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Maritime coverage and interoperability calculations of HKWA

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Contents

1 Introduction

The initial version of this document was based on the assumption that the wind park owner would not would not require marine radio VHF communication. All simulations and interference measurements in Stellendam were based on this assumption. However, the selected wind park owner required VHF communication, which demanded a major adaption of the antenna configuration on decks 1 and 5. Given the time frame no new interference measurements were possible in Stellendam, hence all figures are based on theoretical simulations (July/August 2023)

In this document the coverage of communication and navigation systems will be presented for Hollandse Kust West Alpha (HKWA, lot VI).

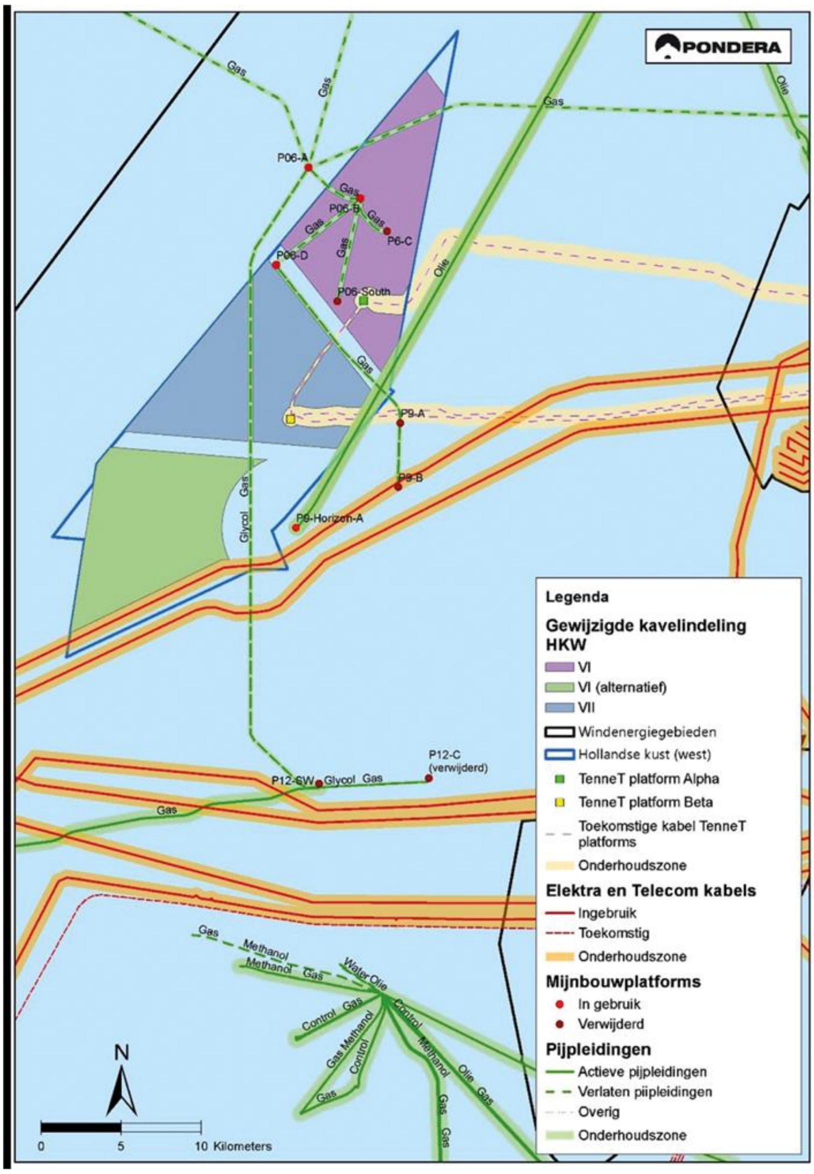

Figure 1.1 Hollandse Kust West, lot 6 and 7. The purple area denote wind field 6. i.e.: “Alpha” (taken from Staatscourant 2022-4381).

Coverage and Isolation calculations are presented for systems operating on VHF and UHF (i.e.: Marine radio, AIS, TETRA, LoRa, RTK and SDNS). The coverage requirements have been provided by RWS[1]. Regarding marine radio, calculations and simulations have been conducted for receive signal strengths of -80, -90 and -100 dBm (equalling a very good, good and sufficient signal level for maritime communication, respectively). The results are presented in coverage performance figures. The aim is to provide at least -90 dBm, preferably -80 dBm signal levels throughout the entire HKWA wind park. For DMR a signal level of -85 dBm has been used, with a handheld device as target communication object. LoRa may operate under very low signal levels (down to -148 dBm), while SDNS picks up air plane location information at -90 dBm signal levels. RTK provides correction signals for GNSS, which improves GPS accuracy. Coverages maps for LoRa, SDNS and RTK are provided.
All coverage areas have been calculated based on the available transmitter power in the HKWA mast. This depends on the obtained isolation between transmitters and receivers operating in the same band. This isolation is the key factor to determine whether full transmit power may be used, or a reduction is required in order to protect reception. This will be explained in chapter 3.
The actual height of the antennas at the platform varies between 50 m and 65 m above sea level (a.s.l.). Partnering systems are expected either to be allocated on ships (6 m a.s.l.), near to the sea (2.5 m a.s.l.) or on a Turbine (18.5 m a.s.l.).

