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Interference measurements HKWA mast at Stellendam

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Contents

1 Introduction

1.1 Offshore windfarms

In the Energy Agreement for Sustainable Growth, it is agreed that in 2023 at least 4.5 GW of power will come from offshore wind energy, supplying 3.3% of all energy in the Netherlands. This policy is agreed to continue. The target being about 11 GW by 2030 which is 8.5% of all energy in the Netherlands.

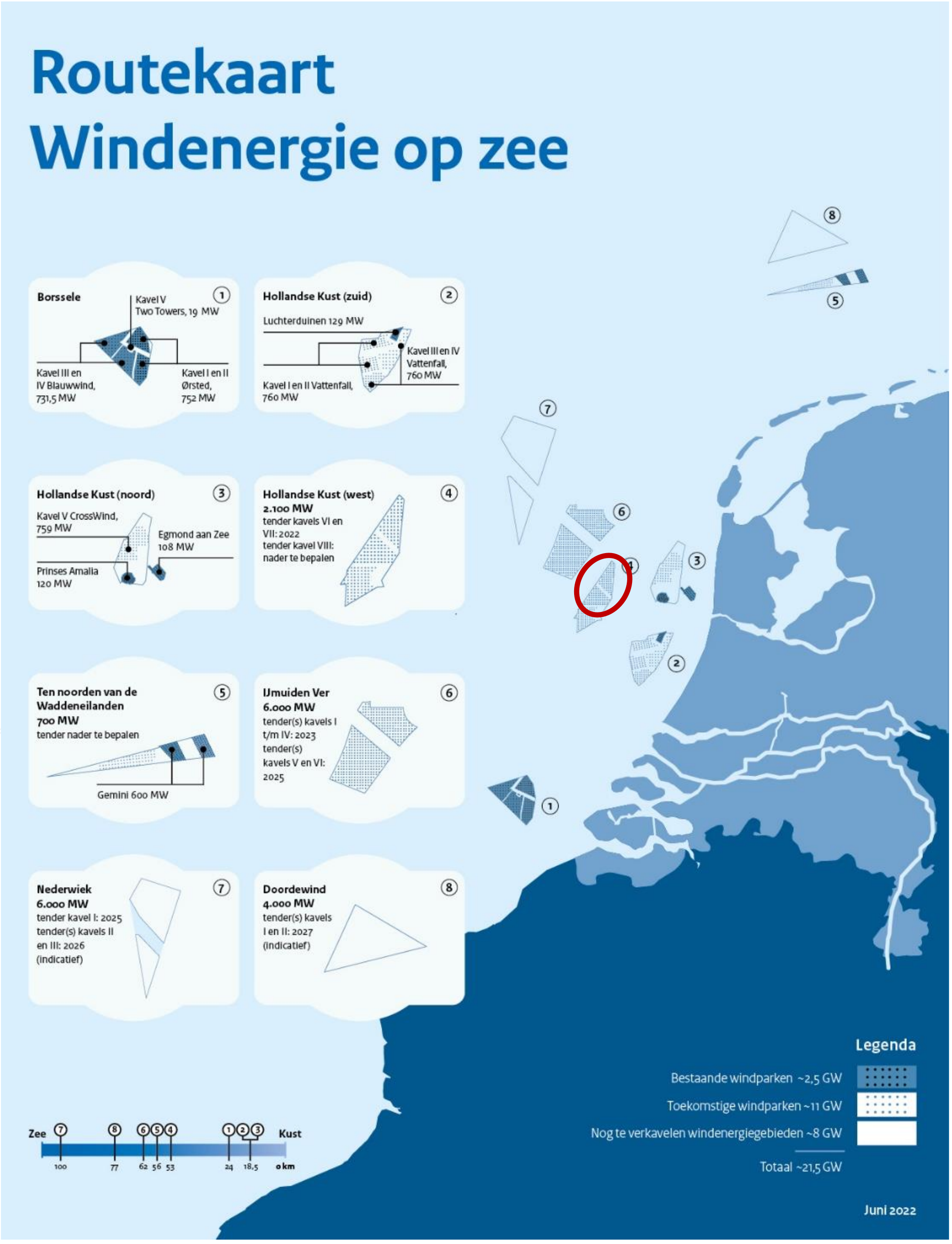

Figure 1.1: Offshore windfarms (Routekaart Windenergie op zee[1]). In the red ellipse “Hollandse Kust West (Alpha & Beta)”.

[1] Energietransitie op de Noordzee - Noordzeeloket

The Borssele windpark is operational, while Hollandse Kust Zuid and Hollandse Kust Noord will be fully operational in the course of 2023. To meet the goals for 2030, additional wind farms are planned: Hollands Kust West, IJmuiden Ver and Ten Noorden van de Waddeneilanden.

1.2 Offshore platforms

To transport the electricity produced by the windfarms to shore, the required infrastructure (cables and converters) will be provided by TenneT. For this, TenneT provides offshore platforms in each wind farm at which the electricity from the wind turbines is collected, converted, and exported to shore.

These offshore platforms will also accommodate equipment to provide wireless communications with ships, helicopters and personnel working within the wind farms. For this purpose, each platform will have a mast in which the required antennas will be mounted. To monitor the environment, nautical and bird radars may also be mounted in or located near this mast, as well as other sensors, like for instance a wind speed/direction sensor. In addition, the mast may be used to mount antennas for use by third party systems.

1.3 Investigations by TNO

To avoid radiocommunication related problems, which are very costly to solve once the platform is at sea, TNO is asked to investigate the best mounting positions of the antennas in the mast:
- taking into account the priority and required coverage of each system, while
- minimising mutual interference between systems.

These antenna mounting positions are proposed in an “Antenna plan”, which includes the calculated coverage of each system and the obtainable isolation between antennas based on simulations. This allows possible problems to be discovered in an early phase.

In a second phase, measurements on the actual mast and communication equipment at Stellendam are performed. This allows all remaining problems (foreseen or unforeseen) to be discovered and solved before the equipment is mounted on the platform and transported to sea.

In a third phase, interference measurements and coverage measurements are performed at sea as soon as the offshore platform is located on its position. The interference measurements are done once. Coverage measurements are performed before and after the wind turbines are erected. The results of these measurement sessions are used to determine the influence of the wind turbines on the radio coverage.

1.4 Scope of this report

In this report the isolation and interference measurements performed at Stellendam, with the communication equipment to be used on OSS platform Hollandse Kust West (HKWA), will be discussed (second phase). They are compared with the results of simulations which are contained in the phase 1 report “Maritime coverage and interoperability calculations of HKWA”.

2 Windfarm Hollandse Kust West Alpha

The windfarm Hollandse Kust West Alpha has been assigned to lot VI.

