency parameter, output power, environment, number of radars simultaneously operated, and cost, across multiple technologies.

At frequencies below 20 MHz, where available allocated spectrum is limited, division of these among different users is desirable via FDM. However, too narrow a bandwidth per radar can result in too large a radar cell to be useful for many applications. This leads one toward operation via several techniques (e.g. MM (modulation multiplexing) and other techniques).

At frequencies above 20 MHz, mutual interference among nearby radars becomes considerably less limiting. Radars can be more closely packed together without needing precise timing because simultaneous operation on the same frequency becomes possible.

Descriptions of coordination technologies such TDM, FDM and beam steering are discussed in Annex 2. Modulation multiplexing techniques are discussed in Annex 3.

Other annexes detail complementary techniques: Annex 1 describes a technique that could be used for call sign identification; Annex 4 addresses oceanographic radar sweep factors, Annex 5 describes radar technologies other than FMCW and Annex 6 contains a detailed description of the data elements used for electronic submission of information related to oceanographic radars.

2 Frequency administration

In order to effectively use the spectrum that has been allocated for oceanographic radar operations, a global approach will need to be taken to the management of the available spectrum.

– Administrations should coordinate with each other under *resolves* 6 of Resolution **612 (Rev.WRC-12)**, which defines the separation distances between the oceanographic radar and the border of other countries, and Report ITU-R M.2234;
– Frequency assignment to the radiolocation service to be used for the oceanographic radar of each country should be managed by each administration.

2.1 Allocations

A number of frequency bands have been allocated to the radiolocation service for operation of oceanographic radars. The frequency bands are listed in Table 1 below. In some cases the allocated bandwidth is not significantly larger than the typical radar transmit bandwidth for the given frequency range of operation. Therefore careful planning and spectrum sharing between radars is required to ensure access to the frequency bands by all oceanographic radar operators. This is especially important for real-time operation of permanent, extended coastal networks fulfilling societal needs. Mitigation techniques allowing for an efficient use of the allocated frequency bands for oceanographic radar purposes is covered in Annexes 2, 3 and 4. Operation of experimental radars could also use the same coordination techniques.

TABLE 1

Allocated frequency bands (kHz)

ITU Region 1	**ITU Region 2**	**ITU Region 3**
4 438-4 488 (S)**	4 438-4 488 (P)**	4 438-4 488 (S)**
5 250-5 275 (S)**	5 250-5 275 (P)**	5 250-5 275 (S)**
9 305-9 355 (S)*	No allocation	9 305-9 355 (S)*
13 450-13 550 (S)**	13 450-13 550 (P)**	13 450-13 550 (S)**
16 100-16 200 (S)*	16 100-16 200 (P)*	16 100-16 200 (S)*
24 450-24 600 (S)**	24 450-24 650 (P)**	24 450-24 600 (S)**
26 200-26 350 (S)**	26 200-26 420 (P)**	26 200-26 350 (S)**
39 000-39 500 (S)**	No allocation	39 500-40 000 (P)**
42 000-42 500 (S)**	No allocation	No allocation
P – Indicates a primary allocation S – Indicates a secondary allocation		

* RR No. **5.145A** states that "Stations in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the fixed service. Applications of the radiolocation service are limited to oceanographic radars operating in accordance with Resolution **612 (Rev.WRC 12)**."

** RR No**. 5.132A** states that "Stations in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the fixed or mobile services. Applications of the radiolocation service are limited to oceanographic radars operating in accordance with Resolution **612 (Rev.WRC 12)**."

RR No. 5.161A: *Additional allocation:* in Korea (Rep. of) and the United States, the frequency bands 41.015-41.665 MHz and 43.35-44 MHz are also allocated to the radiolocation service on a primary basis. Stations in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the fixed or mobile services. Applications of the radiolocation service are limited to oceanographic radars operating in accordance with Resolution **612 (Rev.WRC-12)**.

Secondary stations can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date (Ref. RR Volume 1 – RR No. **5.31**).

2.2 Frequency management issues

As of 2012 there are approximately 500 oceanographic radars in operation. The majority of these radars are operated worldwide in real time and the expectation is that their numbers will continue to increase. In the past, the majority of these systems were operated under assignments based on RR No. **4.4**. Total spectral usage was spread over approximately 7 MHz of spectrum. As a result of Resolution **612 (Rev.WRC-12)**, nearly all of these radars operating on a permanent basis below 30 MHz are now required to fit within allocated frequency bands totalling no greater than 700 kHz.

Furthermore, from an operational perspective, it has been shown that a majority of radars must operate within a 200 kHz bandwidth between 10 and 20 MHz in order to meet their mission objectives. This means that many radars must operate simultaneously within the same frequency band within a geographic region. Since many of these radars will be within radio reception range of each other they can mutually interfere and impede their collective ability to perform sea state measurements. This results in the need for coordinated operation of radar stations installed within a geographic area and possibly under the jurisdiction of multiple administrations. In order to achieve interference free operation a variety of different system parameters and design options need to be taken into account.

In addition to coordination with other allocated services and between oceanographic radar operators, a requirement imposed by Resolution **612 (Rev.WRC-12)** requires that oceanographic radar stations must transmit station identification in international Morse code at manual speed, at the end of each data acquisition cycle, but at an interval of no more than 20 minutes. In practice the purpose of the call sign is to identify a station that may be interfering with other radio services.

2.3 Call-sign identification

A call sign in Morse code should be detectable by international monitoring stations (Article **16** of the RR). Experienced Morse code listeners can receive at rates of 15 words per minute or more. In accordance with Resolution **612 (Rev.WRC-12)** the call sign shall be transmitted on the assigned frequency. The call sign signal heard by the impacted radio should be transmitted at the same power level as the normal radar signal. The details that are associated with several call sign identification techniques can be found in Annex 1.

3 Operational considerations

3.1 Oceanographic radar database

WRC-12 allocated a number of frequency bands in the frequency range of 3-50 MHz to the radiolocation service limited to oceanographic radars operating in accordance with Resolution **612 (Rev.WRC-12)**. The Resolution resolves, inter alia, that the oceanographic radars shall be coordinated with neighboring administrations if they are located at certain distances to the border.

The establishment of a database on existing and planned oceanographic radars may considerably facilitate this coordination process. Such a database would serve as reference information for coordination purposes and would not have any regulatory status. Administrations wishing to obtain the status of international recognition for their radars still need to record the frequency assignments in the master international frequency register.

Given a worldwide nature of this potential database and a significant involvement of the ITU in the regulation of oceanographic radars, it might be appropriate that such a database is established and maintained by the Radiocommunication Bureau and populated by the ITU administrations.

The data elements of the database are described in Annex 6.

3.2 Coordination of multiple radars

Taking into account the present development and usage of oceanographic radars, as well as the expectation that their numbers will continue to increase, considerations that are fundamental to any coordination effort and be found in Annex 2 “Non-modulation specific coordination techniques” and Annex 3 “Frequency modulated continuous wave modulation multiplexing coordination techniques”.

The bandwidth of oceanographic radars determines the range cell size, where an inverse relationship exists between bandwidth and range cell size. For example, a 50 kHz bandwidth leads to a 3 km range cell; 150 kHz leads to a 1 km range cell, etc. Selecting the appropriate bandwidth is a trade-off between achieving the best possible range resolution while minimizing bandwidth utilization. Radars which are operating at the same frequency could, depending upon the stability, modulation and bandwidth, have a potential for interfering with one another's operation. A detailed discussion of the impact that these factors could have on an operational network can be found in Annex 4 – "Oceanographic radar sweep factors impacting radar to radar interference".

3.3 Emergency management

Oceanographic radars are generally designed for reporting current data and sea state once or twice an hour. In the case an emergency event, (e.g. tsunami, search and rescue, oil spills, etc.) the radars are required to report data immediately and continuously using short time intervals without interference from other radars which are located within the same region.

Therefore, when several radars coexist in the same region and there is a possibility of interference between them, the following methods are recommended for emergency operation:

1) To prioritize in advance the radars for emergency use in this area.

2) To stop transmission of the radars with low priority for an appropriate period after the emergency event occurs.

In order for the above arrangement in certain area, coordination among the radar operators may be required. This depends on licensing policy of each Administration. This method is applicable when the radar is required to perform continuous monitoring immediately after the emergency event.

4 Summary and conclusions

Efficient use of the radio spectrum by oceanographic radars requires coordination between Administrations authorizing the operation of these radars. The information that has been presented in this Report and its' annexes can be used by Administrations, oceanographic radar operators, spectrum managers, regulators and regional operator groups to achieve effective use of the allocated frequency bands.

Annex 1

Call sign identification

1 A1A/A2A Method

Operation of the oceanographic radar should be in accordance with Resolution **612 (Rev.WRC-12),** which resolves that each oceanographic radar station shall transmit station identification (call sign) on the assigned frequency, in international Morse code at manual speed, at the end of each data acquisition cycle, but at an interval of no more than 20 minutes.

Table 1 shows requirements for transmitting the call-sign under the Resolution **612 (Rev.WRC-12)**. Based on this, the call-sign is transmitted in standard CW (A1A/A2A) signal, and can be demodulated by a general HF receiver such as a receiver with single side band (SSB) reception. This method is in accordance with Recommendation ITU-R M.1677.

TABLE 1

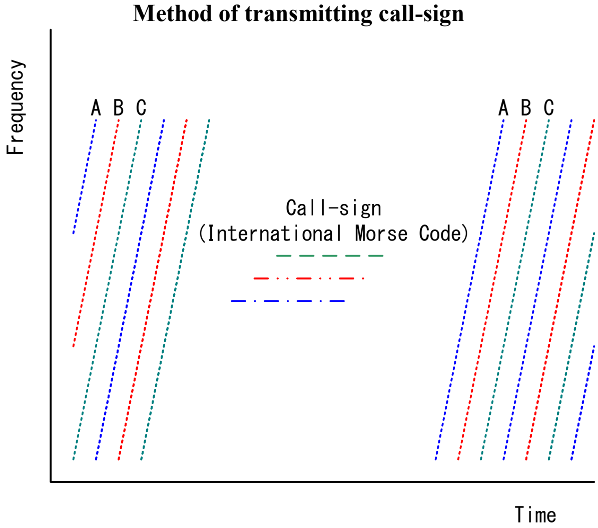
Transmission of call-sign

Item	Requirements
Frequency	Assigned frequency[1]
Transmission power	Call sign signal power spectral density equal to radar signal power spectral density
Transmission antenna	Radar's antenna
Modulation	A1A/A2A
Code	International Morse code in accordance with Recommendation ITU-R M.1677

Figure 2 indicates an example of the time vs frequency chart for three radars simultaneously operated with call-sign without interference.

FIGURE 2

Method of transmitting call-sign



Annex 2

Non-modulation specific coordination techniques

1 Coordination considerations

The following sections discuss various techniques that can be used to facilitate coordination of multiple radars.