In August 2022 interference measurements have been conducted in Stellendam at the Off shore Expertise Centre (OEC). The results are published in report “Interference measurements HKWA mast at Stellendam”.

[1] MEMO: Functionele specificaties nautische voorzieningen voor de windparken Hollandse Kust Noord en Hollandse Kust Zuid, RWS 11 juni 2019

2 Antenna positions on HKWA mast

At time of writing of this version of the report, the WPO was not known. Hence, based on assumptions from RWS and TNO regarding the anticipated systems, an antenna configuration has been proposed. This configuration has been the basis for the simulations, conclusions and recommendations throughout this report.
Table 2.1 provides an overview of all the VHF and UHF communication and navigation antennas, their application and antenna types, except RADAR[2]. The antenna numbering has been aligned for as much as possible with the former platforms (i.e.: BSA, BSB, HKZA and HKZB).

Table 2.1 *Overview of antenna, height and position of the Antennas in the mast.*

			Antenna positions[3]					
Ant. nr	**Unique Equipment Code**	**Anten na height [mm]**	**X [mm]**	**Y [mm]**	**Z [m][4]**	**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	450	3950	15.6	5	Maritime radio, RX3 (DSC) Procom CXL 2-1	TNT
4	S04-TNT-VHF-04	1300	2200	-500	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
6	S61-ECW-VHF-01	1300	2000	-2300	15.6	5	Maritime radio, RX1 Procom CXL 2-1	ECW
7	S61-ECW-VHF-02	1300	1870	1870	15.6	5	Maritime radio, RX2 Procom CXL 2-1	ECW
9	S61-ECW-VHF-03	1300	2000	-2300	5.1		Maritime radio, TX1 Procom CXL 2-1	ECW
10	S61-ECW-VHF-04	1300	1100	1100	5.1		Maritime radio, TX2 Procom CXL 2-1	ECW
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
23	S31-RWS-AIS-03	120	-1900	500	15.6	5	AIS1, GPS Synergy systems VIC-100	RWS
17	S60-ECW-TTR-01	500	100	2700	10.4	3	TETRA1, RX Procom CXL 70-3HD	ECW
18	S60-ECW-TTR-02	500	150	2750	5.1	1	TETRA1, TX&RX Procom CXL 70-3HD	ECW
21	S60-ECW-TTR-03	120	1100	1100	10.4	3	TETRA1, GPS Synergy systems VIC-100	ECW
20	Sxx-xxx-TTR-04	500	850	-2700	10.4	3	TETRA2, RX Procom CXL 70-3HD	ECW
28	Sxx-xxx-TTR-05	500	850	-2700	5.1	1	TETRA2, TX&RX Procom CXL 70-3HD	ECW
22	Sxx-xxx-TTR-06	120	-2150	500	10.4	(3)	TETRA2, GPS Synergy systems VIC-100	ECW
25	S58-RWS-LRA-01A	620	2500	-250	7.9	2	LoRa	RWS

[2] Memorandum Arne Theil DHW-2021-RT-100340904 , 27 July 2021.
[3] The x-, y- and z-positions refer to the centre of the stairs in the mast.
[4] Base mounting height of the antenna on the Bracket.

							ANT-OMNI-868-01	
12	S59-EXT-LRA-01	620	-250	2400	7.9	2	LoRa ANT-OMNI-868-01	EXT
37a	S45-LVN-MSS-01	120	-2010	-1400	7.9	2	SDNS1	LVN
37b	S45-LVN-MSS-02	120			7.9	2	GPS	LVN
37c	S45-LVN-MSS-03	120	1650	-2150	7.9	2	SDNS2	LVN
37d	S45-LVN-MSS-04	120	-2150	1650	7.9	2	SDNS3	LVN
40	S49-RWS-TBS-01	80	-270	2400	13	4	BAT telemetry RX Laird Y1505_115	RWS
41	S49-RWS-TBS-02	80	-2160	1000	13	4	BAT telemetry RX Laird Y1505_115	RWS
42	S49-RWS-TBS-03	80	-1650	-1850	13	4	BAT telemetry RX Laird Y1505_115	RWS
47	S49-RWS-TBS-04	120	-1660	1000	13	4	BAT GPS1 Synergy systems VIC-100	RWS
43	S49-RWS-TBS-05	80	900	-2160	13	4	BAT telemetry RX Laird Y1505_115	RWS
44	S49-RWS-TBS-06	80	2400	-270	13	4	BAT telemetry RX Laird Y1505_115	RWS
45	S49-RWS-TBS-07	80	1090	1090	13	4	BAT telemetry RX Laird Y1505_115	RWS
48	S49-RWS-TBS-08	120	900	-1660	13	4	BAT GPS2 Synergy systems VIC-100	RWS

*) Antenna 37 consists of an SDNS- and GPS-part in a single enclosure, formerly designated as 37a and 37b.