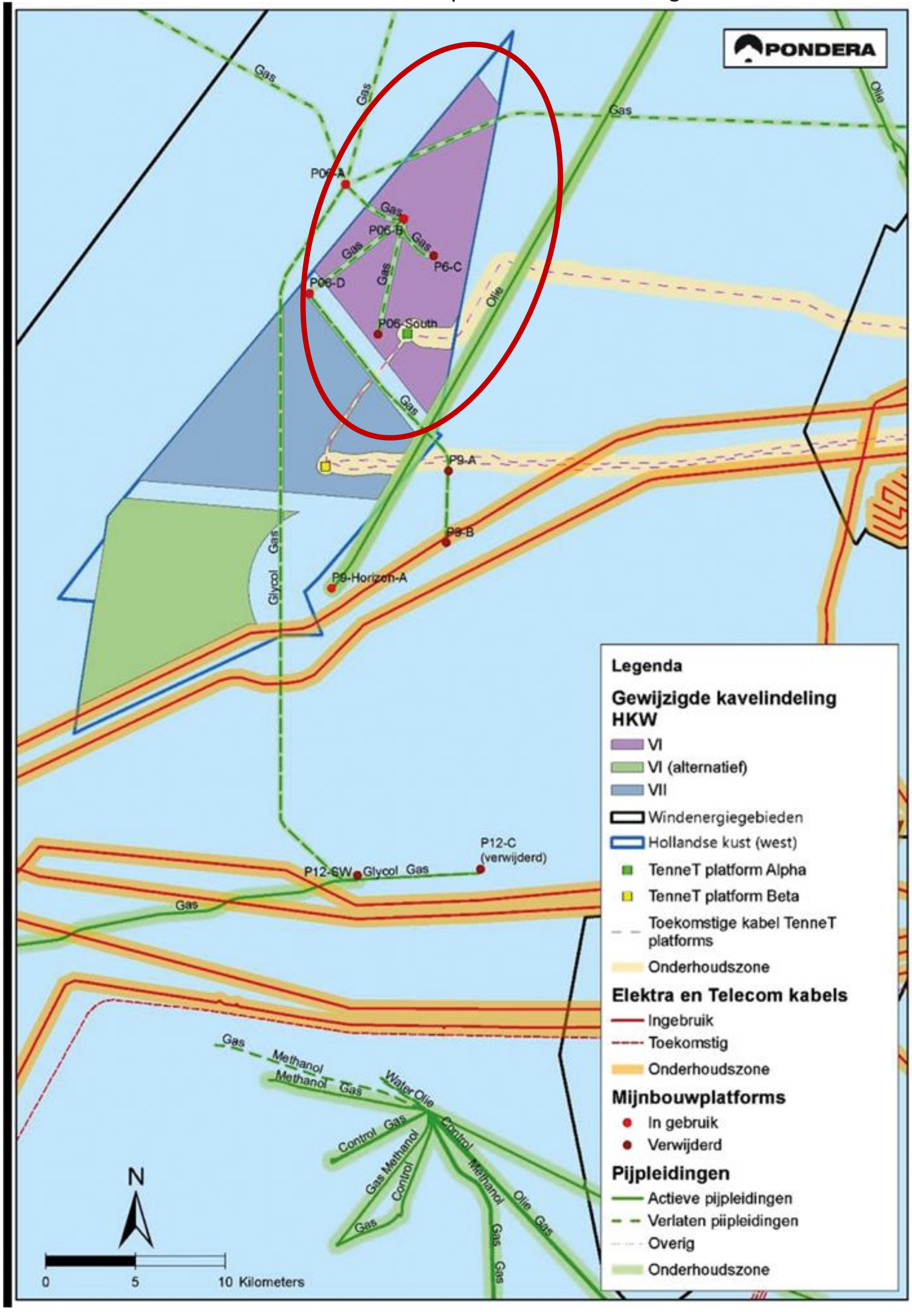

Figure 2.1 Overview of windfarm “Hollandse Kust West Alpha”, with the OSS platform indicated by the red ellipse.

3 Mast and antenna positions

The mast and antenna positions on OSS Hollandse Kust West Alpha are as described in the report “Maritime coverage and interoperability calculations of HKWA”. In *this* report the results of interference and isolation measurements in Stellendam are presented and compared with the simulations.

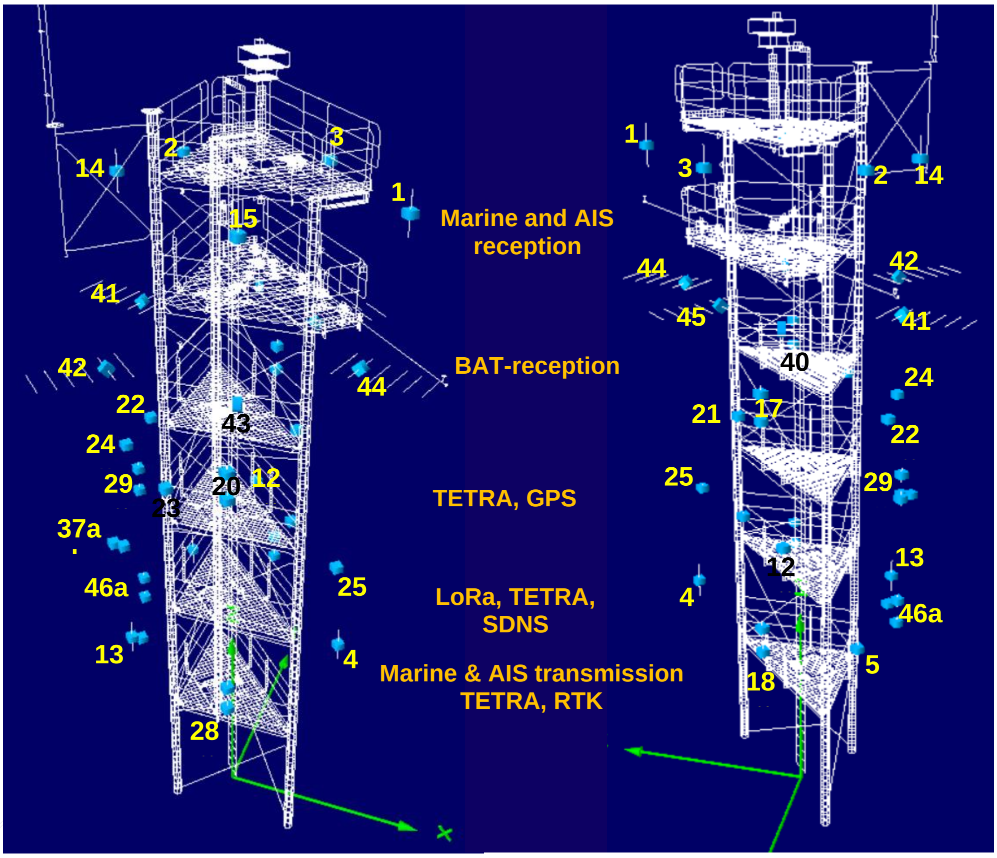

Figure 3.1 The HKWA mast and antenna numbering as seen from two angles.

Note: TETRA (or DMR), SDNS and RTK have not been tested due to the absence of systems and antennas. Only one AIS receive antenna was available.

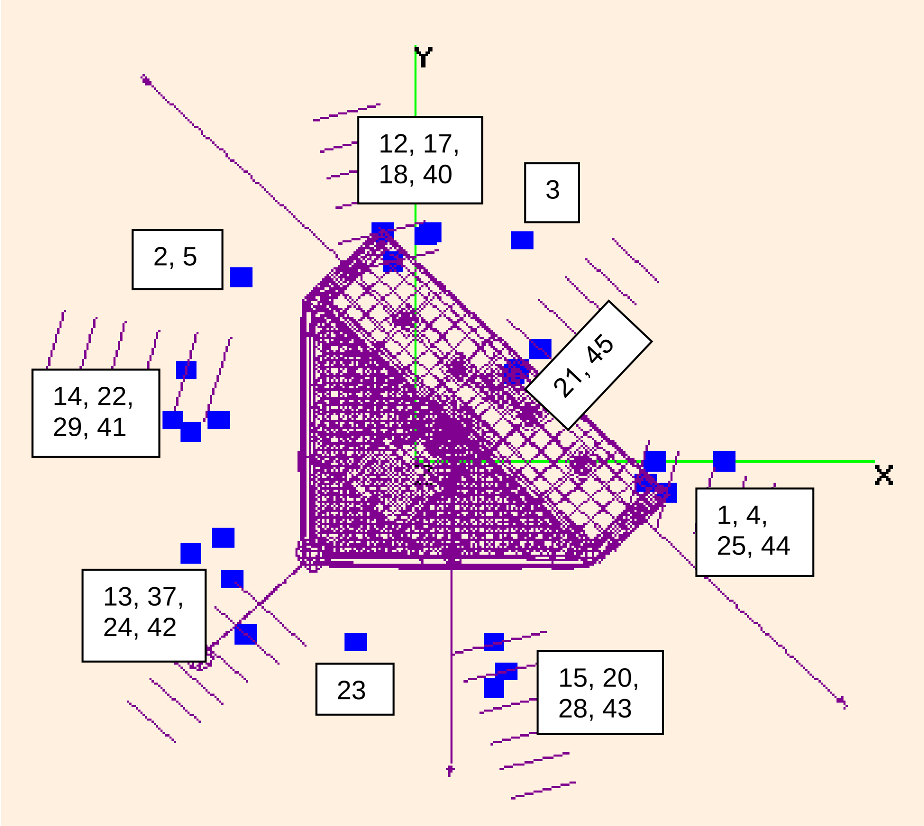

Figure 3.2 Top View of the HKWA mast, showing antenna numbers.

Table 3.1 Overview of antenna, height and position of the Antennas in the mast.

			Antenna positions[2]					
Ant. nr	**Unique Equipment Code**	**Antenna height [mm]**	**X [mm]**	**Y [mm]**	**Z [m][3]**	**Deck**	**Application Antenna model**	**Owner**
1	S04-TNT-VHF-01	1300	3350	0	15.6	5	Maritime radio, RX1 Procom CXL 2-1	TNT
2	S04-TNT-VHF-02	1300	-1900	2200	15.6	5	Maritime radio, RX2 Procom CXL 2-1	TNT
3	S04-TNT-VHF-03	1300	1150	2650	15.6	5	Maritime radio, RX3 (DSC) Procom CXL 2-1	TNT
4	S04-TNT-VHF-04	1300	2600	0	5.1	1	Maritime radio, TX1 Procom CXL 2-1	TNT
5	S04-TNT-VHF-05	1300	-1900	2200	5.1	1	Maritime radio, TX2 Procom CXL 2-1	TNT
13	S31-RWS-AIS-01	1300	-2000	-1400	5.1	1	AIS1, TX CXL 150-1LW-SS-R, Procom	RWS
14	S31-RWS-AIS-02	1300	-2650	-500	15.6	5	AIS1, RX CXL 150-1LW-SS-R, Procom	RWS
15	Sxx-xxx-AIS-01	1300	850	-2150	15.6	5	AIS2, RX CXL 150-1LW-SS-R, Procom	WPO
23	S31-RWS-AIS-03	120	-660	-2150	10.4	3	AIS1, GPS Synergy systems VIC-100	RWS
24	Sxx-xxx-AIS-02	120	-2100	-900	10.4	3	AIS2, GPS Synergy systems VIC-100	WPO
17	Sxx-xxx-TTR-01	500	100	2700	10.4	3	TETRA1, RX Procom CXL 70-3HD	WPO

[2] The x-, y- and z-positions refer to the centre of the stairs in the mast.
[3] Base mounting height of the antenna on the Bracket.