Without implementation of any sharing techniques, radars in the same bands have a risk of interfering with each other. The level of interference depends on antenna pattern, modulation and distances. Different technical methods allow one to quickly manage the level of interference between radars,

[1] Assigned frequency includes not only centre frequency but also various frequencies throughout the operational bandwidth of the oceanographic radar. The use of different frequency within the assigned frequency to each radar would be effective to avoid the interference.

especially if users and operators try to perform some planning and identify the best method before starting the deployment process.

For radars using the same family of modulation, “fine tuning and fine synchronization” methods allow optimization of coordination, and yield increased radar capacity in the frequency band. This is the subject of the Annex 3 for the frequency modulated continuous wave (FMCW) class of modulation. For sequence coded radars of the Annex 5, the use of the same family of orthogonal sequences may be a way to obtain a higher radar capacity.

The approaches described in the following sections in this Annex have the advantage of not putting any restrictions on modulation schemes or waveforms. The three approaches are independent and can be combined. Nevertheless, considering the potential need, they yield a limited number of independent channels in comparison to modulation multiplexing (Annex 3).

2 Time division multiplexing

The time division multiplexing (TDM) case studies for the direction finding (DF) radar and the digital beam forming (DBF) radar are shown in Tables 2 and 3, respectively. The case considered here represents a common operational use of oceanographic radars: production of current maps, typically at an hourly update rate. The last column in Tables 2 and 3 illustrate how the time period could be broken into slots suitable for TDM. The algorithmic methods used for DF (Table 2) and DBF (Table 3) differ considerably; these tabulated estimates that are meant to serve as guidelines.

TABLE 2

TDM case studies within the allocated frequency bands for the DF radar

ITU frequency bands (kHz)	Doppler offset (df) for speed 5 cm/s (milli-Hertz)	Typical minimum acquisition time ≥ 3 × (1/df)	Minimum time slots/ maximum number of slots on an hour basis
4 438-4 488	1.5	2 028 s = 34 minutes	34 minutes/2 slots
5 250-5 275	1.75	1 714 s = 29 minutes	29 minutes/2 slots
9 305-9 355	3.1	967 s = 16 minutes	16 minutes/5 slots
13 450-13 550	4.5	669 s = 11 minutes	11 minutes/5 slots
16 100-16 200	5.4	559 s = 9 minutes	9 minutes/6 slots
24 450-24 600	8.1	368 s = 6 minutes	6 minutes/10 slots
26 200-26 350	8.7	344 s = 6 minutes	6 minutes/10 slots
39 000-39 500	13	231 s = 4 minutes	4 minutes/16 slots
42 000-42 500	14	214 s = 4 minutes	4 minutes/17 slots

TABLE 3

TDM case studies within the allocated frequency bands for the DBF radar

ITU frequency bands (kHz)	Doppler offset (df) for speed 5 cm/s (milli-Hertz)	Proposed minimum acquisition time ≥ (1/df)	Minimum time slots/ maximum number of slots on an hour basis
4 438-4 488	1.5	676 s = 11 minutes	11 minutes/5 slots
5 250-5 275	1.75	571 s = 10 minutes	10 minutes/6 slots
9 305-9 355	3.1	322 s = 5.4 minutes	5.4 minutes/11 slots
13 450-13 550	4.5	223 s = 3.7 minutes	3.7 minutes/16 slots
16 100-16 200	5.4	186 s = 3.1 minutes	3.1 minutes/19 slots
24 450-24 600	8.1	123 s = 2.10 minutes	2.0 minutes/29 slots
26 200-26 350	8.7	115 s = 1.9 minutes	1.9 minutes/31 slots
39 000-39 500	13	77 s = 1.3 minutes	1.3 minutes/47 slots
42 000-42 500	14	71 s = 1.2 minutes	1.2 minutes/50 slots

TDM can be applied in various time patterns and can be used to coordinate systems of different brands and modulation types, Table 4 and Fig. 3 show an example of schedule/time table for the TDM radars combining the modulation multiplexing (MM) (refer to Annex 3) and the TDM technique. If operational coordination between these radars is carried out based on Table 4, flexible multiplexing can be realized between several radars with different technical characteristics as shown in Fig. 3. The TDM technique makes it possible to select the parameters flexibly. Table 5 and Fig. 4 show another example of two DBF radars and two DF radars operation in the same area.

TABLE 4

Example of schedule/time table for TDM radars

Time (HH:MM)	Group	Remarks
00:00 – 00:15	A	• Multiple radars can operate by combining MM and TDM technique. • Observation period is 15 minutes with an interval of 30 minutes.
00:15 – 00:30	B	• Multiple radars can operate by combining MM and TDM technique. • Observation period is 15 minutes with an interval of 60 minutes.
00:30 – 00:45	A	Second window for Group A.
00:45 – 01:00	C	For experimental radars with characteristics that do not conform to Group A or Group B.

FIGURE 3

Example of schedule/time table for TDM radars

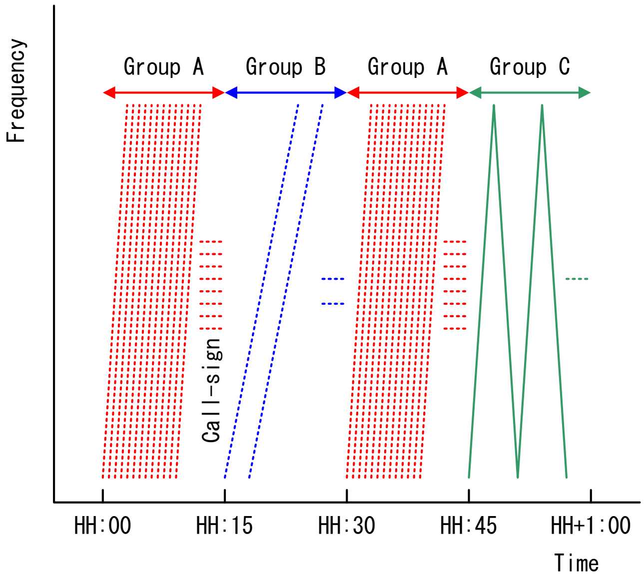


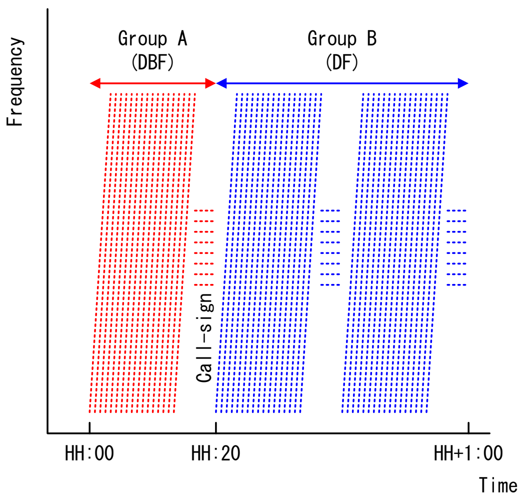
TABLE 5

Example of schedule/time table for TDM radars

Time (HH:MM)	Group	Remarks
00:00 – 00:20	A (DBF)	• 2 DBF radars and 2 DF radars can operate by combining MM and TDM technique. • Observation period is 20 minutes with an interval of 60 minutes. • 10 minutes for reserve in this observation periods
00:20 – 01:00	B (DF)	• 2 DF radars and 2 DBF radars can operate by combining MM and TDM technique. • Observation period is 40 minutes with an interval of 60 minutes.

FIGURE 4

Example of schedule/time table for TDM radars



The TDM technique and MM are not mutually exclusive and can be used in combination. This leads to compatibility of simultaneous observation by several radars, and flexible selection of the operational parameters. In practical operation using both TDM and MM, several radars with the same sweep parameters use the MM technique as one sharing group, and the TDM technique is used for several sharing groups.

3 Frequency division multiplexing

As justified in the following discussions several of the allocated frequency bands may be split in two or more sub-band radar channels. Operation in the given channels will assure that the radars which are operating on those channels will not interfere with one another. This coordination method is the frequency division multiplexing (FDM).

The requirement on radial grids has to be thought of in conjunction with the cross-range grid.

Certain useful spectral information within the Doppler spectrum of the backscattered signal is raised above the noise by filtering phenomena like the Bragg resonance. This resonance is stronger when the resolution cell contain many periods of the Bragg wave length.

The spatial variability scales of the relevant and radar well-identified ocean surface features are generally accepted as being finer closer to the coast and coarser offshore. In some cases complicated sea states and current patterns, often close to the coast would require study with VHF radars for which a wider bandwidth is available. Furthermore, the distance of interaction between VHF radars is much less than the one for HF and so, the coordination between radars should be easier.

The combination of these considerations have suggested a 25 to 50 kHz bandwidth requirement in the 10 to 20 MHz frequency band, whereas 60 kHz is acceptable around 27 MHz, and 150 kHz to 300 kHz are useful for the very littoral observations allowed with the short range 40 MHz radars.

Very long range radars at 5 MHz are typically used with 25 kHz radar channels but channels with larger bandwidths may be required as a function of the application. So we see that several allocated frequency bands may be split in two or more sub-band radar channels, namely FDM.

4 Beam steering

Mutual interference can be avoided and coordination realized by adjusting the directivities of antennas on a phased array system or by null-steering in an antenna's radiation pattern. The details of these methods are as follows.

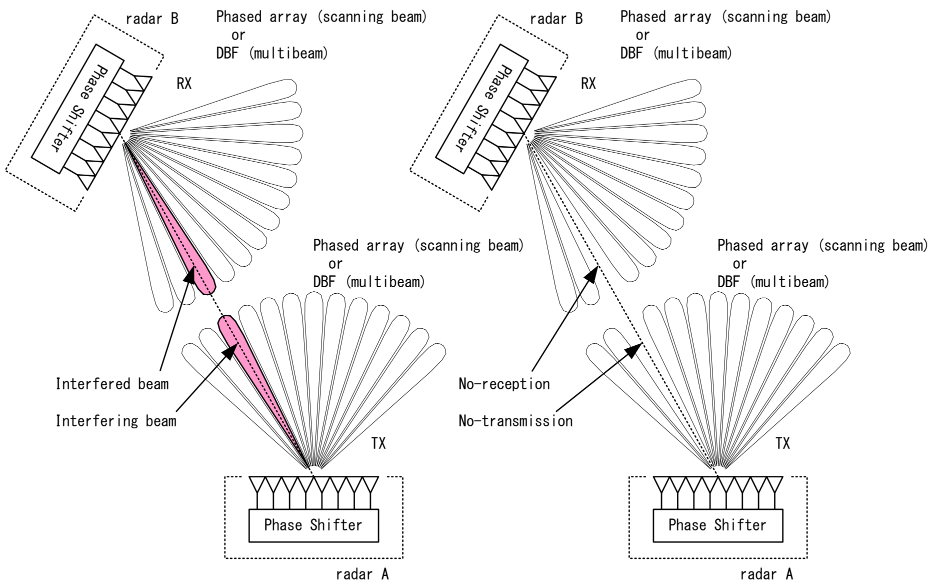
4.1 Coordination by adjusting an antenna's directivities

Phased array and DBF radars such as those described as Systems 10-13 in Recommendation ITU-R M.1874-1, can form narrow beams. By forming the narrow beams, it is possible to minimize interference between two radars. Beam forming techniques can also eliminate transmission or reception along specific beams to avoid interference. Figure 5 illustrates this method; the left image shows the case of transmission/reception with potential for interference, and the right image shows the case of eliminating transmission toward, or reception from, the direction of the opposite radar.