RWS = Rijkswaterstaat, EXT = External party, ECW = Ecowende, LVN = Luchtverkeersleiding Nederland, TNT = TenneT.

The relationship between communication systems, specifically with GPS, is presented in Table 2.2.

Table 2.2 Antenna pairs and GPS designations

Purpose	**RX-antenna**	**TX-antenna**	**GPS-antenna**	**User**
VHF Marine TNT 1	1	4		TNT
VHF Marine TNT 2	2	5		TNT
VHF Marine TNT 3 (DSC)	3			TNT
VHF Marine ECW 1	6	9		ECW
VHF Marine ECW 2	7	10		ECW
VHF Marine ECW 3 (DSC)	7			ECW
AIS1	14	13	23	RWS
LoRa	25	25		RWS
LoRa EXT	12	12		EXT
TETRA1	17	18	21	ECW
TETRA1	18	18	21	ECW
TETRA2	20	28	22	ECW
TETRA2	28	28	22	ECW
SDNS1	37a		37b	LVN
SDNS2	37c		37b	LVN
SDNS3	37d		37b	LVN
BAT telemetry receiver	40			RWS
BAT telemetry receiver	41			RWS
BAT telemetry receiver	42			RWS
BAT telemetry receiver	43			RWS

BAT telemetry receiver	44		47[5]	RWS
BAT telemetry receiver	45		48	RWS

[5] Both GPS antennas 47 and 48 are for the general BAT- reception set-up, not RX-antennas 44 and 45 specifically.

3 Antenna mast model

The HKWA-mast has a similar height as previously used at HKZA&B and the Borssele OSSs. The stairs are running all the way from bottom to top, contrary to the HKZB mast design.
For VHF marine communication and AIS navigation/location multiple systems may be running in the same frequency band at the same time. When transmit and receive antennas from different systems are near one another the isolation is low and this neighbouring receiver may get overloaded. Increased isolation will enable that multiple systems can operate without causing problems on co-sited receive systems. The starting point is to physically separate transmit and receive antennas as much as possible. In general the receive antennas are placed on the top decks, transmit antennas on lower decks.