18	Sxx-xxx-TTR-02	500	150	2750	5.1	1	TETRA1, TX&RX Procom CXL 70-3HD	WPO
21	Sxx-xxx-TTR-03	120	1100	1100	10.4	(3)	TETRA1, GPS Synergy systems VIC-100	WPO
20	Sxx-xxx-TTR-04	500	850	-2700	10.4	3	TETRA2, RX Procom CXL 70-3HD	WPO
28	Sxx-xxx-TTR-05	500	850	-2700	4.9	1	TETRA2, TX&RX Procom CXL 70-3HD	WPO
22	Sxx-xxx-TTR-06	120	-2150	500	10.4	(3)	TETRA2, GPS Synergy systems VIC-100	WPO
29	Sxx-xxx-DMO-01	500	-2460	350	7.9	2	TETRA DMO Procom CXL 70-3HD	WPO
25	S58-RWS-LRA-01A	620	2500	-250	7.9	2	LoRa ANT-OMNI-868-01	RWS
12	S59-EXT-LRA-01	620	-250	2400	7.9	2	LoRa ANT-OMNI-868-01	EXT
37a	S45-LVN-MSS-01	120	-2460	-1100	7.9	2	SDNS	LVN
37b	S45-LVN-MSS-02	120	-2220	-1100	7.9	2	SDNS GPS	LVN
40	S49-RWS-TBS-01		-270	2400	10.6	4	Bat telemetry RX WY 140-6	RWS
41	S49-RWS-TBS-02		-2160	1000	10.6	4	Bat telemetry RX WY 140-6	RWS
42	S49-RWS-TBS-03		-1650	-1850	10.6	4	Bat telemetry RX	RWS
43	S49-RWS-TBS-04		900	-2160	10.6	4	Bat telemetry RX WY 140-6	RWS
44	S49-RWS-TBS-05		2400	-270	10.6	4	Bat telemetry RX WY 140-6	RWS
45	S49-RWS-TBS-06		1090	1090	10.6	4	Bat telemetry RX WY 140-6	RWS
46	S57-xxx-RTK-01		-2650	-900	15.6	1	RTK CXL70-3LW	WPO
46a	S57-xxx-RTK-02	120	-2410	-900	15.6	1	RTK, GPS GA830	WPO

WPO = Wind Park Owner TNT = TenneT RWS = Rijkswaterstaat, LVN = Luchtverkeersleiding Nederland, EXT = External party

Table 3.2 Overview of Antennas, model, type and owner as installed on OSS HKWA

Ant. nr	Internal RWS code	Owner	Application	Antenna type
1	S04-TNT-VHF-01	TNT	Marine Comms	Procom CXL 2-1
2	S04-TNT-VHF-02	TNT	Marine Comms	Procom CXL 2-1
3	S04-TNT-VHF-03	TNT	Marine Comms	Procom CXL 2-1
4	S04-TNT-VHF-04	TNT	Marine Comms	Procom CXL 2-1
5	S04-TNT-VHF-05	TNT	Marine Comms	Procom CXL 2-1
13	S31-RWS-AIS-01	RWS	AIS1 - TX	CXL 150-1LW-SS-R, PROCOM
14	S31-RWS-AIS-02	RWS	AIS1 – RX	CXL 150-1LW-SS-R, PROCOM
15	Sxx-xxx-AIS-01	WPO	AIS2 - RX	CXL 150-1LW-SS-R, PROCOM
23	S31-RWS-AIS-03	RWS	GPS, AIS1	Synergy systems VIC-100
24	Sxx-xxx-AIS-02	WPO	GPS, AIS2	Synergy systems VIC-100
17	Sxx-xxx-TTR-02	WPO	TETRA1, RX	Procom CXL 70-3HD
18	Sxx-xxx-TTR-03	WPO	TETRA1, RX&TX	Procom CXL 70-3HD
21	Sxx-xxx-TTR-04	WPO	TETRA1, GPS	Procom CXL 70-3HD
20	Sxx-xxx-TTR-05	WPO	TETRA2, RX	Procom CXL 70-3HD
28	Sxx-xxx-TTR-06	WPO	TETRA2, RX&TX	Procom CXL 70-3HD
22	Sxx-xxx-TTR-07	WPO	TETRA2, GPS	Synergy systems VIC-100
29	Sxx-xxx-DMO-01	WPO	TETRA, DMO	Procom CXL 70-3HD
25	S58-RWS-LRA-01A	RWS	LoRa	ANT-OMNI-868-01

12	S59-EXT-LRA-01	EXT	LoRa	ANT-OMNI-868-01
37a	S45-LVN-MSS-01	LVN	SDNS	
37b	S45-LVN-MSS-02	LVN	SDNS GPS	
40	S49-RWS-TBS-01	WUR	Bat Telemetry, RX	Laird Y1505_115
41	S49-RWS-TBS-02	WUR	Bat Telemetry, RX	Laird Y1505_115
42	S49-RWS-TBS-03	WUR	Bat Telemetry, RX	Laird Y1505_115
43	S49-RWS-TBS-04	WUR	Bat Telemetry, RX	Laird Y1505_115
44	S49-RWS-TBS-05	WUR	Bat Telemetry, RX	Laird Y1505_115
45	S49-RWS-TBS-06	WUR	Bat Telemetry, RX	Laird Y1505_115

Table 3.3 Antenna pairs and GPS designations

Purpose	**RX-antenna**	**TX-antenna**	**GPS-antenna**	**User**
VHF Marine	1	4		TNT
VHF Marine	2	5		TNT
VHF Marine (DSC)	3			TNT
AIS	14	13	23	RWS
AIS (DCS)	15		24	WPO
LoRa	25	25		RWS
LoRa Ext	12	12		EXT
TETRA1	17	18	21	WPO
TETRA2	20	28	22	WPO
SDNS	37		37a	LVN
Bat telemetry receiver	40			WUR
Bat telemetry receiver	41			WUR
Bat telemetry receiver	42			WUR
Bat telemetry receiver	43			WUR
Bat telemetry receiver	44			WUR
Bat telemetry receiver	45			WUR

4 Measurement plan

Simulations have been conducted which show the isolation values between the various antennas. Based on these results, recommendations are given regarding the maximum transmit power of the maritime radios to prevent interference issues. Isolation with other wireless systems is also taken into account, which may lead to additional recommendations when operational consequences are expected.

The goal of the measurement campaign in Stellendam is twofold: To verify the isolation figures and to perform interference scenarios which confirm the desired operation of the wireless systems. The latter has been restricted to the maritime radios and bat telemetry systems due to the unavailability of other wireless systems, as no Wind Park Owner (WPO) was known at time of taking the measurements.

The measurements have been conducted as follows:

1. Isolation measurements between (nearly) all antennas. Source to target, with the source antenna determining the measurement frequency.
2. Interference tests which provide data regarding multi operational scenarios. I.e.: whether or not interference will occur between any of the communication systems.

4.1 Isolation between antennas

Simulations have been performed using a model of the mast as will be employed on OSS HKWA. A nearly identical mast is available for measurements in Stellendam, where the antennas are mounted exactly as in the simulations.

Measurements have been performed using a network analyzer to determine all isolation values between the various antennas. The results are compared with the earlier outcomes from the simulations. If the measurement results deviate too much from the initial simulations, it might eventually lead to a change in the antenna configuration or changes in the transmit power recommendations of the maritime radios.

4.2 Interference tests

Multiple communication systems specifically aimed for maritime applications are installed on the mast in HKWA. The mast in Stellendam did not contain TETRA/DMR, RTK and SDNS hardware nor antennas at the moment of testing in August 2022 due to the absence of a WPO. Hence, no measurements have been conducted on these systems. It was not possible to properly test interference with the AIS systems due to their very brief transmit time slots.
The mast in Stellendam did not contain all LoRa systems, hence no measurements have been conducted on these systems either. So, the interference tests were only performed on the maritime radio systems.

To perform the marine radio interference tests, a SINAD audio signal of 20 dB (for a specific signal level as specified in the marine standard[4]) has to be set at the DUT receiver. For the marine radios, every radio channel combination which may be operationally used will be tested for possible SINAD degradation.

[4] ETSI EN 301 929 V2.1.1 (2017-03)

The possible sources of interference are every other transmitter situated on the mast, either operating in the marine radio band (156 – 164 MHz), TETRA or DMR (415/425 MHz) and RTK (440 MHz).
LoRa operates at very low power levels and at a very large frequency offset. No harmful interference is anticipated, hence interference tests are not deemed necessary anymore (no cases of interference on any of the former platforms were observed).

In order to prevent any disturbance caused by the RF noise from the solar panel system in Stellendam, they were switched off during the interference measurement.

5 RF Isolation measurements

5.1 Measurements

The isolation is measured by considering any pair of antennas as a 2-port system and measuring the S12- and S21-parameters which provide the isolation between both ports. The S-parameters have been measured in the applicable frequency bands within the range of 100 - 900 MHz.
Note: S12 and S21 indicate the direction between two ports were the transfer in dB is measured.