FIGURE 5

Coordination by adjusting antenna's directivities

(Left: continuous transmission/reception,
Right: stopping transmission toward, or reception from, the direction of the opposite radar)



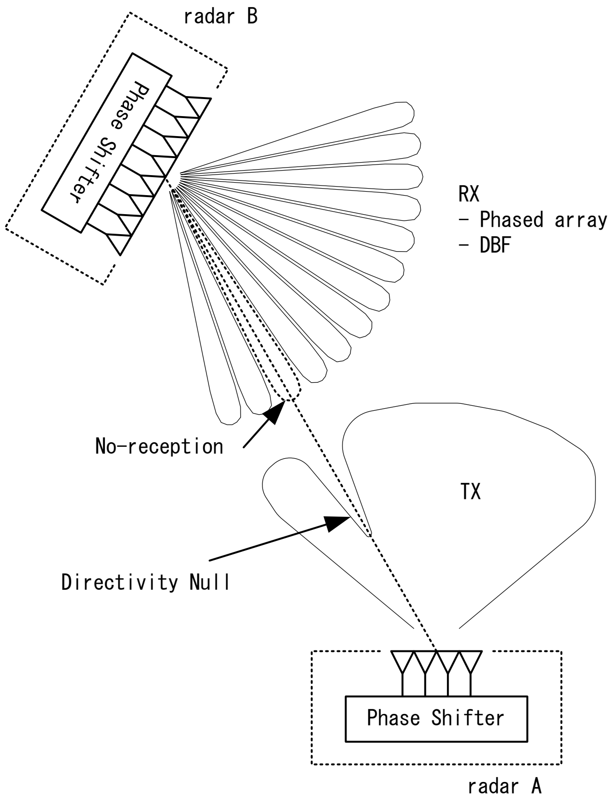
The phased array radar such as System-11 in Recommendation ITU-R M.1874-1 uses the narrow transmit antenna beam scanned by electronically. Although there are some examples for microwave DBF radar, there is no example for HF DBF radar at this moment.

4.2 Coordination by null-steering of an antenna's radiation pattern

As shown in Fig. 6, the null-steering of the antenna's radiation pattern to the direction of the interfering radars or the interfered radars can avoid mutual interference.

FIGURE 6

Coordination by the null-steering of the antenna's radiation pattern



Annex 3

Frequency modulated continuous wave modulation multiplexing coordination techniques

For modulation multiplexing (MM) to be used three frequency sweep parameters need to be nearly identical for all radars of a group: the centre frequency, the sweep bandwidth (BW) and the sweep rate (SR). A defined delay of the "sweep start" for each system within a geographic area can provide an adequate frequency separation to operate multiple systems on the same center frequency. This method may be applicable if systems of various manufacturers are used.

In this Annex, the FMCW notation will refer to both pure (non-gated) FMCW and to gated FMCW (also known as frequency modulated interrupted continuous wave (FMICW)). When there is a need for distinction, it is clearly stated (see glossary for these words).

Coordination methods using TDM or FDM were discussed in Annex 2. Considering the characteristics of FMCW signal modulation within the time-frequency domain, one can find good ways to coordinate radars and avoid mutual interference. For instance within the confined spectral space of the allocated frequency bands, or when TDM is not an acceptable solution, one should consider the MM approach.

1 Method 1 (Modulation multiplexing with slot allocation)

1.1 Modulation multiplexing within the frequency modulated continuous wave linear sweeps

In this section, two simple and powerful coordination methods of the radar sweeps are presented. They are not manufacturer specific, and can be achieved within available clock stability constraints. They yield, for a given geographic area, a capacity over 25 radar stations. Finer sweep coordination may facilitate the deployment of an even larger number of stations, as well as bi-static and multi-static systems.

In the linear frequency sweep that is used for FMCW oceanographic radar, the carrier frequency slope (in Hz per second) which is called the SR is constant during the sweep, and discontinuity only occurs during the very short flyback.

The SR is the product of the bandwidth (BW) and SRF. The BW is related to the range resolution, whereas the SRF defines the Doppler unambiguity and it has to be chosen in relation to the maximum speed of the targets within the cell (e.g. Bragg waves, current, moving vessels, etc.).

The SR, in combination with the selected SRF, is in fact, the key parameter for FMCW radar coordination. In the time-frequency domain, the sweeping FMCW carrier is described by a straight line, whether it is ascending or descending, according to the sweep direction.

In this time-frequency space, the delayed sea scattered signals are occupying a close-by information band on one side of the carrier. The backscatter offset frequency is the product of the SR by the propagation delay. The maximum information bandwidth is determined by the maximum expected range. The signals from the farther distances are the weaker ones. The full information bandwidth must not be contaminated. Thus, radar channels are the useful spectral sweeps that cross the time-frequency space.

For instance, with a 100 kHz/s SR and a 150 km maximum expected range, the maximum propagation delay is 1 millisecond and the information bandwidth is 100 Hz.

Two parallel well separated spectral sweep generated with the same SR and SRF will never overlap, except during the sweep flybacks. Flybacks are made very short and significantly reduce interactions between FMCW radars.

Considerations leading to the SRF selection and sweep-start offset selection, as well as tradeoffs, will be discussed later. The optimum choice for SR depends on the allocated frequency band, but its value should be agreed upon over areas where several radars are or will be operated. Once a SRF and a BW are chosen, the SR is also defined by the direct calculation SR = SRF × BW. Under these conditions FMCW radar coordination by MM is achieved by the selection of an inter-radar spectral sweep offset acting as a spectral separation “distance”, wide enough to isolate the information bandwidth.

Whereas very well synchronized and highly compatible radars could be operated with a very small offset, radars with differing stabilities, drifts or hardware performance limitations may need a wider separation. If there is an agreed upon common offset separation value, the so called nominal slot offset (NSO) may be defined for each allocated frequency band. Once such a spectral sweep (offset) is defined, nominal slots (NS) may be defined. The slots should be allocated on a given geographic area basis.

There are several ways to associate a radar or groups of radars to nominal slots. The simplest way to go is to give one radar one slot. As very highly synchronized radars will not need a large offset, and as the information bandwidth are quite narrow, several well synchronized radars may be grouped within only one such nominal slot. This technique is already applied on some radar networks.

1.2 Possible technical performance on carrier and time base stability to maintain the radar slots

To maintain the separation between two radar spectral sweeps, we can identify two kinds of requirement. First, the carrier accuracy and drift must be maintained to keep the required separation. Second, the radar time base must ensure that the sweep start time accuracy is maintained. The two needs may be simultaneously achieved through the use of a high quality master clock, but several scenarios may also be used for resynchronization from external references. This is discussed further in § 1.7 after technical performance has been analysed.

1.3 Compatibility of the modulation multiplexing method for pure frequency modulated continuous wave and gated frequency modulated continuous wave radars

The compatibility for pure FMCW and gated FMCW (FMICW) is assumed. Due to their modulation technique, FMICW transmitters produce a few sidebands. The number of these sidebands is normally kept to a minimum by use of appropriate filtering and pulse shaping.

As a result, the data contained in the transmitters' signal is replicated in sidebands. So the FMICW radar produces a wider occupation of the time-frequency space. The Gating Frequency (GF), and the gating shape determine this expansion. (See Report ITU-R M.2234.)

From a radar to radar compatibility perspective, a first cautious implementation should be considered to maintain a larger time-frequency separation between a FMICW radar and other FMCW radars. Several adjacent nominal slots (NS's) may be dedicated to one FMICW radar or to a group of such radars (see § 1.5 Annex 3).

For example, the rapid GF with respect to the slow SRF lays down a modulation pattern of circular peaks/nulls on the received amplitude from the sea surface within the distance over which the radar can see. The gate width and GF must be carefully designed to accommodate the expected maximum range. For example, assume a pure FMCW radar would see out to about 75 km. Then with square-wave gating, to match this 75 km range we need a 1 000 microsecond gating period. With the corresponding 1 kHz GF, the gating duty factor reaches a maximum at a range of 75 km. At exactly twice this range (150 km), the duty factor has dropped to zero, and we call this null a blind zone (it is named range limit in Table 6, Annex 3), at and near which, targets cannot be detected. Such maxima and blind zones repeat periodically at 150 km range intervals for this example. So a 1 kHz GF is compatible with this range example. The correct values will inversely scale with the range limit of the allocated band on which the radar operates (see Table 6, Annex 3).

With a smooth gating and a 50% gating duty cycle, the spectrum replica will be concentrated near the carrier and near the sidelobes corresponding to the first odd harmonics of the GF. See Fig. 92 page 121 in Report ITU-R M.2234. With a 1 kHz GF, the first sidelobes are then sitting on both sides of the carrier at 1 kHz, 3 kHz, 5 kHz, with decreasing amplitudes at higher baseband frequencies.

A more careful approach to avoid interference from an FMICW radar may be achieved, if the nominal slot offset is an even harmonic of the GF, since there are no FMICW sidelobes around the even harmonics for the 50% gating. It is found for this example that 2 kHz[2] is a good candidate as a common NSO.

---

[2] This 2 kHz value is compatible with already available radar characteristics.

So, in the 13 500 MHz example below in § 1.4, we see that a FMCW may operate at least 6 kHz (i.e. 3 × NSO) away from an FMICW radar. Nevertheless, the FMICW to FMICW radar separation must be kept about twice as wide since their relative sidelobes may overlap.

1.4 Slot allocation according to different frequency modulated continuous wave radar technology

For each allocated frequency band, to ease the heterogeneous radar coordination, gated frequency FMICW radars should be operated at 50% duty cycle as is stated before in § 1.3, and with a nominal GF, compatible with the allocated frequency band range limit.

For instance, for the 13 500 MHz and at 16 100 MHz bands, with a 1 kHz GF, the NSO could be set to 2 kHz, yielding 50 slots over both 100 kHz bandwidth.

Then, a FMICW radar or a FMICW group of synchronized radars (as described in § 1.5) could be attributed a set of 6 to 10 slots. Some pure FMCW radars could be attributed one single slot, whereas less stable radars could be attributed to a couple of adjacent slots.

1.5 Coordinating modulated continuous wave radar with synchronization by global navigation satellite systems signals or other highly accurate frequency sources

If a more accurate clock stability and synchronization between radars can be achieved (as with GPS synchronized radars), and when using radars with state machines directly driven by similar master clocks and circuitry (typically same brand and same generation radars), then almost no relevant relative drift will occur, and it is possible to use very close spectrum sweeps.