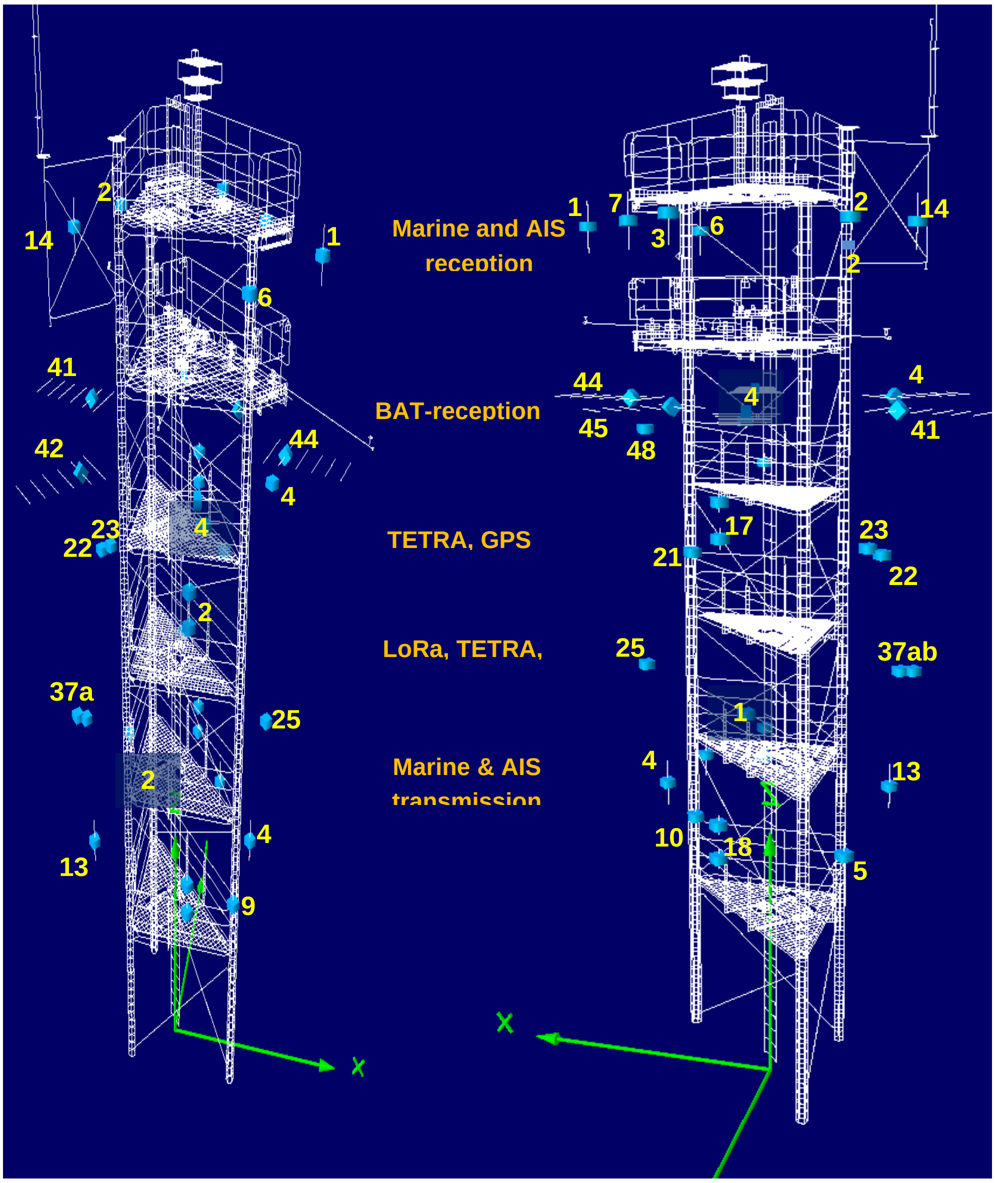

Figure 3.1 provides the final positions of the antennas. The exact mounting details of the antennas can be found in Chapter 8, appendix 2.