5.2 Measurement setup

The S-parameters have been measured using an R&S ZVL-6 Vector Network Analyzer. Preceding the measurements, the device has been calibrated over the full frequency range of the measurements (100-900 MHz) using the Wiltron calibration kit (Full Calibration 2-port) after a warmup period of half an hour.

5.3 Measurement results

The measurement results are shown in Table 5.1. They show the isolation (in dB) between any pair of antennas. The isolation is given between the antenna number noted in the column and the antenna number noted in the row, with the antenna numbers corresponding with those in Chapter 3, at the frequency noted in the column.

It should be noted that not all isolation factors are relevant for our purposes. The isolation between two receive antennas is not very relevant, since nothing is transmitted by a receiver that can cause interference to another receiver (unless the values are very low, 20 dB or less). Similarly the isolation between two transmit antennas is not relevant (unless the values drop under ≈40 dB), since no receiver is involved which can be interfered with. At very low isolation levels (i.e. < 40 dB) intermodulation products may be generated and extra measures must be taken.

Most important are the isolation factors between a transmit and receive antenna and in particular the isolation between a transmit antenna noted in the column and a receive antenna noted in the row (for which the isolation is measured at the mid-band frequency of the transmitter involved). In addition, both Tx and Rx have to operate in the same frequency bands (if not, an antenna/receiver will be able to provide additional filtering, hence diminish the signal strength of the interfering transmission). The important isolation factors are highlighted in the Table. Only isolation values less than 60 dB are marked with a colour in the table.

Coloured numbers:
Green = isolation measurement between transmitters.
Yellow = measurement indicates an isolation value < 60 dB between a transmitter and receiver both operating in the same frequency band.
Orange = measurement indicates an isolation value < 40 dB between transmitters operating in the same frequency band. A circulator in the transmit line to improve isolation is recommended.

Low isolation levels between receive antennas will not be marked, unless ≤ 20 dB.

The minimum required isolation of 60 dB was determined in the report “Maritime coverage and interoperability calculations HKWA” and takes into account an additional margin of 3 dB.

Table 5.1: Measured isolation (dB) between antennas.

		Marine					AIS		LoRa	BAT		
		RX	RX	RX	TX	TX	TX	RX		RX	RX	RX
	Frequency [MHz]:	159	159	159	159	159	159	159	868	150	150	150
	Antenna	**1**	**2**	**3**	**4**	**5**	**13**	**14**	**25**	**41**	**43**	**45**
Marine	**1**		40	31	*n/a*	56	58	38	76	55	50	42
	2	40		32	56	*n/a*	57	23	84	39	55	55
	3	32	31		56	56	56	34	69	55	53	47
	4	52	56	56		42	42	57	85	65	54	42
	5	56	56	58	42		27	58	70	55	60	54
AIS	**13**	58	57	56	42	27		53	70	50	50	61
	14	38	23	34	57	58	*n/a*		59	44	54	54
LoRa	**25**	54	56	51	29	51	47	56				
BAT	**41**	61	39	58	59	55	51	46	75			
	43	52	56	60	54	60	51	58	85	63		
	45	42	56	47	44	54	61	53	87	56	55	
BAT with input BPF	**41**	95	75	95	100	90	90	85				
	43	90	90	95	100	90	85	100				
	45	78	95	85	80	90	95	95				

Due to absence of antennas and equipment, no measurements were conducted on DMR, RTK, GPS antennas (active antennas), AIS antenna 15 and Bat antennas 40, 42 and 44.

The measured isolation values require a minor reduction in transmit power of the maritime transmitters. However, as phase noise increases at small frequency offsets, it is advised to keep the transmit power at a sufficiently low level which satisfies the purpose of the transmitter, i.e. sufficient coverage. For the HKWA situation a maximum transmit power of +41 dBm (12 Watt)[5] for both maritime radio transmitters 1 and 2 is advised (i.e. attached to antennas 4 and 5).

It is strongly advised to insert RF isolators in antenna lines 5 and 13, given their small isolation value of 27 dB.

Table 5.2 Recommended output power levels of marine radio’s

System	Antenna nr.	Maximum Power (W / dBm)
Marine radio1	**4**	**12 / +41**
Marine radio2	**5**	**12 / +41**
Marine radios 1&2, Ch. 90L	**4 & 5**	**3 / +35**
AIS	**13**	**12 / +41**

Note: The interference measurements have been conducted using the transmit level based on simulation the, i.e. 8 W (+39 dBm) for marine radio2.

[5] TNO report, Maritime coverage and interoperability calculations of HKWA, paragraph 4.7.1

Note
During the isolation measurements one of the maritime radio transmit antennas (Procom CXL-2-1) showed a poor reflection coefficient. The particular antenna was replaced and the faulty situation disappeared.
A measurement on the faulty antenna showed that slight mechanical pressure on the radiating element made the fault appear and disappear. Obviously a bad contact had occurred inside the radiating element. If such a situation occurs on a platform at the transmit antenna, a bad SWR situation will trigger alarms of the Jotron equipment. When a receive antenna is affected by the same issue, it will be far less obvious as the reception is "less than normal", but likely not wiped out. Hence, it is harder to detect a faulty receive antenna.

6 Interference measurements

All marine radio transmitters and receivers have been supplied by Jotron[6], since OSS Borssele Alpha. Isolation simulations and interference measurements have been conducted based on the supplied specifications provided by Jotron and the standard[7] covering marine radio communications.
The standard, nor the radio manual from by Jotron, provide any specifications regarding phase noise of the receiver and transmitter oscillators. Under many circumstances phase noise levels may be an insignificant property, but when signal levels are very high and ambient noise levels very low, they may become a limiting factor and impact the sensitivity and dynamic range of receivers. The smaller the frequency difference between transmitter and receiver, the stronger this effect manifests itself.

Analysis shows that increased noise levels are required in order to conduct proper blocking calculations, and associated interference (SINAD) measurements. The interference measurements in Stellendam have been conducted using the noise insertion method. Accountability, see TNO: "Interference measurements HKN mast at Stellendam, chapter 5".

6.1 Measurement setup for maritime radios

Measurements for the maritime radios have been performed using the setup shown below. Noise is injected to limit the required SINAD sensitivity to 20 dB at a signal level of -101 dBm (as required by the standard).

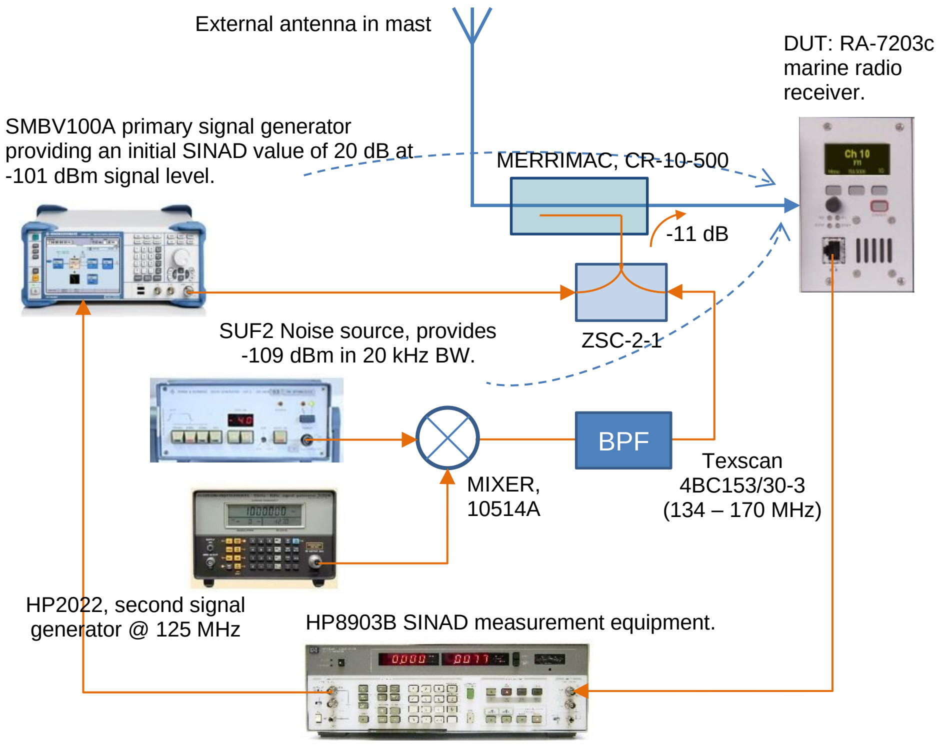

Figure 6.1 Interference measurement setup (maritime radios).