The number of usable information bandwidths depends on the information bandwidth and on the GF. As the information bandwidth is on the order of 100 Hz or less, using high stability, the separation offset can be reduced, and the band capacity is accordingly improved.

With FMICW radars, for a 1 kHz GF, within the 1 kHz gap between the carrier and the first sideband, ten 100 Hz spectrum sweeps may be installed, this means 10 radars. But in fact, the total spectral foot print is spreading over several kHz on both sides, due to the side lobe replication. Then several very finely synchronized FMICW radars can be gathered in groups, but such groups have to be separated by a gap of about 10 kHz.

1.6 Modulation multiplexing carrier offset methods

This offset can be achieved by two methods:

– offsetting the sweep central frequency;

– offsetting the sweep start time.

The two methods are briefly discussed in the next sections.

1.6.1 Modulation multiplexing by centre frequency offset

With the centre frequency offset method, as the bandwidth which is used for each of the radars is shifted, the total bandwidth required by all radars increases with the number of radars, and the fixed spectral sub band splitting required for FDM coordination as proposed in Annex 2 may not be applicable to all configurations.

The advantage of this method is that all radar flybacks occur at almost the same time and this reduces, even farther, the risk of interference. Radars with excessive carrier drift would also be easier to identify.

1.6.2 Modulation multiplexing by start time delay offsets

To separate the parallel radar spectral sweeps, one can delay the different radar sweep starts by a portion of the sweep period. Once the SR and the NSO are defined, the slot to slot start nominal delay step is the ratio of NSO over SR. For instance, a 2 kHz NSO with a 100 kHz/s SR gives a 20 ms start delay step. Then the slots can be defined by a slot number (SN) and the sweeps start with a delay equals to SN × 20 ms. A common, accurate time base needs to be shared between operators in order that the sweep start drift stability over the acquisition period should be small enough in the comparison of the 20 ms start delay step.

As this delay method maintains the same bandwidth use independent of the number of operating radars, it is the preferred way to generate the separation between FMCW radar sweeps. The main way to accommodate this method is to use three identical parameters for the frequency sweeps: the center frequency, the BW and the SRF. As a consequence, the two SR are also identical.

1.7 Carrier frequency and sweep time base accuracy and stability

Section 1.2 provided the general conditions that are required to maintain the radar slots. This section details the calculation of the required accuracy and stability figures. It should be conducted for each allocated band, once SR, GF and NSO are chosen.

Carrier accuracy and stability: assuming the 13.500 MHz frequency band, with a 2 kHz NSO, the maximum allowable carrier drift could be standardized, for instance, to one third of the NSO: 650 Hz, then the carrier accuracy and stability is 650 Hz / 13 MHz, that is just about 50 ppm. The maximum allowable carrier drift is such that two operating radars will not overlap their information sweeps.

Sweep time base: assuming the 13.500 MHz frequency band, and a 100 kHz/s SR, we found that the sweep start delay offset is equal to 2 kHz/100 kHz/s = 20 ms. Assuming a maximum allowable drift of one third of the NSO, we find a maximum start drift of 6 ms over the full acquisition period, or between two sweeps. For an acquisition or resynchronization interval of 10 minutes, the relative clock to clock limit is equal to 6/(10 × 60 × 1 000), i.e. a 10 ppm requirement. For a one hour acquisition or resynchronization interval, the requirement is 1.5 ppm.

If both the carrier generator and sweep timing are driven from the same time base, then the most stringent requirement has to be chosen.

For some existing radars those figures may be difficult to achieve. Instead of defining a less stringent NSO to accommodate them, one should adopt reasonably fine NSO, and allocate multiple successive slots to those radars operating at lesser accuracy, as stated before in § 1.4 of this Annex.

1.8 Band capacity using the sweep offset modulation multiplexing method

Using the 13.500 MHz example from the previous section, i.e. a slot offset of 2 kHz, we see that 25 radars (or groups of radars) can operate together within the same area within each of two 50 kHz sub-bands (yielding a total of 50 radars over the full width).

To extend the approach to the other allocated bands, the next Table 6 summarizes a complete set of compatible parameters. This table is first built from the Bragg wave Doppler frequency and the Doppler frequency due to radial speed of a passing fast vessel. Then the rounded value for SRF is chosen according to Shannon criteria, as SRF is the Doppler domain sampling frequency. The nominal channel BW values are a tradeoff between the total available allocated BW, the expected resolution, and the radar capacity. The SR is then the result of the calculation SR = SRF × BW. The range limit is an empirical limit, obtained from experience. This value gives a limit on propagation time PT = (2 × RL)/c. Then, the information width sweep width (IW) is the result of the calculation IW=PT × SR. The GF for FMICW radar is a rounded value (extracted from a standard sequence of compatible values) according to the range limit. The NSO is a value compatible with the cumulative

IW, GF harmonics consideration, general clock drift consideration, and the goal for a good allocated band capacity. Then, the geographic area radar capacity per channel is the ratio between the channel BW and the NSO.

TABLE 6

Example of a set of parameters compatible with MM

Allocated Band	FBragg	FDopp for a 20 knot vessel	Nominal sweep repetition Freq. (SRF)	Nominal channel BW*	Nominal SR	Range limit	Info. band width	Nominal gating freq. (GF)	NSO	Area radar capacity per channel	Area radar capacity per allocated band
kHz	Hz	Hz	Hz	kHz	kHz/s	km	Hz	Hz	kHz		
4 438-4 488	0.21	0.3	1	25	25	600	100	250	2	12	24
5 250-5 275	0.23	0.3	1	25	25	600	100	250	2	12	12
9 305-9 355	0.30	0.6	2	25	50	300	100	500	2	12	24
13 450-13 550	0.37	0.9	2	50	100	150	100	500	2	25	50
16 100-16 200	0.40	1.1	2	50	100	150	100	1 000	2	25	50
24 450-24 600	0.50	1.5	4	75	300	100	180	1 000	2	37	74
26 200-26 350	0.51	1.8	4	75	300	100	180	1 000	2	37	74
39 000-39 500	0.63	2.7	4 (or 8)	250	1 000	50	330	2 000	8	32	64
42 000-42 500	0.65	2.8	4 (or 8)	250	1 000	50	330	2 000	8	32	64

* There may be more than one channel per allocated frequency band.

2 Method 2 (Modulation multiplexing with 50 ppm stability[3])

As for the FMCW, Figs 7 and 10 explain how to set a frequency separation for a coarser frequency stability. The dynamic frequency band occupied by one radar must be outside the bandwidth of any other radar. Assuming the 24.5 MHz frequency band with a radar information bandwidth of 200 Hz, receiver baseband bandwidth of 1 000 Hz, and frequency deviation of 1 225 Hz corresponding to frequency stability of 50 ppm, the frequency separation of more than 3050 Hz[4] can, for this example, realize simultaneous operation of several radars in the same frequency band without any mutual interference.

In the above explanation, the time base stability is assumed 0.1 ppm resulting in 0.12 ms drift per 20 minutes of TDM slot if time base synchronization is achieved every 20 minutes (20 × 60 × 1 000). 0.12 ms drift causes 300 kHz/s × 0.12 ms = 36 Hz which does not affect to the radar number of the simultaneous operation.

On the other hand, the stability of ~ 50 ppm is sufficient for avoiding interference between radars when using only monostatic mode with TDM.

The 24.5 MHz frequency band used in this example has a 150 kHz allocated bandwidth.

[3] Maximum allowance by Appendix **2** of the RR.

[4] 3 050 Hz equals to 1 000 Hz/2 + 200 Hz/2 + 1 225 Hz × 2. In this case, 1 000 Hz/2 is the lower half of receiving bandwidth (maximum). 1 225 Hz × 2 are frequency stabilities of both radars, in which 200 Hz/2 is lower half of the information bandwidth.

In case of FMCW monostatic mode, referring Figs 7 and 10, 49 radars (= 150 kHz/3 050 Hz) can be simultaneously operated with 50 ppm stability.

In case of FMICW monostatic mode, referring to Figs 8 and 11, 16 radars (= Sweep bandwidth /(pulse repletion frequency × 6 + frequency separation) = 150 kHz/(1 kHz × 6 + 3.05 kHz)) can be simultaneously operated with 50 ppm stability.

As for FMICW, it is necessary to take into account higher order harmonics of the GF as mentioned in § 1.3 of Annex 3 and are shown in Figs 8, 9 and 11. Its waveform and spectrum are shown as Fig. 9 which is an enlargement of Fig. 92 in Report ITU-R M.2234. Figures 9 and 11 explains how to separate the frequency when not more than six harmonics are taken into account. In this case, the separation frequency is 9 050 Hz (= 1 000 Hz × 6 + 1 000 Hz/2 + 200 Hz/2 + 1 225 Hz × 2) with using the above mentioned FMCW parameters and 1 000 Hz of the GF. In the above explanation, the clock stability is assumed 0.1 ppm and the drift caused by sweep rate is 36 Hz. This value does not affect the number radars in simultaneous operation.

FIGURE 7

Model to avoid the interference of two radars which operate simultaneously in frequency modulated continuous wave (in time axis)

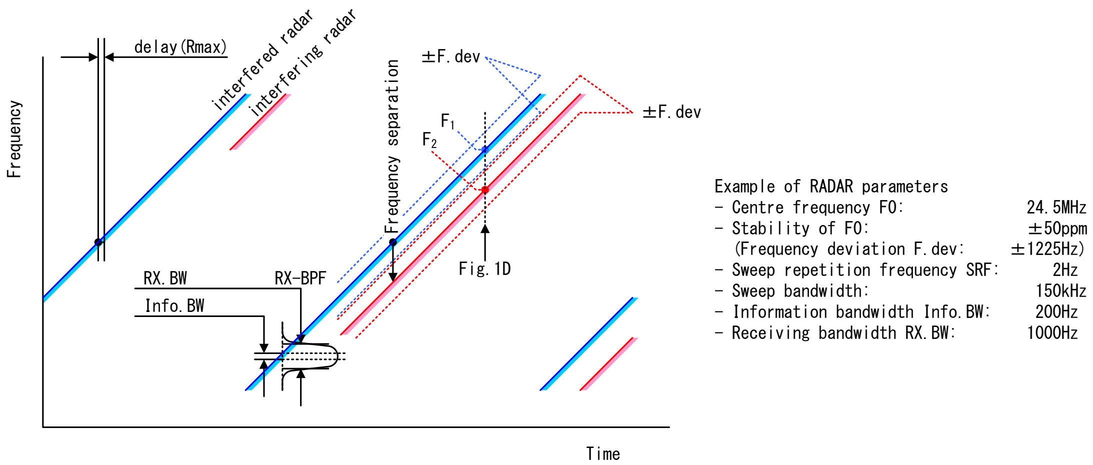


FIGURE 8

Model to avoid the interference of two radars which operate simultaneously in gated frequency modulated continuous wave (in time axis)