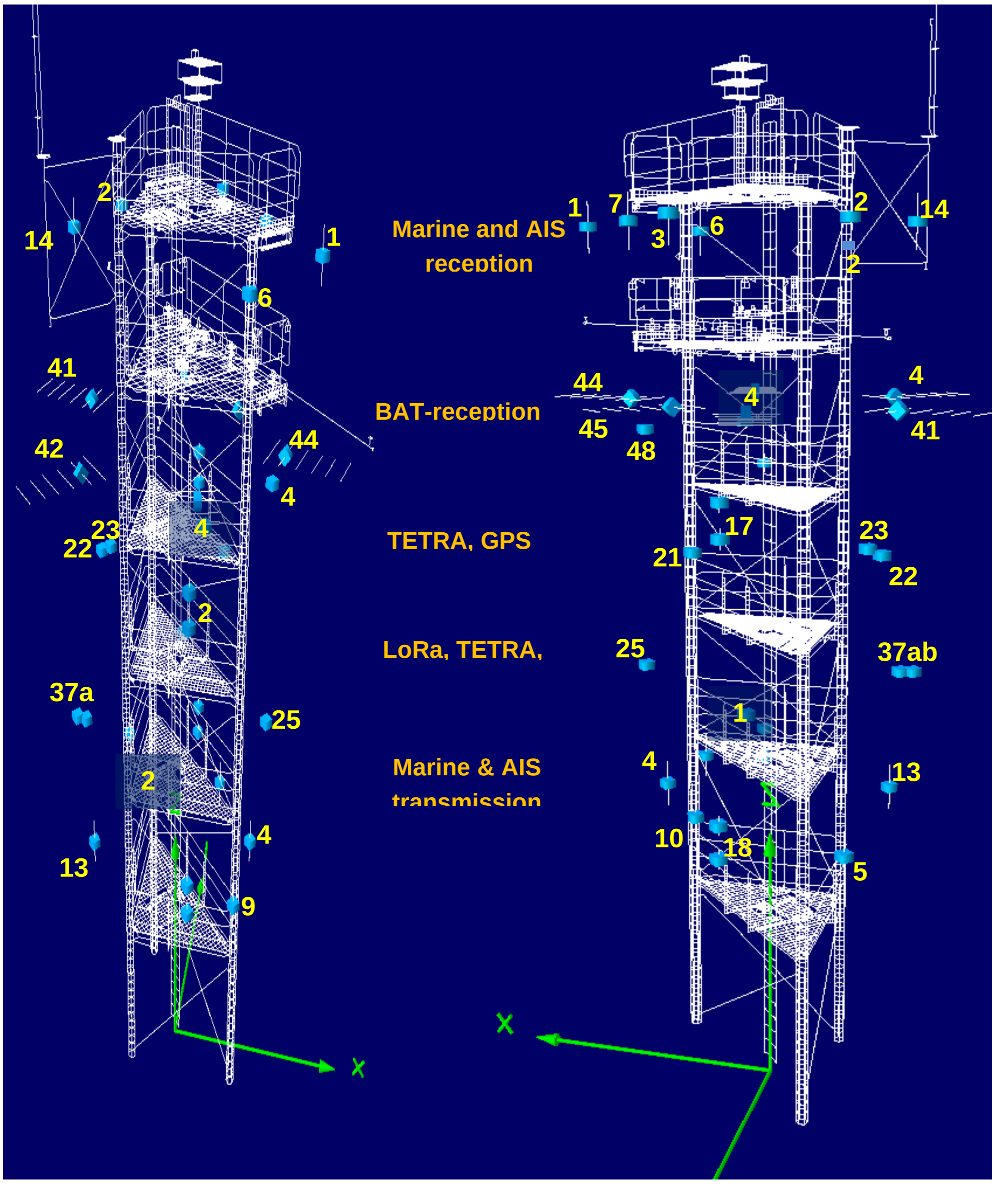

Figure 3.1 HKWA mast and antenna numbering, according to Table 2.1.

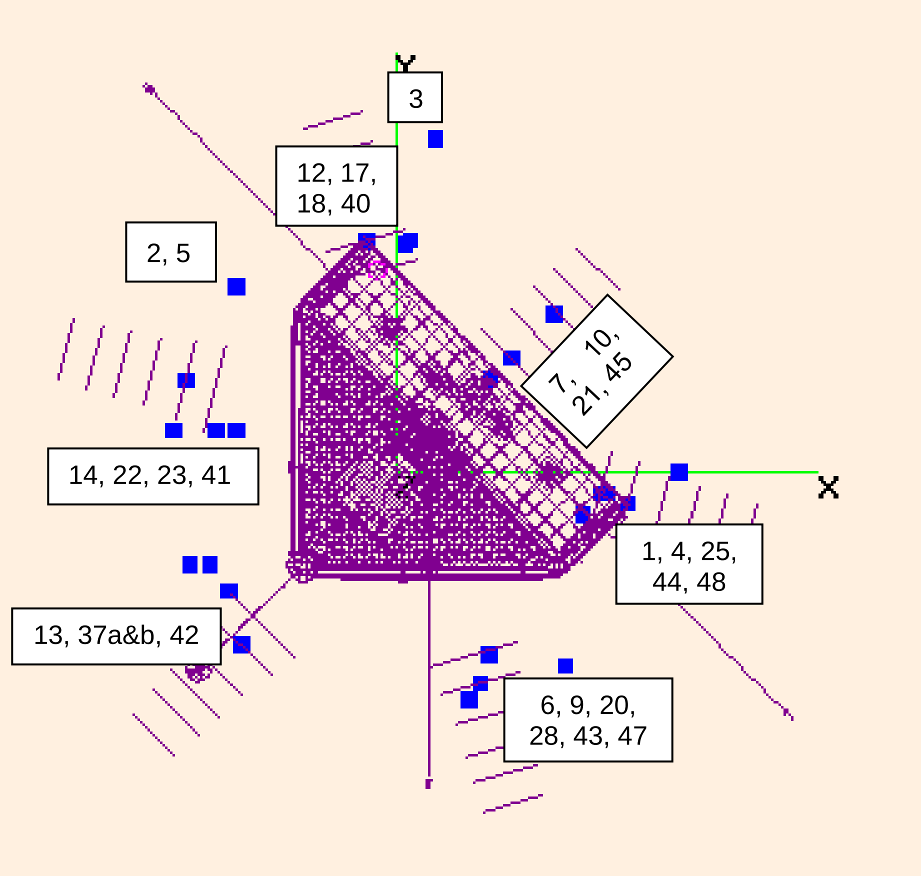

Figure 3.2 Top View of the HKWA mast. The numbers indicate the TNO antenna designation.

4 Isolation between antennas

Addendum, August 2023
After the design phase and the mock-up measurements, it was decided that Ecowende required marine radios. Hence, the antenna plan was changed, but it was not possible to repeat the interference measurements in Stellendam. The marine radio power levels will be solely based on (new) simulation results.

Determination of the mutual isolation between antennas is important in order to asses possible negative influences on receivers and transmitters. Of main concern is desensitisation of receivers due to the presence of other (in-band) transmitters.
All possible coupling paths between antennas have been calculated. Initially a rough scheme of antenna positions was used, which along the optimization process was fine tuned for optimal isolation and in order to obtain the required coverage performance.
The isolation (decoupling) between a transmitter and all receivers will be shown in this chapter as well as the isolation between transmitters operating in the same frequency band. An extensive list of all possible coupling values can be found in Appendix 1.