[6] Operator and installation manual, TR-7750c, TA-7650c, RA-7203c
[7] ETSI EN 301 929 V2.1.1 (2017-03)

6.2 Measurement procedure for maritime radios

The measurement procedure consists of the following steps:

1. Noise is injected in the marine receiver under test (DUT) in order to satisfy a SINAD level of 20 dB at a reference signal level of -101 dBm. It is required to insert a directional coupler into the coaxial receive line. See the set-up as depicted in Figure 6.1.
2. The HP8903B SINAD audio analyser is set to produce a 1 kHz audio signal which is fed into the SMBV100A RF signal generator, producing a (3 kHz FM-modulated) ‘desired’ signal.
3. The carrier frequency is set to the required Rx frequency on the SMBV100A RF signal generator.
4. The DUT receiver is selected, using the TNO switch Box, which routes the received audio signal to the HP8903B SINAD audio analyser.
5. The (transmit) power level of the SMBV100A RF signal generator is adjusted till the HP8903B SINAD audio analyser indicates that the received audio signal has a SINAD of 20 dB.
6. One by one the maritime transmitters connected to antennas 4, 5, x and y are activated and the resulting SINAD shown on the HP8903B SINAD audio analyser is noted.
7. A SINAD reduction of > 6 dB is considered unacceptable by the marine standard. However, it should be noted that the standard does not define interference for frequency offsets less than 1 MHz.
8. The noise injection circuit is inserted in the next DUT receiver line. Steps 5, 6 and 7 are repeated for the other maritime transmitters.
9. The interference measurements must be conducted for all the operational channels.

6.3 Transmitter power settings during trials and used channels

The transmit power levels of the maritime transmitters during these measurements were set to:

- Transmitter1 attached to antenna 3 +41 dBm (12 W)
- Transmitter2 attached to antenna 4 +39 dBm (8 W)

The channels used for the interference measurements are shown in the Table below.

Table 6.1 Overview of used channels

Channel Nr.	Simplex (S)/ Duplex (D)	Rx Frequency (MHz)	Tx Frequency (MHz)	Purpose (Use)
6	S	156.300	156.300	Intership traffic
15	S	156.750	156.750	Intraship traffic
16	S	156.800	156.800	Emergency channel
17	S	156.850	156.850	Intraship traffic
23	D	157.150	161.750	Coast guard
70	S	156.525	156.525	DSC
77	S	156.875	156.875	Social & Provisioning
83	D	157.175	161.775	Coast guard
90L	S	157.525	157.525	Oil control vessels

6.4 Measurement results for maritime radios

Three examples of measurement results are shown in the Tables below. In the heading of each Table the parameters of the 'desired' signal are shown:
- Rx antenna (number) used,
- receive channel and frequency, as well as
- whether it is a simplex or duplex channel.

Each row in the Tables provides settings of the interfering maritime transmitter:
- the Tx antenna (number) being used,
- the channel and frequency on which it transmits,
- the frequency difference between the carrier frequency of the 'desired' and interfering signal, and
- the resulting SINAD

All tables can be found in Appendix 2.

6.4.1 Receiver 1 connected to antenna 1

Table 6.2 Rx: Antenna 1, Channel 6, Freq. 156.300 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	*SINAD (dB)*
Antenna 5 is paired with TX-antenna 2				
5	15	156.750	0.450	*20*
5	16	156.800	0.500	*20*
5	17	156.850	0.550	*21*
5	23	161.750	5.450	*21*
5	70	156.525	0.225	*19*
5	77	156.875	0.575	*20*
5	83	161.775	5.475	*21*
5	90L	157.525	1.225	21

6.4.2 Receiver 2 connected to antenna 2

Table 6.3 Rx: Antenna 2, Channel 6, Freq. 156.300 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	15	156.750	0.450	21
4	16	156.800	0.500	21
4	17	156.850	0.550	21
4	23	161.750	5.450	21
4	70	156.525	0.225	15
4	77	156.875	0.575	20
4	83	161.775	5.475	21
4	90L	157.525	1.225	21

6.4.3 *Receiver 3 connected to antenna 3*

Table 6.4 Rx: Antenna 3, Channel 70, Freq. 156.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 3 is not paired with a specific antenna				
4	6	156.300	0.225	13
4	15	156.750	0.225	12
4	16	156.800	0.275	15
4	17	156.850	0.325	16
4	23	161.750	5.225	20
4	77	156.875	0.350	16
4	83	161.775	5.250	20
4	90L	157.525	1.000	19

6.5 Analysis

At small frequency offsets (< 300 kHz) the SINAD will drop. At very small offsets, of 75 kHz or less, a good quality is rarely achieved and SINAD values as low as 2 dB have been observed (marked in orange in the tables). The cause of the low SINAD values is due to the phase noise of the receiver and transmitter oscillators which raises the noise level in the receiver, hence decrease the SINAD.

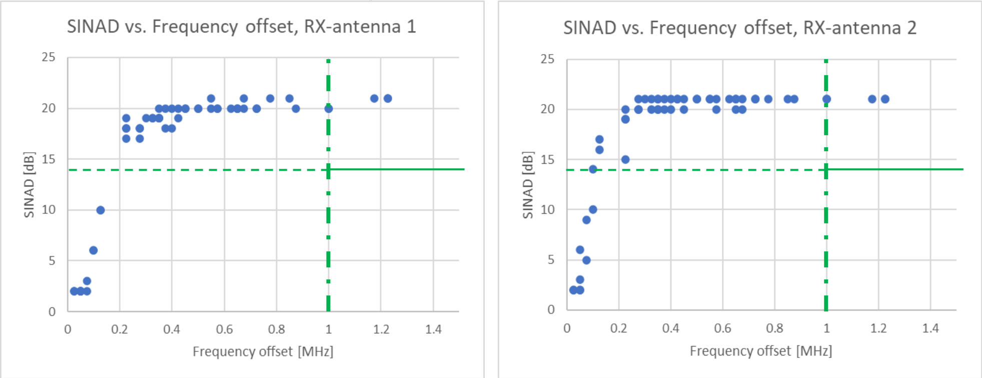

Figure 6.2 SINAD versus frequency offset of a maritime transmitter for receive antennas 1 and 2. The green line indicates the acceptable SINAD degradation according to the maritime standard, but only the region beyond 1 MHz (i.e. to the right of the dot-dashed line) is mandatory by the standard.

In the maritime standard the receiver specifications are defined for frequency separations of ≥ 1 MHz[8]. No degradation of more than a dB or so of the SINAD have been recorded for such frequency separations, as shown in Figure 6.2 and Figure 6.3.

Figure 6.2 and Figure 6.3 show the SINAD for the three receivers versus frequency offset of the interfering transmitter (The duplex transmit channels at > 4 MHz are not shown, but no decrease of the SINAD is observed there).

[8] ETSI EN 301 929 V2.1.1 (2017-03), 9.9 Blocking or desensitization

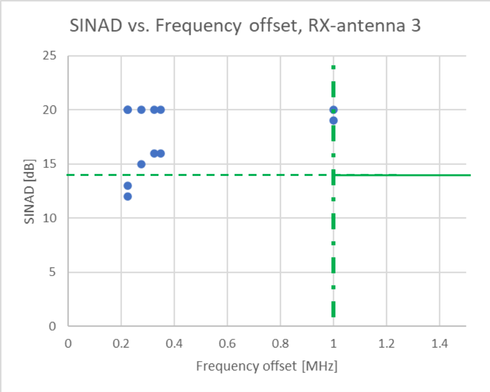

Figure 6.3 SINAD measurements at antenna 3. Receive channel was for all instances was channel 70. The green line indicates the acceptable SINAD degradation according to the maritime standard, but only the region beyond 1 MHz (i.e. to the right of the dot-dashed line) is mandatory by the standard.

6.6 Conclusions maritime radio interference

The interference measurements show that co-located maritime transmissions will not reduce the reception quality for frequency separations of more than 225 kHz, which is far better than the maritime standard specifies (≥ 1 MHz frequency separation). However, as many of the allocated maritime channels have frequency separations less than 225 kHz, in some instances some interference may be observed. Moreover, due to the low ambient background noise level, the receivers enables the reception of vessels at far longer distances than required. Phase noise from collocated transmitters may mask these transmissions, also beyond frequency separations of 225 kHz.

7 Tracking bats in coastal regions and at sea

Bats are tagged in the coastal areas in order to investigate their migration behaviour. Bats are known to fly between the continent and the UK and with the advent of wind turbine parks their behaviour may change. The Wageningen University & Research is investigating any anomalies in the behaviour and life expectancy of migrating Bats and have joined the MOTUS detection system[9], which employs tiny radio transmitters, called “tags”.

The MOTUS detection system utilizes 150.1 MHz to send telemetry from the bat transmitters (tags) to the observation receivers. Along the coastlines of Denmark, Germany, The Netherlands, Belgium and the United Kingdom, hundreds of reception stations monitor and record incoming tag Identifications (IDs). The decoded IDs are send over the internet to a server in Canada and analysed. Each tag ID is unique and can be linked to an individual bat. The weight of a bat tag is very minute: 0.8 gram, which includes the antenna and battery! Obviously very little processing can be implemented, hence a simple pulse sequence is transmitted in short bursts and repeated roughly every 7 seconds. The time separation between the pulses and repetition time is used to create a unique ID.

For reception relatively simple SDR dongles (Software Defined Radio) are employed. The advantage of these receivers is that reception frequency, intermediate frequency filter bandwidth and detection mode can easily be programmed and changed at will. The drawback lies in the limited implementation of hardware filters which determine the RF input bandwidth. The digitisation of the RF signals is usually performed using 8 bit ADC, which determine the dynamic range. Hence, RF strong signals may either overload the input stages of the SDR or push the internal ADC into saturation.