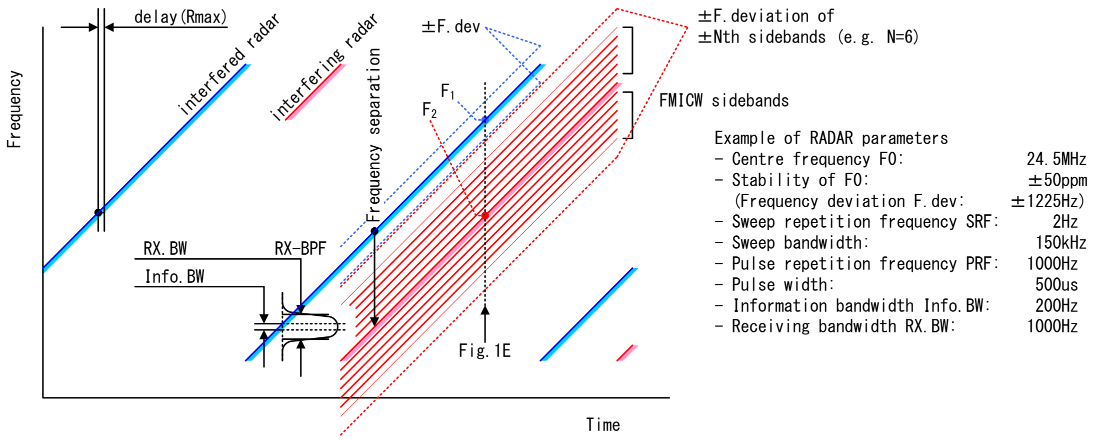


FIGURE 9

Waveform and spectrum for the gated frequency modulate continuous wave (enlarged of Figure 92 in Report ITU-R M.2234)

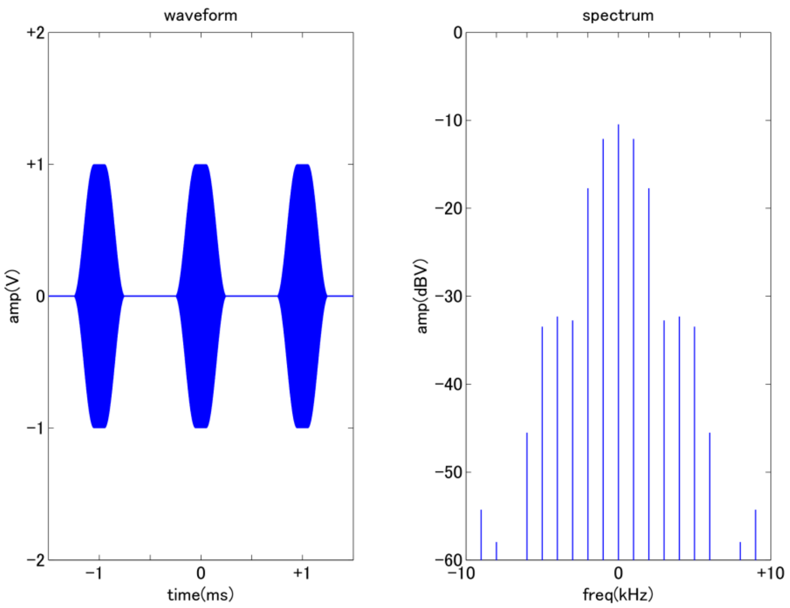


FIGURE 10

Model to avoid the interference of two radars which operate simultaneously in frequency modulated continuous wave (in frequency-axis)

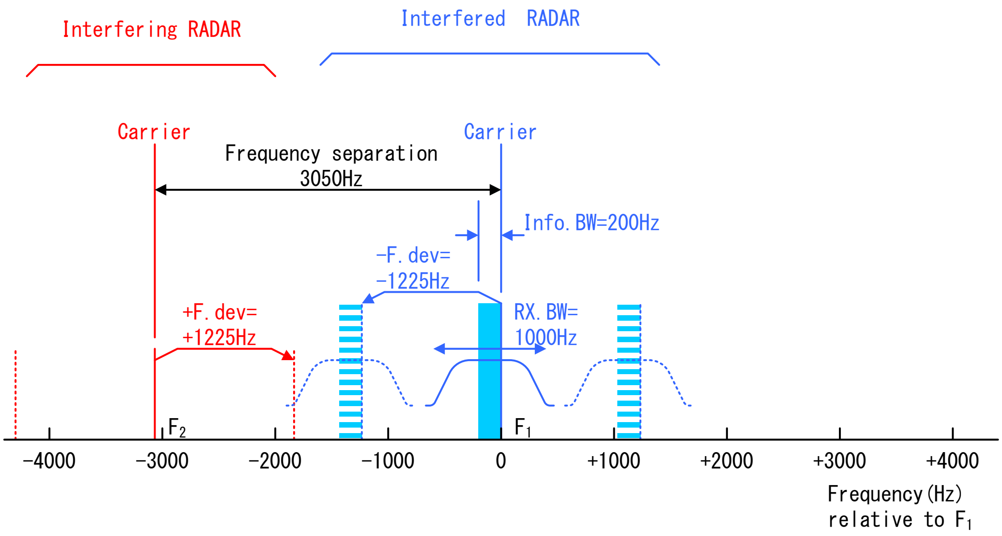
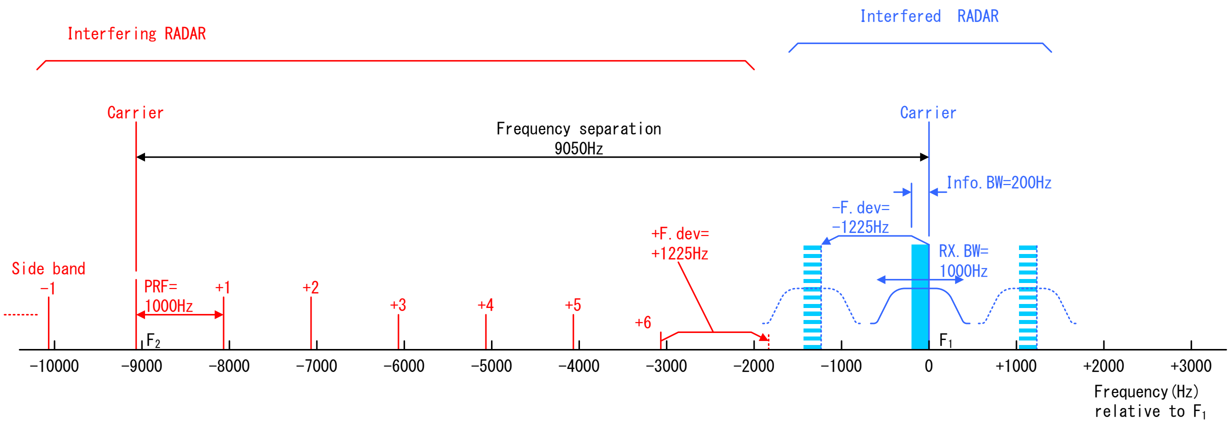


FIGURE 11

Model to avoid the interference of two radars which operate simultaneously in gated frequency modulated carrier wave (in frequency-axis)



3 Method 3 (modulation multiplexing using high stability transmitters)

Networks that require high stability use techniques that are described in this section. This high stability supports high density networks and bistatic/multistatic operations.

Modulation multiplexing (MM) is a method for simultaneous frequency sharing that is useful for FMCW and FMICW waveforms. These waveforms are used by all of the more than 500 known oceanographic radars in operational use today. The purpose of this section is to describe and analyse the MM methodology, as it is being applied to over 200 oceanographic radars in several countries, as a guide to possible use by other users and administrations. This section analyses the methodology – with an example – that is based on inherent timing/frequency stability exceeding 10^{-11}, which we nominally refer to as 10^{-12}.

3.1 Assumptions behind operational modulation multiplexing are described in this section

MM is applicable for FMCW/FMICW radars through designed offsets to the different radars' sweep modulations. As described elsewhere in this report, this can be done by:

a) offsetting the start time of each sweep;

b) Offsetting slightly the centre frequency of each radar's sweep band. Both essentially accomplish the same goal.

When demodulated in the receiver by mixing received echo signals with the sweeping signal being presently transmitted (the reference), echoes from the second radar are delayed so that they do not lie within the same “information band” of the first radar. Thus, mutual contaminating interference among nearby radars on the same allotted frequency is circumvented.

In fact, this method of MM can be exploited with 10^{-12} stability when extending to multi-static configurations of transmitters and receivers. Bistatic (or multi-static) in this context involves echoes from one or more a separated transmitters (e.g. on a buoy) being processed in a second receiver, often simultaneously with its own backscatter signals. Again, the offsets are purposely chosen, both to avoid interference after demodulation but also to produce simultaneous bistatic echoes. This multi-static augmentation vastly increases the capability and utility of a single backscatter radar by itself; it is in fact presently being implemented on many oceanographic radars based on MM.

Essential to implementing MM is precise synchronization of signals among spaced radars. This is dictated by the frequency (or alternatively timing) stability of the radar signals. With coarser timing stability, multi-static operation is not possible. Nor can many radars occupy the same RF spectral space without overlapping interference. Other parts of this report analyse frequency stabilities in use, from 50 PPM (50×10^{-6}) at the lower end, up to 10^{-12} at the high-stability end.

MM methods have been in operational practice for FMCW oceanographic radars for 15 years. Several different readily available methods have been in existence that can achieve 10^{-12} timing stability for MM synchronization, including global satellite timing broadcasts (such as GPS), as well as rubidium clock modules. The techniques discussed below are all based on between 10^{-11} and 10^{-12} stability. These MM methods have been used by oceanographic radars for 12 years. This is allowing simultaneous operation of as many as 10 oceanographic radars in single geographic groupings, as well as multi-static augmentation of national networks. For these reasons, we restrict our analysis in this Annex to systems that intend to apply MM to FMCW/FMICW radar waveforms that are disciplined by clock stabilities of this order: 10^{-11} to 10^{-12}.

3.2 Impacts on frequency modulated continuous wave waveform parameters in modulation multiplexing of timing stability

3.2.1 Centre frequency/Sweep bandwidth coordination

The typical oceanographic radar transmits a FMCW or gated/pulsed FMCW signal. Through proper planning of FMCW signal parameters, centre frequencies, and coordination between systems, many systems can be simultaneously operated in the same frequency range. Uncoordinated operation of systems, or inadequate synchronization timing stability within a given geographic area can lead to inefficient use of spectrum and will result in the inability to meet the spectrum requirements and/or operational requirements for the global oceanographic radar user community.

3.2.2 Centre frequencies

Centre frequency is the first and foremost signal parameter to consider. In nearly all HF-VHF oceanographic radars that use FMCW signal formats, all waveform parameters are generated with direct digital synthesis (DDS) firmware. This means that all other parameters will be synchronized to a radar's centre frequency timing base.