4.1 Marine radios and AIS

The standard for Marine qualified radio's depicts a minimum desensitization point of **-12 dBm[6].** This sets the signal strength of an unwanted in-band signal at which the SINAD of the receiver has decreased by 6 dB. Given the maximum possible EIRP[7] of +46 dBm for marine radios and +41 dBm for AIS, the isolation between transmitter and receiver has to be at least 58 respectively 53 dB. When lower transmit power levels are employed for in-band radio's, an equal reduction in the required isolation between the antennas level may be applied. If the coverage area is sufficiently large, a recommendation will be made for an additional 3 dB power reduction, which should improve the reception of weak signals at small frequency offsets. Hence initial isolation values of 61 and 56 dB will be used, referenced to the maximum power level of 46 respectively 41 dBm.

This should be validated based on the interference and decoupling measurements which will be conducted on the mock-up at the OEC in Stellendam.

In Table 4.1 to Table 4.8 the simulated isolation between the antennas are shown. Values less than 61 dB (AIS: 56 dB) which concern the same frequency band have been marked orange as a reduction from the maximum possible transmitter power setting may be required. The tables show the simulated isolation values, of which the most stringent (= lowest) isolation values should be used to determine the power level for that specific transmitter.

[6] EN301929
[7] Effective Isotropic Radiated Power

4.2 BAT receive antennas

For telemetry purposes six horizontally polarised antennas are projected to become operational at some moment in time. These antennas will be situated on deck 4. The operating frequency of the BAT-systems is 150.1 MHz, which is just a few MHz below the marine radio and AIS-transmitters (156 - 163 MHz). According to the simulations the lowest decoupling values are approximately 47 dB (antenna 4, transmitting at 41 dBm), which would amount to a signal level of -6 dBm at the BAT-receiver input. Such level will very likely cause a strong detrimental effect on the reception properties. Opposed to the marine- and AIS-systems where power reductions may be imposed in order to provide simultaneous operations, such measures cannot be applied to mitigate desensitization effects on the BAT-receivers. Additional band pass filtering must be added to the front-end of the BAT-receivers in order to guarantee proper operation.

4.3 Required power reductions and simulated isolation values for VHF

On the mast there is a distinct separation between some applications. For example, marine radio and TETRA operate in entirely different frequency bands. On the other hand, marine radio, AIS and BAT receivers, all operate in the same band. The required isolation values are much easier achieved between different bands due to the default receive filters or otherwise may be improved using additional band filters.

In the tables presented on the next pages, the emphasis is on VHF systems which use the same band. Isolation between different bands is treated differently, i.e. only when isolation levels are very low, there will be a note of possible additional requirements which may have to be implemented.

Table 4.1 Isolation between TX antenna 4 (TenneT marine radio) and all other antennas operating in the same band (150 – 164 MHz). Antenna 1 is not considered as it is the RX-antenna of this particular system.

Ant. nr.	**Application**	**Isolation [dB]**		**Req. power reduction [dB]**		**TX ANT4 for no sensitivity loss [W // dBm]**
		Simul.	**Meas.**			
ANT2	Marine RX	57		4		
ANT3	Marine RX	76				12.5 / +41
ANT5	Marine TX	40				
ANT6	Marine RX	56		5		
ANT7	Marine RX	54		**7**		
ANT9	Marine TX	20				Insert an isolator
ANT10	Marine TX	21				Insert an isolator
ANT14	AIS1 RX	62				
ANT13	AIS1 TX	37				Insert an isolator
ANT40	BAT1	61				
ANT41	BAT2	67				
ANT42	BAT3	73				
ANT43	BAT4	79				
ANT44	BAT5	85				
ANT45	BAT6	91				

*) Additional band filtering is required to prevent saturation of the BAT receivers. Values between brackets indicate the extra attenuation due to the input bandpass filter.

Based on the simulated isolation values, the power level applied to antenna 4 should be decreased by 7 dB, i.e. a power level of +39 dBm.

Table 4.2 Isolation between TX antenna 5 (TenneT marine radio) and all other antennas operating in the same band (150 – 164 MHz). Antenna 2 is not considered as it is the RX-antenna of this particular system.