On the Offshore Substation (OSS) Hollandse Kust West Alpha (HKWA) directional reception antennas (Yagi’s) will be installed to decode tagged bats in an area roughly 8 kms around the OSS. The Yagi’s are installed near the top of the communication mast, in a circular patterns covering a 360 degrees angle. In the same communication mast several communication systems are deployed. Maritime radios operate in the 156 to 162.5 MHz band while AIS navigational support uses 162 MHz. The transmit power of the maritime radio systems may be as high as 40 W, while AIS is limited to 12 W. Given the limited RF input filter capabilities of the employed bat reception SDRs, overload may occur during AIS and maritime radio transmissions. Hence, a test was set-up to investigate the sensibility of the bat receivers for transmissions occurring in the frequency band 156.0 to 162.5 MHz.

7.1 Bat transmission tag and receiver set-up

At the Stellendam Offshore Expertise Centre (OEC) the Mock-Up of the HKWA communication mast has been fitted with maritime radios and three Yagi’s for bat reception purposes. The Yagi’s have horizontal polarisation, the omni directional maritime radio antennas are vertically polarised. Based on simulations, isolation values as little as 40 dB were anticipated posing a serious risk of overload of the bat -receivers. Measurements showed that was the case between antenna 4 (maritime radio) and antenna 45 (bat antenna), as the isolation was only 42 dB. Given the transmit power a signal level of approximately 0 dBm (1 mW) was anticipated at the SDR-input.

[9]https://motus.org/

To test whether transmissions of the maritime radios interfere with the bat reception, it's necessary to create a very low signal level for the bat transmitter.
It was not possible to attach an RF cable to the tiny bat transmitter (the tags) and connect it directly to the bat-receiver with sufficient attenuation. Hence two tags were positioned on the windows facing the mock-up at the G-floor of the RWS main building in Stellendam. The RWS main building is situated roughly 500 m from the OEC were the bat-receivers are located. The tags were fixed to the windows in such a way that the IDs could just be received by the bat- receivers. See picture (Figure 7.1) of the tags.

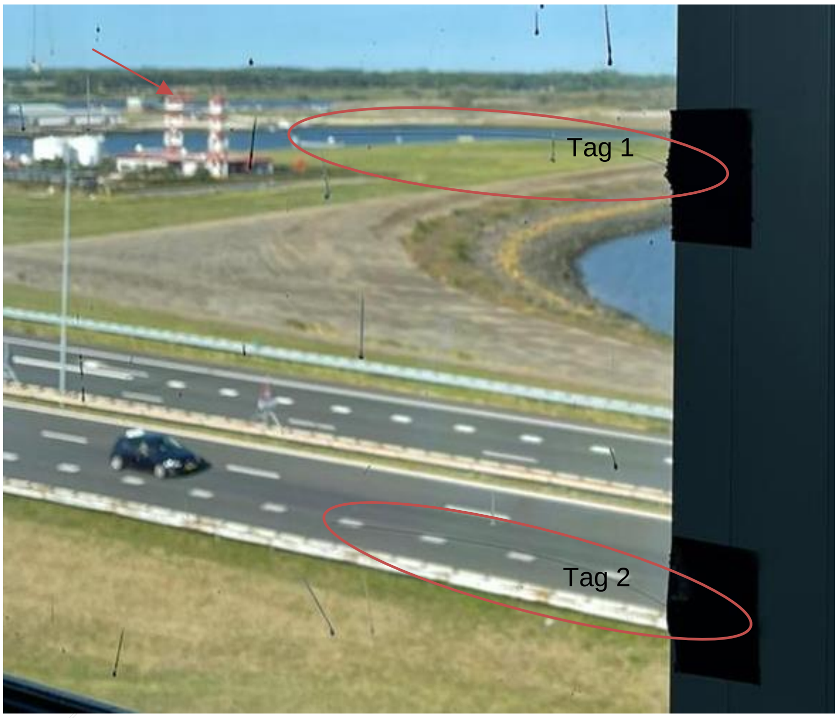

Figure 7.1 Two BAT tags taped to the window frame (#66 and #88). The utter most left red/white painted mast contains the BAT receive equipment.

Tests were conducted observing the reception of tag IDs 66 and 88, which were transmitted at 7.1 s and 8.9 s intervals respectively while transmissions were initiated on various maritime radio channels at the same time.
Custom made bandpass filters were available to be fitted in the reception line, between the bat receive antennas and SDR. See Table 7.1 through 7.3 for results.
Due to the positioning of the 3 Yagi antennas, only antenna 45 received IDs, as it was pointing towards the RWS main building. Antenna 45 is the antenna with the lowest isolation with the maritime antennas, so it also represented a worst-case situation.

Table 7.1 Without RF bandpass filter in front of the bat SDR-receivers

Antenna / Transmitter #	Channel nr.	Tag ID 66	Tag ID 88
No Transmission		√	√
4	90L	-	-
5	23	-	√
4	6	-	-
4	83	-	-
4	23	-	-

Table 7.2 With single RF bandpass filter inserted in the antenna line before the SDR

Antenna / Transmitter #	Channel nr.	Tag ID 66	Tag ID 88
No Transmission		√	√
4	90L	-	√
4	6	-	√
4	83	-	-
4 5	90L *) 23 *)	-	√

*) Simultaneous transmissions

Table 7.3 Two bandpass filters in series, inserted in the antenna line before the SDR

Antenna / Transmitter #	Channel nr.	Tag ID 66	Tag ID 88
No Transmission		√	√
4	90L	-	√
5	23	-	√

7.1.1 *Analysis*

Accurate signal strength data of the individual tags was not available, but it was evident that tag ID 88 had more margin (i.e.: a stronger signal) than tag ID 66. Depending on the used maritime radio transmit channel, both tags suffered from the transmissions. Table 7.1 clearly shows that the use of antenna 4 blocks all receptions of the bat tags. This is in accordance with the measured isolation between the antennas involved.

The differences in signal strength between the two tags can be attributed to discrepancies in their transmit power or specific multipath aspects. The exact cause is hard to determine and not very relevant. However, the fact that two signals with different signal strengths were received provided a better insight in the mechanisms which caused the positive identifications to fail under various circumstances.

The application of filter(s), inserted in the reception line of antenna 45, only improves the reception of tag ID 88, not for tag ID 66. Also the use of a second (identical) filter did not improve the reception of tag ID 66, while overload of the involved SDR was clearly impossible (a total of > 70 dB extra isolation due to the two filters in this measurement, which added to the existing 42 dB isolation between antenna 4 and 45).

Summarizing

The loss of the reception of tag ID 66 is unlikely to be caused by a signal overload, an increase of receiver noise seems a viable cause. To prove this, the noise floor of antenna 45 was determined within the receiver bandwidth for transmitter 4 Off and On.

Noise floor estimation at the bat receive frequency

The noise floor was measured using a ZVL6 spectrum analyser, preceded by 2 low noise amplifiers in order to improve its noise floor. Two bat RF-filters were placed in front of the first LNA to prevent any risk of overload by the transmitters operating in the maritime band.

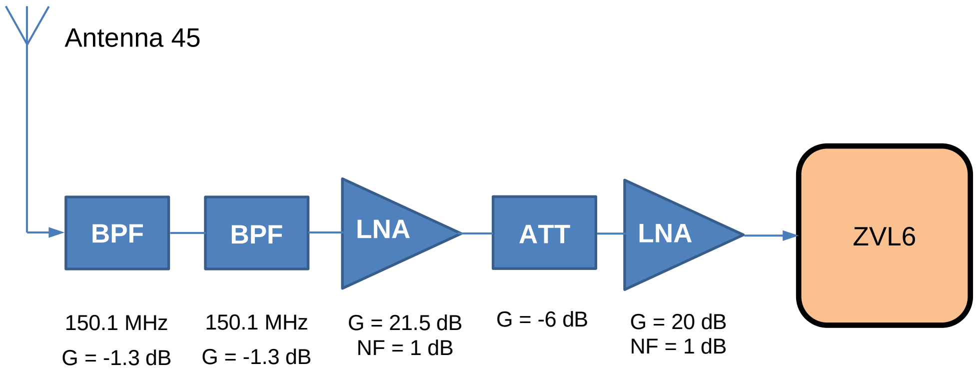

Figure 7.2 Noise floor measurement set-up

Using a 50 Ohm reference load, the noise floor at 290 K was established to be approximately -87.5 dBm in a 100 kHz Resolution Bandwidth (Figure 7.3). This is a relative level to be used as reference for the levels observed in