Assuming no stability or drift problems, there are two factors to consider when selecting the centre frequency:

1) Its exact value and how unintended incremental differences in its that value could impact the potential for interference between multiple radars; and

2) The temporal stability of the centre frequency of individual radars, the time base from which they are derived, and the impact that those factors can have on mutual interference.

Considerations regarding stability are addressed only once, because all other waveform and frequency parameters are locked together by the DDS, and so the stability requirements that are discussed here are derived from this apply to all waveform parameters.

A sweep-time start offset to be used to achieve MM sharing. Therefore, all radars within the same shared frequency range should be assigned the same centre frequency. In order to do so, the radars' centre frequencies will have to be stable enough to ensure that they do not drift into the operational range of other radars.

Efficient use the allocated frequency spectrum demands that operational bandwidths and centre frequencies must be carefully selected in order to maximize the number of systems that can operate within a given frequency band. Analysis of methods to accomplish this task are covered in the following sections.

The first step in analysing operational parameters that result in the most efficient use of the allocated frequency bands is to define sweep parameters for each operational frequency such that multiple radars can share the same spectrum while avoiding mutual interference. A key element in achieving this goal is to make certain that the same waveform timing parameters are used for all radars operating at a given frequency

3.2.3 Sweep bandwidth of frequency modulated continuous wave signals

The sweep bandwidth of oceanographic radars determines the range cell size. An inverse relationship exists between these: for example, 50 kHz leads to a 3 km range cell; 150 kHz leads to a 1 km range cell, etc. Selecting the appropriate sweep bandwidth is a trade-off between achieving the best possible range resolution while minimizing occupied bandwidth. Radars which are operating at the same frequency could, depending upon the stability and setting of their sweep bandwidths, have a potential for interfering with one another’s operation. Which leads to the question of how much difference can there be between the sweep widths of two radars within radio range of each other without causing mutually interference?

As an example, suppose that a 20 MHz radar is programmed with a 50 kHz sweep width, corresponding to a 3 km range cell (a common configuration). What happens if nearby radar operating at exactly 20 MHz has a sweep width of 49.8 kHz? Does this pose an interference issue? (Often differing brands of radars and their DDS firmware will round up/down to some value slightly off from that requested.) With everything else synchronized, at the beginning of the sweeps (assume they start together), both radars are on the same frequency. At the end of the sweep, they differ by 50 kHz – 49.8 kHz = 200 Hz. Over the course of the sweep (e.g. 0.5 s for a 2-Hz sweep repetition frequency), the strong direct signal from the second radar sweeps and spreads over 200 Hz in the first radar's receiver. After demodulation, this constitutes an interference pedestal that is 200 Hz wide. Normally, with each range cell occupying 2 Hz of spectral width after demodulation this strong interfering signal can corrupt 100 range cells. This happens because the direct other-radar signal is much stronger than desired echoes from the sea surface. As the sweep widths become closer to equal, the other-site signal becomes confined to fewer range cells. E.g. if the second site's sweep bandwidth is 49.998 kHz, then they are always within 2 Hz of each other. The stability of the centre frequency (20 MHz in this example) must be maintained at one part in 10^{12} (based upon GPS or similarly disciplined sweepalignment). This follows from the fact that the frequencies at the start and the end of the sweep shift with the same unstable offsets as the modulation centre frequency.

3.2.4 Sweep repetition frequencies of frequency modulated continuous wave signals – example of stability impact

For all oceanographic radars employing FMCW signals, a low sweep repetition frequency (SRF) between 1-8 Hz is typically employed. The minimum SRF that can be used is dictated by the expected velocities of targets (e.g. ocean waves), through the Doppler relation. An SRF much higher than needed to resolve target echoes leads to file sizes larger than necessary and increased computational burden.

Changes to waveform parameters such as SRF are typically made in powers of two. As an example, assume that two radars are operating within the same geographical area where radars can mutually interfere: one with an SRF of 2 Hz and an adjacent companion with SRF 4-Hz SRF. Unfortunately, even if frequency and timing parameter choices are identical this mode of operation will result in unacceptable mutual interference. With a 50 kHz sweep bandwidth, the difference frequency between the two return signals, after demodulation, will vary linearly by exactly 50 kHz over the ½-second sweep repetition period (SRP) corresponding to the 2 Hz SRF. Thus, the strong direct signal from one of the radars will, after demodulation, be spread across the baseband of the companion radar raising its noise floor to a level which will result in a severe reduction in the radar's range.

From an interference analysis perspective, assume as a second example that one of the radars is operating with an SRF of 2 Hz while its companion radar is operating at an SRF of 1.99 Hz. In this example both of the radars are sweeping over the same 50 kHz sweep bandwidth. The difference in SRF, however, means that one site ends its sweep modulation at a 0.5 s, while the other site ends at 0.5025 s. After 0.5 s their frequencies are 50 000 × (1 – 1.99/2) = 250 Hz apart. This effect becomes cumulative over multiple sweep periods, and at the end of the second (SRP) period the sites are now 500 Hz apart. This slow linear sweep difference continues to accumulate until a complete “beat” period is achieved, i.e. the reciprocal of (1/1.99 – 1/2), or t = 398 s after the start at t = 0. At that time, the sites are 50 kHz apart. Then the cycle starts over.

In the above case, the direct signal from the radar site whose SRF is off by only 0.5% from the companion radar is intense and, after demodulation, drifts through the baseband information bandwidth of the companion radar in ~400 s. The contaminated baseband width is exactly the same amount as that of the radar whose SRF is twice that of the companion radar. But in that case the contamination of the baseband took 0.5 s.

The severity of the interference is the same, because a typical Doppler FFT integration period is several hundred seconds, and so the cumulative interfering energy in the spectral contamination is the same. The interference in both cases is intolerable and must be eliminated.

In either example discussed above, the only way to remove the inter-site interference that occurs because of unequal SRFs is to lock to the same SRF within one part in 10^{-12}, achievable with satellite-broadcasted timing or other similarly precise synchronization.

Some systems operate in a bistatic mode with a separate stand-alone transmitter on a buoy or offshore rig where no pulsing modulation is applied to the FMCW sweep at all. This can be considered a degenerate case of pulsing where there is no off time. These can (and are) operated interspersed with pulsed/gated (or FMICW) radars, using the MM method and frequency stabilities discussed here.

To ensure that different brands of radars that use FMCW do not mutually interfere with one another one effectively offsets the start of each other's modulations in a controlled synchronized way. It is noted here (and elsewhere in this report) that MM can be implemented by either issuing different sweep start timings or by issuing different centre frequencies; they effectively accomplish the same thing as GPS synchronization, as there is a simple mathematical relationship between the two. However, both techniques require the same level of timing stability (one part in ten to the twelfth).

3.2.5 Pulse/Gate repetition frequencies of frequency modulated continuous wave signals – example of stability impact

Except for tapering which is done at the leading/trailing edges of the pulse to reduce out-of-band interference the pulse/gating waveform is essentially a square wave with a 50% duty cycle. Over 90% of the worldwide oceanographic radars use this pulsed-gated (FMICW) waveform. Pulsing is done at a more rapid rate than sweeping. For example, the pulse repetition frequency (PRF) for a 20 MHz radar would be about 2 kHz, having a pulse repetition period (PRP) about 0.5 milliseconds. This allows a range of about 75 km before the first "blind range" is reached. Thus the SRF is much slower than the PRF: 2 Hz compared to 2 kHz.

Range to target is obtained from the sweeping, and its bandwidth determines the range-cell size. The sole purpose of the pulsing is to avoid saturating the receiver front end when the two are collocated for backscatter radars. The PRP is adjusted to give the maximum target-echo duty factor at a distance commensurate with the expected range of the radar (e.g. based on the power transmitted, path loss, etc.). For the example in the previous paragraph, this "maximum duty-factor distance" is 75/2 = 37.5 km.

In some cases, a more complex pulse coding modulation is overlain onto the FMCW signal over the PRP. Instead of the uniform square wave, the PRP begins with rapid on/off intervals, but then slows this periodicity until the end of the PRP is reached; then the sequence starts again. Duty factor is still ~50%. This technique redistributes the echo-energy "duty-factor" spatial pattern so that more signal-to-noise ratio (SNR) is achieved at short radar ranges, at the expense of slightly less at distant ranges. This allows, for example, better retrieval of wave sea-state information near the radar when radiated power is limited (e.g. the 25 dBW e.i.r.p. limit approved by WRC-12).

Other systems operate in a bistatic mode with a separate stand-alone transmitter, for example on a buoy. In this example no pulsing modulation is applied to the FMCW sweep.

From an interference perspective, if the waveform and all aspects of its parameters are generated by DDS methodology, pulsing of any kind, or no pulsing at all, can be made not to cause mutual interference or mutual inter-radar signal degradations, with the 10^{-12} stability understood herein. In fact, different pulse repetition frequencies can be synchronized together if they differ by a factor of two. And, FMCW radar formats with no pulsing at all can be (and are being) used with the MM method disclosed herein. This is demonstrated with examples. It is assumed that the pulsing waveform identically repeats in its pattern for every sweep period. This is proven by the operation of up to 10 radars within a close geographical grouping that has been in practice for over 12 years.

If a radar is assigned a frequency that falls in the centre of the allocated band and uses the full allocated bandwidth use of that spectrum by other radars in the same geographic area would be limited. In order to efficiently use the allocated frequency spectrum, these centre frequencies will need to be modified in order to maximize the number of systems that can operate within a given frequency band, i.e. employ FDM to efficiently use available spectral space. Methods to accomplish this task have been covered in this section of this document.

Table 7 summarizes recommended sweep parameters that should be used when configuring oceanographic radars in order to optimize spectral use and ensure mutual compatibility among adjacent radars.

TABLE 7

Summary of suggested sweep parameter settings

Frequency	Sweep bandwidth (kHz)	Sweep up or down	Sweep rate (Hz/sec)	Sweep repetition frequency (Hz)
4 438-4 488 kHz	25	either	25 000	1
5 250-5 275 kHz	25	either	25 000	1
9 305-9 355 kHz	25	either	25 000	1
13 450-13 550 kHz	50	either	100 000	2
16 100-16 200 kHz	50	either	100 000	2
24 450-24 600 kHz	150	either	300 000	2
24 450-24 650 kHz	150	either	300 000	2
26 200-26350 kHz	150	either	300 000	2
26 200-26 420 kHz	150	either	300 000	2
39.0-39.5 MHz	250	either	1 000 000	4
39.5-40.0 MHz	250	either	1 000 000	4
43.35-44.0 MHz	325	either	1 300 000	4

3.3 Summary example of modulation multiplexing of operational parameters

Methods based on sweep timing of the FMCW modulation allow multiple contiguous radars to operate simultaneously without mutual interference. In one administration at least 50 radars operate in this manner where centre frequencies of up to 11 radars are identically the same. Sharing the same licensed waveform, FMCW sweep offset timings have been established that space their signals at baseband so that there is no overlapping mutual interference. Table 8 is an example that includes parameters of an existing case where eight radars are synchronized together in this manner and have operated without mutual interference on the East coast of the United States of America. The distance span of this radar grouping is over 1 000 km.