Ant. nr.	Application	Isolation [dB]		Req. power reduction [dB]		TX ANT5 for no sensitivity loss [W // dBm]
		Simul.	Meas.			
ANT1	Marine RX	50		11		
ANT3	Marine RX	58		3		
ANT4	Marine TX	41				
ANT6	Marine RX	90				
ANT7	Marine RX	65				
ANT9	Marine TX	43				
ANT10	Marine TX	44				
ANT14	AIS1 RX	52		9		
ANT13	AIS1 TX	23				Insert isolator
ANT40	BAT1	57		*)		
ANT41	BAT2	54		*)		
ANT42	BAT3	58		*)		
ANT43	BAT4	60		*)		
ANT44	BAT5	53		*)		
ANT45	BAT6	53		*)		

*) Additional band filtering is required to prevent saturation of the BAT receivers

Based on the simulated isolation values, the power level applied to antenna 9 should be decreased by 11 dB, i.e. a power level of +35 dBm.

Table 4.3 Isolation between TX antenna 9 (Ecowende marine radio) and all other antennas operating in the same band (150 – 164 MHz). Antenna 6 is not considered as it is the RX-antenna of this particular system.

Ant. nr.	Application	Isolation [dB]		Req. power reduction [dB]		TX ANT9 for no sensitivity loss [W // dBm]
		Simul.	Meas.			
ANT1	Marine RX	54		7		
ANT2	Marine RX	66				
ANT3	Marine RX	52		9		
ANT4	Marine TX	20				Insert isolator
ANT5	Marine TX	42				
ANT7	Marine RX	56		5		
ANT10	Marine TX	30				Insert isolator
ANT14	AIS1 RX	55		6		
ANT13	AIS1 TX	28				Insert isolator
ANT40	BAT1	52		*)		
ANT41	BAT2	55		*)		

ANT42	BAT3	59		*)		
ANT43	BAT4	54		*)		
ANT44	BAT5	57		*)		
ANT45	BAT6	63		*)		

*) Additional band filtering is required to prevent saturation of the BAT receivers

Based on the simulated isolation values, the power level applied to antenna 5 should be decreased by 9 dB, i.e. a power level of +37 dBm.

Table 4.4 Isolation between TX antenna 10 (Ecowende marine radio) and all other antennas operating in the same band (150 – 164 MHz). Antenna 7 is not considered as it is the RX-antenna of this particular system.

Ant. nr.	**Application**	**Isolation [dB]**		**Req. power reduction [dB]**		**TX ANT9 for no sensitivity loss [W // dBm]**
		Simul.	**Meas.**			
ANT1	Marine RX	77				
ANT2	Marine RX	58		3		
ANT3	Marine RX	77				
ANT4	Marine TX	23				Insert isolator
ANT5	Marine TX	26				Insert isolator
ANT6	Marine RX	64				
ANT9	Marine TX	33				Insert isolator
ANT14	AIS1 RX	54		7		
ANT13	AIS1 TX	38				Insert isolator
ANT40	BAT1	55		*)		
ANT41	BAT2	55		*)		
ANT42	BAT3	79		*)		
ANT43	BAT4	57		*)		
ANT44	BAT5	51		*)		
ANT45	BAT6	62		*)		

*) Additional band filtering is required to prevent saturation of the BAT receivers

Based on the simulated isolation values, the power level applied to antenna 10 should be decreased by 7 dB, i.e. a power level of +39 dBm.

Table 4.5 Isolation between TX antenna 13 (AIS1 of RWS) and all other antennas operating in the same band (150 – 164 MHz). Antenna 14 is not considered as it is the RX-antenna of this particular system.

Ant. nr.	Application	Isolation [dB]		Req. power reduction [dB]		TX ANT13 for no sensitivity loss [W // dBm]
		Simul.	Meas.			
ANT1	Marine RX	56				
ANT2	Marine RX	70				
ANT3	Marine RX	67				
ANT4	Marine TX	31				Insert isolator
ANT5	Marine TX	36				Insert isolator
ANT6	Marine RX	59				
ANT7	Marine RX	54				
ANT9	Marine TX	22				Insert isolator
ANT10	Marine TX	32				Insert isolator
ANT40	BAT1	54		*)		
ANT41	BAT2	48		*)		
ANT42	BAT3	78		*)		
ANT43	BAT4	46		*)		
ANT44	BAT5	62		*)		
ANT45	BAT6	67		*)		

*) Additional band filtering is required to prevent saturation of the BAT receivers

Based on the simulated isolation values, the power level applied to antenna 13 does not need to be decreased. Although the receiver connected to antenna 7 may experience minor desensitisation, the duration of each broadcast is only 26 ms, thus generates little annoyance.

4.3.1 *Non-interference marine and AIS radio Power levels*

High power levels (25 – 40 W), which are standard settings for ship marine radio's, are not required for the HKWA OSS to obtain coverage of the wind turbine park. Given the adverse effects on other communication systems, lower power settings should be used, as presented in Table 4.6.

The presented coverages in Chapter 5, are calculated according to these reduced power settings.