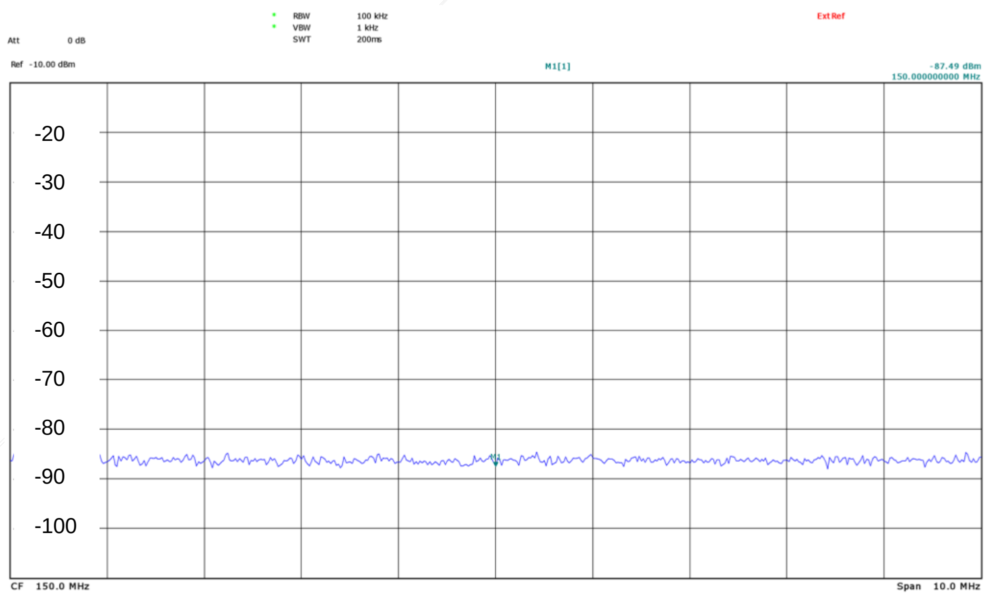

Figure 7.3 Noise floor with antenna 45 substituted by a 50 Ohm load. Centre frequency: 150 MHz, span: 10 MHz, RBW: 100 kHz, VBW: 1 kHz

The results of the noise measurements made it absolutely clear what caused the loss of the reception of tag 66 ID: Wide band (Phase) noise emanating from the transmitter attached to antenna 4, as can be seen from the pictures in

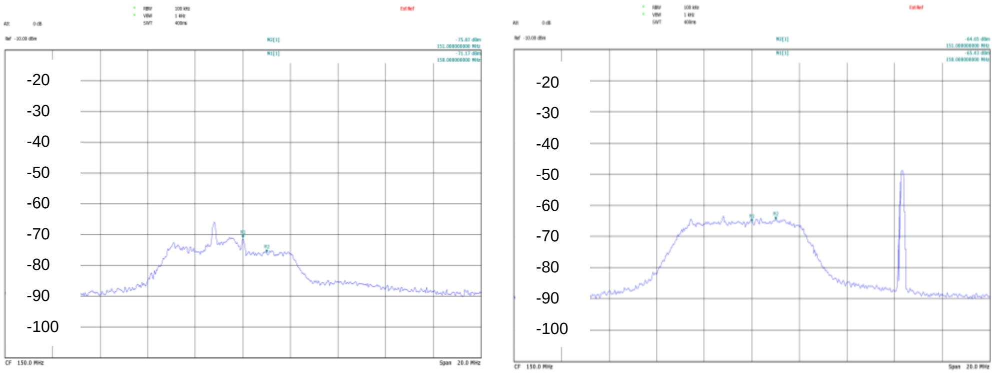

Figure 7.4 Left hand side: Maritime transmitter Off, Right hand side transmitter is On (antenna 4). Centre frequency: 150 MHz, span: 20 MHz, RBW: 100 kHz, VBW: 1 kHz

Figure 4, left hand side
Given the 290 K reference noise level on the spectrum analyser equalling a signal level of -87.5 dBm, the background noise in Stellendam on antenna 45, is -75,9 dBm, which equals 11.6 $dBkT_0$. This is slightly higher than earlier observed in other measurements in Stellendam. Some distinct sources of noise, either at the OEC or off-site are present as well, which cause a slight noise increase and distinct “bumps”.

Figure 4, right hand side
Activation of transmitter 1, attached to antenna 4 shows a significant noise increase. A noise increment of > 10 dB is observed, which clearly demonstrates the cause of the reception issues with tag ID 66.

Wide band (phase) noise originating from a transmitter can be combatted by increasing the isolation between antennas (e.g.: transmit and/or receive antennas with cleaner patterns), placing RF filters between the transmitter and antenna (limiting its noise bandwidth) or improvements of the transmitter (phase) noise properties.

7.2 Bat tag reception conclusions

The addition of RF bandpass filters in front of the bat SDR receivers effectively prevents overload of these receivers by maritime transmitters, increasing the reliability while maritime transmissions may occur simultaneously.

During transmissions from the maritime transmitters, wide band (phase) noise may however increase the noise floor of bat receivers, in spite of the RF bandpass filters placed in front of the bat receivers, causing a decrease of the reception of weak bat tags.

Reduction of transmitter (phase) noise is not easily accomplished unless different equipment is used.
Installing transmitter bandpass filters would solve the transmitter noise issues but would be fairly expensive and may limit the frequency usage of the maritime transmitters.

The use of bat receive antennas with a cleaner radiation pattern, may improve the isolation with the maritime radio transmitters, hence decreasing the noise emanating from antenna 4.
The present installed antennas during the measurements (Sirio) will be replaced for rugged off-shore capable antennas, TNO has advised for an antenna with improved radiation characteristics.

8 Conclusions

In August 2022 at the Off-Shore Expertise Centre in Stellendam, measurements were conducted on the proposed HKWA-mast. Isolation and interference tests between similar communication systems were performed.

The interference results obtained in Stellendam, have been performed under noise conditions which provide a SINAD of 20 dB at a signal level of -101 dBm, as ordained by the maritime standard as minimum signal level.

Based on the simulations and measurements, it is advised to limit the transmit power supplied to antennas 4 and 5 according to Table 8.1.

Table 8.1 Recommended power settings for the maritime radios

System	Antenna nr.	Maximum Power (W / dBm)
Marine radio1	**4**	**12 / +41**
Marine radio2	**5**	**12 / +41**
Marine radios 1&2, Ch. 90L	**4 & 5**	**3 / +35**
AIS	**13**	**12 / +41**

Due to the better sensitivity of maritime radios and low ambient noise on an OSS, contacts with ships far outside the anticipated coverage area may occur. Signal levels as low as -111 dBm may produce good quality audio, i.e. SINADs ≥ 20 dB. Those contacts may be compromised by the phase noise of transmissions of any of the co-sited marine transmitters. This could be interpreted as "non-compliant", but is due to the effect of low ambient noise in combination with the phase noise emanating from the transmitters.

The isolation between the marine transmitter antennas is relatively poor, hence an RF-isolator is strongly recommended to be inserted at the AIS (antenna 13) and marine transmitter 2 (antenna 5). This will eliminate possible intermodulation effects.

At time of measurements (August '22) the WPO was not known, hence TETRA (or DMR), nor RTK, nor SDNS were incorporated in the campaign. Depending on the requirements of the WPO, additional simulations and possibly measurements in Stellendam will have to be considered.

9 Appendix 1

Figure 9.1 shows the measurement set-up for the SINAD interference tests, and the initial values for the Stellendam environment. An artificial noise level is added to the environmental noise in order to obtain a 20 dB SINAD level given a reference signal of -101 dBm.

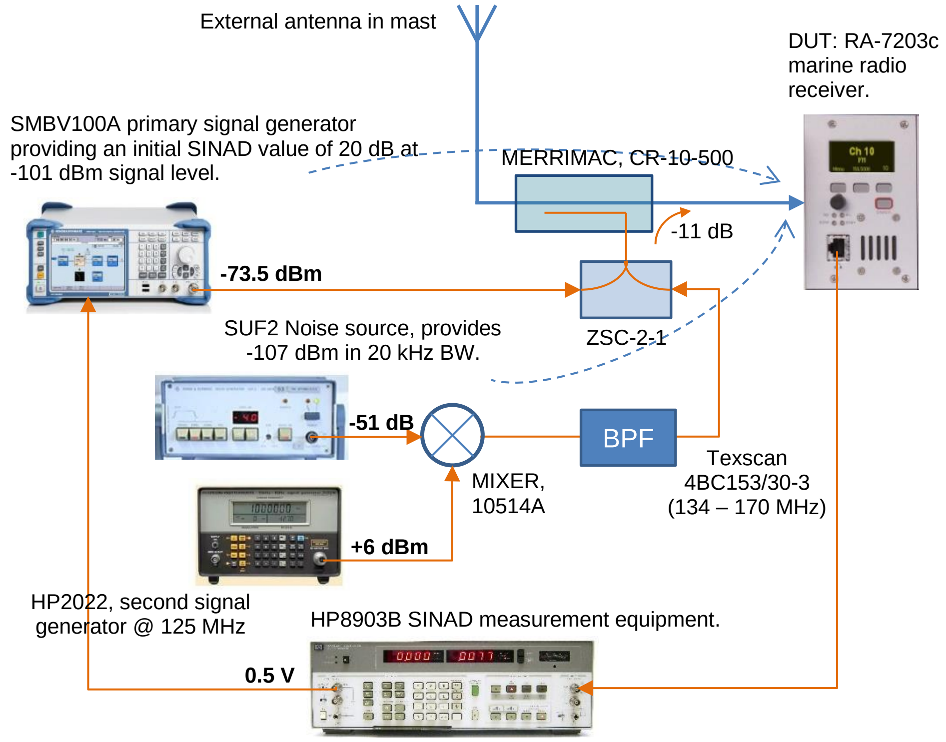

Figure 9.1 Interference measurement set-up for future Mock-Up tests.