TABLE 8

Summary of example system operational parameter settings for eight HF radars with modulation starts synchronized together

Radar site identifier code	Modulation sweep start timing offset (µs)	Centre frequency (MHz)	Required centre frequency stability (ppm)	Sweep bandwidth (kHz)	Sweep repetition frequency (Hz)	Pulse/Gate repetition period (µs)
NAUS	6.8	4.513	10^{-12}	25	1	2 600
NANT	3 666	4.513	10^{-12}	25	1	2 600
MVCO	6 888	4.513	10^{-12}	25	1	2 600
BLCK	10 135	4.513	10^{-12}	25	1	2 600
HEMP	19 881	4.513	10^{-12}	25	1	2 600
BRIG	21 683	4.513	10^{-12}	25	1	2 600
WILD	35 000	4.513	10^{-12}	25	1	2 600
MRCH	45 000	4.513	10^{-12}	25	1	2 600

4 Method 4 The selection of one of the two different sweep directions

The modulation can sweep through the bandwidth upward or downward. Two radars or two groups of radars can be swept in opposite directions.

This coordination method is easy to implement and can be used with all types of FMCW radars. This method can also be implemented without any time synchronization between the radars or groups.

Nevertheless, the crossing of upward and downward sweeps is a much more serious concern than the flyback crossing issue. As the crossings last for a non-negligible time within the information bandwidth, some energy leaks from one group to the other one. A minimum separation distance (on the order a few tens of kilometers) will help in facilitating successful coordination between radars. Applicability of this technique must be analysed on a case by case basis.

5 Combination of techniques in one geographic area

FDM and MM techniques can be used together within each sub band. TDM is also compatible with MM within each time slot. Sweep direction (SD) coordination, when applicable, is also compatible with TDM, FDM, and MM. In practical operation using both TDM and MM, several radars with the same sweep parameters use the MM technique as one sharing group, and the TDM technique is used for several sharing groups.

6 Frequency modulated continuous wave radar compatibility, compatibility tests and future work

From what was discussed, the most common radars, i.e. the FMCW radars, where the different brands of radars can accommodate very similar parameters for sweep repetition frequency and sweep rate, will be able to drastically improve the frequency band capacity (for instance by using time-frequency slots). Of course, the different brands of FMCW radars will have to operate more or less the same way. Possible coordination between heterogeneous radars will require careful analysis and may require the use of FDM.

The MM method that was described in this Annex is an important coordination means and it should be tested between different manufacturers in the next decade.

Annex 4

Oceanographic radar sweep factors impacting radar to radar interference

1 Sensitivity to centre frequency

Centre frequency is the first and foremost signal parameter to be considered when selecting system parameters. In nearly all HF-VHF oceanographic radars that use of FMCW signal formats, all waveform parameters are generated with direct digital synthesis (DDS)[5] firmware. This means that all other parameters will be synchronized to a radar's centre frequency time base.

Assuming no stability or drift problems, there are two factors to consider when selecting the centre frequency. Firstly the exact value and how incremental differences in the value of the centre frequency could impact the potential for interference between multiple radars. Secondly the temporal stability of the centre frequency of individual radars, the time base from which the centre frequency is derived can have on mutual interference.

Considerations regarding stability are only addressed here because all other waveform and frequency parameters are locked together by the DDS and so the stability requirements that are discussed here apply to all waveform parameters.

The necessary frequency stability depends on a bistatic mode or monostatic mode (FMCW/FMICW) as follows.

In the bistatic mode, centre frequency drift must be stabilized by orders of magnitude in order to achieve useful compatibility between systems which operate on the same frequency. Suppose we had 0.05 parts per million (ppm) stability (five parts in 10^{-8}) instead of 50 ppm, so that the systems could hold within 2 Hz of each other, rather than 2 kHz. Then the second system could be offset, for example so that its direct signal and information bandwidth are well outside of the information bandwidth of the first radar. However, if we also want to make use of the signals from the second radar in a bistatic mode (a proven capability presently being added to the US IOOS national network), then we need much greater stability than this, because Doppler shift stability must be maintained to the milli-Hertz level (i.e. 0.001 Hz). This is possible with GPS[6] timing synchronization, which has stability of nearly one part in 10^{-12}. Other commercial off-the-shelf technologies besides GPS allow such timing stabilities, e.g. rubidium clock modules.

Each of the radars within a grouping will sweep its FMCW signal within ±half –BW off the radar centre frequency, where BW is the sweep bandwidth of the FMCW signal. To avoid crossing swept radar signals, all radars within a frequency range should be assigned the same centre frequency. In order to do so, the radars centre frequency will have to be stable enough to ensure that its signal does not drift into the operational range of another radar.

In order to efficiently use the allocated frequency spectrum, operational bandwidths and centre frequencies will need to be carefully selected in order to maximize the number of systems that can operate within a given frequency band.

---

[5] Direct digital frequency synthesis (DDFS or simply DDS, is a technique using digital-data and mixed/analog-signal processing blocks as a means to generate real-life waveforms that are repetitive in nature. It is used especially for a precise, fast frequency and phase tuneable output.

[6] In addition to positioning and navigation applications, GPS signals are widely used as low-cost precision time or frequency references. By capitalizing on atomic clocks which are onboard positioning satellites, GPS signals can be used to synchronize equipment to within 15 μs.

The first step in coordinating operational parameters that result in the most efficient use of the allocated frequency bands is to define sweep parameters for each operational frequency such that multiple radars can share the same spectrum while avoiding mutual interference.

2 Sensitivity to sweep bandwidth

How much difference can there be between the sweep widths of two radars within radio range of each other without causing mutual interference?

As an example, suppose that a 24.5 MHz radar is programmed with a 50 kHz sweep width, corresponding to a 3 km range cell (a common configuration). What happens if a nearby radar operating at exactly 24.5 MHz has a sweep width of 49.8 kHz? Does this pose an interference issue? (Often differing brands of radars and their DDS firmware will round up/down to some value slightly off from that requested.) With everything else synchronized, at the beginning of the sweeps (assume they start together), both radars are on the same frequency. At the end of the sweep, they differ by 50 kHz – 49.8 kHz = 200 Hz. Over the course of the sweeps (e.g. 0.5 s for a 2-Hz sweep repetition frequency), the strong direct signal from the second radar sweeps and spreads over 200 Hz in the first radar's receiver. After demodulation, this constitutes an interference pedestal that is 200 Hz wide. Normally, with each range cell occupying 2 Hz of spectral width after demodulation this strong interfering signal can corrupt 100 range cells. This happens because the direct other-radar signal is much stronger than desired echoes from the sea surface. As the sweep widths become closer to equal, the other-site signal becomes confined to fewer range cells.

Example 1:

The second site's sweep bandwidth is 49.998 kHz, then they are always within 2 Hz of each other. The stability of the centre frequency (24.5 MHz in this example) must be maintained at one part in 10^{-7} (see footnote 7).

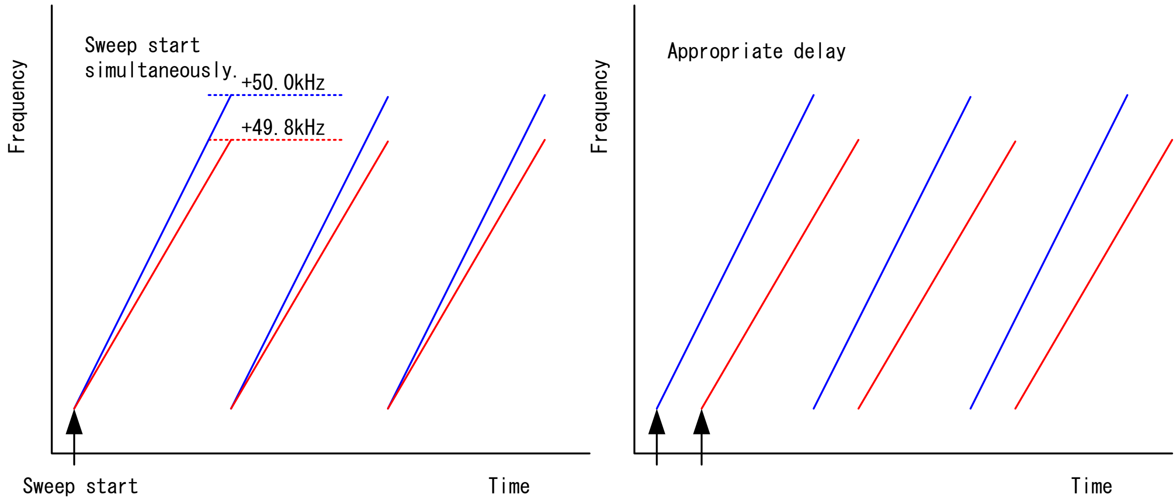
Example 2:

Figure 12 shows an appropriate sweep delay considering sweep bandwidth error for avoiding interference. The image on the left illustrates that when two radars with a small difference between sweep bandwidth, start sweeping simultaneously on the same frequency band, the interfering signal frequency changes in the receive bandwidth of the interfered radar. If one radar delays the timing of the sweep, the frequency and time relation is illustrated in the right image of Fig. 12. As shown in this, when the difference between sweep bandwidths is small, well-controlled sweep timings help to keep the frequency separation between the radars in a sharing group.

[7] 10^{-7} = 2 Hz/24.5 MHz

FIGURE 12

Appropriate sweep delay considering sweep bandwidth error



3 Sensitivity to sweep repetition frequency

For all oceanographic radars employing FMCW signals, a low SRF between 1-8 Hz is typically employed. The minimum SRF that can be used is dictated by the expected velocities of targets (e.g. ocean waves), through the Doppler relation. An SRF much higher than needed to resolve target echoes leads to file sizes larger than necessary and increased computational burden.

The risk of interference increases during the portion of time at which radars in proximity to each other operate on the same frequency. In this case the transmit signal of one radar will directly be received by the other.

Changes to waveform parameters such as SRF are typically made in powers of two. So let’s assume that two radars are operating within the same geography; one with an SRF of 2 Hz and an adjacent companion with an SRF of 4 Hz. Unfortunately, even if frequency and timing parameter choices are identical this mode of operation will result in mutual interference. With a 50 kHz sweep bandwidth, the difference frequency between the two return signals, after demodulation, will vary linearly by exactly 50 kHz over the 0.5 s sweep repetition period (which is 1/SRF). Thus, the strong direct signal from one of the radars will, after demodulation, be spread across the baseband of the companion radar raising its “noise” floor to a level which will result in a severe reduction in the radar's range.

From an interference analysis perspective, let’s assume as a second example that one of the radars is operating with an SRF of 2 Hz while its companion radar is operating at an SRF of 1.99 Hz for 0.5% or 1.9999 Hz for 50 ppm. In this example both of the radars are sweeping over the same 50 kHz sweep bandwidth. The difference in SRF, however, means that one site ends its sweep modulation at a 0.5 s, while the other site ends at 0.5025 s or 0.500025 s. After 0.5 s their frequencies are 50 000 × (1-1.99 or 1.9999/2) = 250 Hz or 2.5 Hz apart. This effect becomes cumulative over multiple sweep periods, and at the end of the second sweep the sites are now 500 Hz or 5 Hz apart.

This slow linear sweep difference continues to accumulate until a complete “beat” period is achieved, i.e. 1/(2-1.99 or 1.9999)[8], or t = 100 s or 10000 s after the start at t = 0. At that time, the sites are 50 kHz apart. Then the cycle starts over.

---

[8] Supposing the sweep time is *N* in one beat period, the sweep time of T1 is *N* + 1. Then, (*N* + 1) × T1 = *N* × T2. It leads *N* = T1(T2 − T1). Therefore, T = *N* × T2 = T1 × T2/(T2 − T1) = (1/SRF1) × (1/SRF2) / (1/SRF2 − 1/SRF1) = 1/(SRF1 − SRF2). Where T is beat period and T1 (= 1/SRF1) and T2 (= 1/SRF2) are the SRF for two radars each other.

In the above case, the direct signal from the radar site whose SRF is off by only 0.5% or 50 ppm from the companion radar is intense and, after demodulation, drifts through the baseband information bandwidth of the companion radar in ~100 s or 10 000 s. The contaminated baseband width is exactly the same amount as that of the radar whose SRF is twice that of the companion radar. But in that case the contamination of the baseband took 0.5 s.

The severity of the interference is the same, because a typical Doppler FFT integration period is several hundred seconds, and so the cumulative energy in the interfering contamination to this spectral analysis is the same. The interference in both cases is intolerable and must be eliminated.

To remove the inter-site interference that occurs because of unequal SRFs is to lock to the same SRF by GPS timing or another precise synchronization. For example, timing calibrations every an hour achieves 0.36 ms of timing error, corresponding to the time-base stability of 0.1 ppm. This stability is achieved by using the crystal oscillator (i.e. OCXO), the standard frequency and time signal (i.e. radio-controlled clock) and the timing signal via dedicated circuits (i.e. optical data transmission).

4 Effect of channel crossing

Here we shall distinguish channel crossing due to channel drifts, channel crossing between upward and downward sweeping radars, and channel crossing due to sweep flybacks (when one of the radar carrier frequency returns rapidly to the bandwidth start). The analysis of frequency band crossing effect must encompass the situation with several radars operating in the same area. The nominal area extension size has to be stated for each frequency band.

If the evolution of the carrier to carrier relative phases of the different radars is not known, then the Doppler extension of the radar to radar interference is not known, and cannot be properly discussed. So, the discussion is focusing on the main parameter: the duration of the channel crossings.

The duration of a channel crossing depends on the radar to radar relative SR. The interference energy is proportional to the crossing time: the period when the carrier of one radar 1 is crossing and polluting the information band of the radar 2 (the sea scatter from radar 1 contains much lesser energy than the carrier direct path contribution).

The summation over the long observation (typically 15 minutes) of the crossings events (from all radars) will deliver a total interference energy that will impact on the quality of the measurements.

Even though the radar to radar interferences have known directions of arrival, this might not always help. A beam-forming (BF) radar will receive a higher noise level in some directions, and some of these radar to radar directions might be common or ambiguous with the sea backscatters, and over all distances. A DF radar might have to deal with more sources than it can.

During the total acquisition time (typically over more than 15 minutes), the gap between spectral sweeps must be wide enough to avoid, the slow overlapping drift of one spectral sweep over the other. Other situations: opposite sweeps, and flyback crossing are evaluated below.

The numbers discussed here are dedicated to the 10 to 20 MHz frequency band. A table shall present the respective values for the 5 MHz, 9 MHz, 13 MHz, 16 MHz, 27 and 40 MHz.

Assuming radars sweeping at 2 Hz over 50 kHz (sweep period 500 ms), the corresponding SR is 100 kHz per second. With a max unambiguous range of 150 km, the information band is 100 Hz wide. Radar to radar interaction over an area extension of 300 km will be considered below.

The radar to radar relative SR between an upward sweeping radar and a downward sweeping radar is 200 kHz/s, the time to cross the information bandwidth is 0.5 ms, which is 1/1 000 of the sweep duration. If 5 radars are installed in the same area, the polluted sweep support is about 5/1 000. This may be a non-negligible figure as the direct path signals are very strong compared to the scattered signals. For a given allocated frequency band (or for a sub-band as discussed before at the large FDM level), the same SD should be defined and used by all radars operating in the same area.

During the sweep flyback, the frequency change is very fast, more than 20 times the normal SR, and the crossing duration is very short. Unless the radars are very close to one another, the flyback crossing interaction can probably be totally neglected. Tests should be reported to confirm this important point.

The next step is to define the nominal channel spectral distance for pure FMCW heterogeneous radars:

For a 300 km area and a 100 kHz/s SR, propagation time produces up to 100 Hz offset on direct carrier signals. As stated before, the Information band width is also 100 Hz. A 2 ms uncertainty on sweep start (over the total acquisition) will result in a ±200 Hz offset between spectral sweeps.

This 2 ms uncertainty over 15 minutes corresponds to a 2 ppm clock to clock offset, which is quite achievable.

So, a 1 kHz channel to channel separation distance would be sufficient. As extra room should be provided for multistatic observations, in order to keep more than one information band within the radar channel. Those very close channels, the “inner slots”, need very fine synchronization. Inner slots have been tested in other administrations, some of which routinely use this fine tuning method.

Annex 5

Examples of other radar technologies

A pseudo-random sequence radar

Radars with pseudo-random sequences modulation, or continuous codes, have been existing for a long time. A characteristic of the continuous codes is to allow at the same time a good resolution in distance (proportional to the duration of the code step) and the good rejection of the space ambiguity (proportional to the code period).

At the spectrum level, within the allowed frequency band, just like a FMCW radar work on all harmonics of the sweep, the coded radars work on all the harmonics of the code repetition rate. It exploits their relative phases, dependent on the particular code. Just like in a FMCW oceanography radar, the Doppler is tracked from the successive reconstructed responses.

The coded radars offer the possibility to decouple several coded radars (up to 90 dB[9] for some systems) by using several codes of the same length but which sequences are orthogonal or almost orthogonal. These performances may be achieved only if the modulation (type, code used, length of code…) and other technical parameters (antenna pattern…) are compatible for all radar stations.

[9] OCOOS 2010 – IEEE conference publishing – Long Range HFWR radar.

Annex 6

Data elements for electronic submission of information related to oceanographic radars

Field name	Field description	Permissible values/units	Length (Max.)	Remark
Int	Action code	"A" or "S"	1	Notification intended for: "A" – Add to the database "S" – Delete from the database
Adm	Responsible ITU Administration	Symbol of the notifying administration	3	ITU symbol designating the administration responsible for radar. Up to 3 characters. Reference: Preface to BRIFIC-terrestrial (http://www.itu.int/ITU-R/terrestrial/docs/brific/files/preface/PREFACE_EN.pdf)
ctry	Geographical area where the radar is located	Symbol of the geographical area	3	ITU symbol designating the geographical area where the radar is located. Up to 3 characters. Reference: Preface to BRIFIC-terrestrial (http://www.itu.int/ITU-R/terrestrial/docs/brific/files/preface/PREFACE_EN.pdf)
stn_type	Station type	"TX", "RX" or "TR"	2	If radar is used in transmission mode enter TX. If radar is used in receiving mode enter RX. If radar is used in monostatic mode enter TR. Maximum 2 characters.
freq_assgn	Centre frequency	MHz	10	Operational centre frequency of the radar. Numeric value, with decimal point. Up to 10 characters.
bdwdth_kHz	Bandwidth	kHz	11	Emission bandwidth. Numeric value, with decimal point. Up to 11 characters.
eirp_dBW[10]	e.i.r.p.[11]	dBW	5	Radiated power. Numeric, with + or – sign and 1 decimal. Up to 5 characters.
emi_cls	Class of emission	ITU codes	5	Emission Class in accordance with Appendix **1** to the Radio Regulations. From 3 to 5 characters.

[10] This data item is to be notified only for transmitting and monostatic radars. For receivers it shall be left blank.

[11] The product of the power supplied to the antenna and the antenna gain G_i in a given direction relative to an isotropic antenna (absolute or isotropic gain) (Radio Regulations, No. **1.161**).

Field name	Field description	Permissible values/units	Length (Max.)	Remark
network_name	Network name	As provided by administration/ owner	30	Indicate the name of the group. If not part of the group leave blank. Up to 30 characters.
synch	Synchronization with other radars	"Y" or "N"	1	If radar is synchronized with other radars in the group insert "Y". Otherwise insert "N". Max. 1 character.
util	Utilization	"P" or "N"	1	In case radar is permanent enter "P". In case it is not permanent enter "N". Max. 1 character.
lat	Radar latitude	Latitude (degrees, minutes, seconds)	±DDMMSS –900000 to +900000	The latitude of the location at which the radar is installed. Sign + (plus) for North Latitude, sign – (minus) for South Latitude and leading zeros (when necessary) in DD (degrees), MM (minutes) and SS (seconds).
long	Radar longitude	Longitude (degrees, minutes, seconds)	±DDDMMSS –1800000 to +1800000	The longitude of the location at which the radar is installed. Sign + (plus) for East Longitude, sign – (minus) for West Longitude and leading zeros (when necessary) in DDD (degrees), MM (minutes) and SS (seconds).
site_name	Site name	Name, as provided by administration/ owner	30	The name that is associated with the oceanographic radar site. Up to 30 characters.
Adm_ref_id	Administration unique identifier	Identifier, as provided by administration	20	Unique identifier of the radar given by the administration. In case radar doesn't have it, leave blank. Up to 20 characters.
call_sign[12]	Call sign	Call sign	7	Call sign used in accordance with Article **19** of the RR. Up to max. 7 characters. In case this information is not available leave blank.
email_adm	Administration or authority contact	Email address	–	Email address of the individual who has responsibility for assigning frequency to the radar.
email_op	User contact	Email address	–	Email address of the individual who has responsibility for the operation of the radar.
d_inuse	Date of bringing into use	DD.MM.YYYY		Date (actual or foreseen, as appropriate) of bringing the radar into use.

[12] This data item is to be notified only for transmitting and monostatic radars.

Field name	Field description	Permissible values/units	Length (Max.)	Remark
d_update	Last update in the database			This date is not to be notified. It will be automatically generated by BR.
op_time	Full time	"Y" or "N"	1	In case radar is on whole day insert "Y". Otherwise insert "N". Max. 1 character.
adm_remark			255	Additional information on the duty cycle of the radar (for example: "First 15 min every hour") and any other information that could be useful for coordination. Max. 255 characters in total.

____