For cable lengths between the individual pieces of equipment less than 2 metres these values are valid to run measurements on site, given a warm-up period of 30 minutes. When cable runs are required which are > 2 metres, the individual losses should be determined and noted in the log book, or compensated in the measurements.

The noise level at the DUT should be set to -107 dBm (in 20 kHz BW), the reference level to -101 dB, in order to get an initial SINAD of 20 dB. The settings provided in the table should accomplish this.

Table 9.1 Equipment settings for on-site interference measurements

Type	Purpose	Settings
SMBV100A	Signal Generator, produces reference signal	FM, 3 kHz deviation, -73.5 dBm
Merrimac, CR10-500	Directional coupler	
SUF2	Generate Noise Floor in order to fulfil standard req.	-51 dB, 50 MHz BW setting
4BC153/30-3	Band pass Filter, 134-170 MHz> suppresses unwanted mixing products.	
HP2022	Signal generator to convert 0-50 MHz noise to 125-175 MHz band	125 MHz, modulation OFF, +6 dBm RF level
10514A	MIXER	
ZSC-2-1	3 dB splitter/combiner	
HP8903B	SINAD measurements	SINAD, Amplitude: 0.5V, CCITT=ON, 1000 Hz

Prior to any interference measurement, the system should be tuned to the appropriate SINAD level of 20 dB by changing the noise settings of the SUF2, not by changing the signal level of the SMBV100A.

10 Appendix 2

This appendix provides the tables with the individual interference measurement results between the maritime transmitters and the receivers attached to antennas 1, 2 and 3.

10.1.1 Receiver 1 connected to antenna 1

Table 10.1 Rx: Antenna 1, Channel 6, Freq. 156.300 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	*SINAD (dB)*
Antenna 5 is paired with TX-antenna 2				
5	15	156.750	0.450	*20*
5	16	156.800	0.500	*20*
5	17	156.850	0.550	*21*
5	23	161.750	5.450	*21*
5	70	156.525	0.225	*19*
5	77	156.875	0.575	*20*
5	83	161.775	5.475	*21*
5	90L	157.525	1.225	21

Table 10.2 Rx: Antenna 1, Channel 15, Freq. 156.750 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.450	20
5	16	156.800	0.050	2
5	17	156.850	0.100	6
5	23	161.750	5.000	21
5	70	156.525	0.225	18
5	77	156.875	0.125	10
5	83	161.775	5.025	21
5	90L	157.525	1.175	21

Table 10.3 Rx: Antenna 1, Channel 16, Freq. 156.800 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.500	20
5	15	156.750	0.050	2
5	17	156.850	0.050	2
5	23	161.750	4.950	21
5	70	156.525	0.275	18
5	77	156.875	0.075	2
5	83	161.775	4.975	21
5	90L	157.525	0.725	20

Table 10.4 Rx: Antenna 1, Channel 17, Freq. 156.850 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.550	20
5	15	156.750	0.100	6
5	16	156.800	0.050	2
5	23	161.750	4.900	21
5	70	156.525	0.325	19
5	77	156.875	0.025	2
5	83	161.775	4.925	21
5	90L	157.525	0.675	21

Table 10.5 Rx: Antenna 1, Channel 23, Freq. 157.150 MHz, Duplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.850	21
5	15	156.750	0.400	20
5	16	156.800	0.350	19
5	17	156.850	0.400	18
5	70	156.525	0.625	20
5	77	156.875	0.275	17
5	83	161.775	4.625	21
5	90L	157.525	0.375	18

Table 10.6 Rx: Antenna 1, Channel 70, Freq. 156.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.225	17
5	15	156.750	0.225	18
5	16	156.800	0.275	18
5	17	156.850	0.325	19
5	23	161.750	5.325	21
5	77	156.875	0.350	20
5	83	161.775	5.250	21
5	90L	157.525	1.000	20

Table 10.7 Rx: Antenna 1, Channel 77, Freq. 156.875 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.575	20
5	15	156.750	0.125	10
5	16	156.800	0.075	3
5	17	156.850	0.025	2
5	23	161.750	4.875	21
5	70	156.525	0.350	19
5	83	161.775	4.900	21
5	90L	157.525	0.650	20

Table 10.8 Rx: Antenna 1, Channel 83, Freq. 157.175 MHz, Duplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
5	6	156.300	0.875	20
5	15	156.750	0.425	20
5	16	156.800	0.375	20
5	17	156.850	0.425	19
5	23	161.750	4.575	21
5	70	156.525	0.650	20
5	77	156.875	0.300	19
5	90L	157.525	0.350	19

Table 10.9 Rx: Antenna 1, Channel 90L, Freq. 157.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 5 is paired with TX-antenna 2				
4	6	156.300	1.225	21
4	15	156.750	0.775	21
4	16	156.800	0.725	20
4	17	156.850	0.675	20
4	23	161.750	4.225	21
4	70	156.525	1.000	20
4	77	156.875	0.650	20
4	83	161.775	4.250	21

10.1.2 *Receiver 2 connected to antenna 2*

Table 10.10 Rx: Antenna 2, Channel 6, Freq. 156.300 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	15	156.750	0.450	21
4	16	156.800	0.500	21
4	17	156.850	0.550	21
4	23	161.750	5.450	21
4	70	156.525	0.225	15
4	77	156.875	0.575	20
4	83	161.775	5.475	21
4	90L	157.525	1.225	21

Table 10.11 Rx: Antenna 2, Channel 15, Freq. 156.750 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.450	20
4	16	156.800	0.050	2
4	17	156.850	0.100	10
4	23	161.750	5.000	21
4	70	156.525	0.225	19
4	77	156.875	0.125	16
4	83	161.775	5.025	22
4	90L	157.525	1.175	21

Table 10.12 Rx: Antenna 2, Channel 16, Freq. 156.800 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.500	21
4	15	156.750	0.050	3
4	17	156.850	0.050	2
4	23	161.750	4.950	21
4	70	156.525	0.275	21
4	77	156.875	0.075	5
4	83	161.775	4.975	21
4	90L	157.525	0.725	21

Table 10.13 Rx: Antenna 2, Channel 17, Freq. 156.850 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.550	21
4	15	156.750	0.100	14
4	16	156.800	0.050	6
4	23	161.750	4.900	21
4	70	156.525	0.325	21
4	77	156.875	0.025	2
4	83	161.775	4.925	21
4	90L	157.525	0.675	20

Table 10.14 Rx: Antenna 2, Channel 23, Freq. 157.150 MHz, Duplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.850	21
4	15	156.750	0.400	21
4	16	156.800	0.350	20
4	17	156.850	0.400	20
4	70	156.525	0.625	21
4	77	156.875	0.275	20
4	83	161.775	4.625	21
4	90L	157.525	0.375	20

Table 10.15 Rx: Antenna 2, Channel 70, Freq. 156.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.225	19
4	15	156.750	0.225	20
4	16	156.800	0.275	20
4	17	156.850	0.325	20
4	23	161.750	5.325	21
4	77	156.875	0.350	20
4	83	161.775	5.250	21
4	90L	157.525	1.000	21

Table 10.16 Rx: Antenna 2, Channel 77, Freq. 156.875 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.575	21
4	15	156.750	0.125	17
4	16	156.800	0.075	9
4	17	156.850	0.025	2
4	23	161.750	4.875	21
4	70	156.525	0.350	21
4	83	161.775	4.900	21
4	90L	157.525	0.650	21

Table 10.17 Rx: Antenna 2, Channel 83, Freq. 157.175 MHz, Duplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	0.875	21
4	15	156.750	0.425	21
4	16	156.800	0.375	21
4	17	156.850	0.425	21
4	23	161.750	4.575	21
4	70	156.525	0.650	20
4	77	156.875	0.300	21
4	90L	157.525	0.350	21

Table 10.18 Rx: Antenna 2, Channel 90L, Freq. 157.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 4 is paired with TX-antenna 1				
4	6	156.300	1.225	21
4	15	156.750	0.775	21
4	16	156.800	0.725	21
4	17	156.850	0.675	21
4	23	161.750	4.225	21
4	70	156.525	1.000	21
4	77	156.875	0.650	21
4	83	161.775	4.250	21

10.1.3 Receiver 3 connected to antenna 3

Table 10.19 Rx: Antenna 3, Channel 70, Freq. 156.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD (dB)
Antenna 3 is not paired with a specific antenna				
4	6	156.300	0.225	13
4	15	156.750	0.225	12
4	16	156.800	0.275	15
4	17	156.850	0.325	16
4	23	161.750	5.225	20
4	77	156.875	0.350	16
4	83	161.775	5.250	20
4	90L	157.525	1.000	19

Table 10.20 Rx: Antenna 3, Channel 70, Freq. 156.525 MHz, Simplex

TX-antenna	Channel	Frequency (MHz)	Δf (MHz)	SINAD(dB)
Antenna 3 is not paired with a specific antenna				
5	6	156.300	0.225	20
5	15	156.750	0.225	20
5	16	156.800	0.275	20
5	17	156.850	0.325	20
5	23	161.750	5.225	20
5	77	156.875	0.350	20
5	83	161.775	5.250	20
5	90L	157.525	1.000	20