Based on the assumptions, as described in paragraph 4.1, the transmit power of several VHF-transmitters are required to be reduced in order to prevent harmful desensitization of VHF receivers operating in the same band. The suggested maximum power levels are shown in Table 4.6. The coverage simulations are based on these (reduced) power levels.

Table 4.6 Maximum suggested power levels in order to prevent unacceptable receiver desensitization

System	TX antenna nr.	Maximum Power [W / dBm] EIRP
Marine radio 1	**4**	**8 / +39**
Marine radio 2	**5**	**3 / +35**
Marine radio 3 (ECW)	**9**	**5 / +37**
Marine radio 4 (ECW)	**10**	**8 / +39**

Marine radio 1&2, Ch 90L	**4 & 5**	**5 / +37**
AIS	**13**	**12.5 / +41**

Based on measurements the actual recommendations have been changed. See paragraph 4.6.1.

The coupling levels into neighbouring VHF transmitters is in various instances < 40 dB. In order to prevent intermodulation to be generated in the affected output amplifiers, *it is strongly advised to add an RF isolator*[8] *into the transmit paths of all VHF transmitters*, i.e. marine radio's and AIS.

4.4 TETRA radios

Ecowende will be using TETRA for its communication inside the wind farm. No Direct Mode Operation (DMO) is required.

Table 4.7 Isolation between TX&RX antenna 18 and all other RX-antennas operating in the same frequency band.

Ant. nr.	Application	Isolation [dB]		Remarks
		Simul.	Meas.	
ANT17	TETRA1 RX	52		
ANT20	TETRA2 RX	58		
ANT25	LoRa	67		
ANT28	TETRA2 TX&RX	26		
ANT12	LoRa (EXT)	58		

Table 4.8 Isolation between TX&RX antenna 28 and all other RX-antennas antennas operating in the same frequency band.

Ant. nr.	Application	Isolation [dB]		Remarks
		Simul.	Meas.	
ANT17	TETRA1 RX	58		
ANT18	TETRA1 TX&RX	26		
ANT20	TETRA2 RX	65		
ANT25	LoRa	76		
ANT12	LoRa	61		

No detrimental effect of the TETRA transmissions are to be expected on any of the other systems installed in the tower.

4.5 LoRa and SDNS

On HKWA two LoRa base stations will be installed from two different users: RWS and an external party. The radiated (EIRP) power levels are maximum +27 dBm (500 mW).

[8] Single stage isolator, 5 MHz bandwidth,Tunable, 138-174 MHz – Sinclair Technologies (sinctech.com), Raditek Coaxial Isolators and Coaxial Circulators (100MHz-199MHz) | Raditek

Although both systems are operating in in the same frequency band, the actual frequencies are still 200 MHz apart. Hence, little disturbing effects are to be expected as proper RF-input filtering is easy to accomplish.

Table 4.9 Isolation between LoRa antenna 25 (Freq = 868 MHz) the other LoRa antennas and SDNS.

Ant. Nr.	Application	Isolation [dB]	
		Simul.	Meas.
ANT12	LoRa (EXT)	42	
ANT37a	SDNS1	44	
ANT37c	SDNS2	?	
ANT37d	SDNS3	?	

Table 4.10 Isolation between LoRa antenna 12 (Freq = 868 MHz) the other LoRa antennas and SDNS.

Ant. Nr.	Application	Isolation [dB]	
		Simul.	Meas.
ANT25	LoRa (RWS)	43	
ANT37a	SDNS1	40	
ANT37c	SDNS2	?	
ANT37d	SDNS3	?	

Table 4.11 Isolation between SDNS antenna 37a (Freq = 1090 MHz) and the LoRa antennas.

Ant. Nr.	Application	Isolation [dB]	
		Simul.	Meas.
ANT25	LoRa (RWS)	54	
ANT12	LoRa (EXT)	41	

Isolation between the two LoRa transmitters varies is around 42 dB. These are the levels from “connector to connector”, i.e. incorporating the antenna gains. These low isolation values will likely cause some interference or even blockage on the neighbouring LoRa systems, but as transmissions are rare and short this should not pose a large problem.

The coupling from LoRa to SDNS is 40 dB. However, the frequency separation of 25% between the two systems enables the application of input filters which should provide adequate attenuation of out-of-band signals. No interference is anticipated of the Lora systems on SDNS reception.

4.6 Conclusions and recommendations

4.6.1 Marine radio’s and AIS

Isolation between transmitters and receivers operating in the VHF band is generally high, with just minor required decrease of transmit power regarding the marine radios.

Isolation between the VHF-transmitters is generally rather low. This is due to grouping together some of the transmit antennas in order to obtain sufficient coverage across the wind park. Isolation levels as low as 23 dB may cause undesired intermodulation effects. **It is therefore strongly recommended that all VHF transmitters (i.e.: marine and AIS) are fitted with an Isolator at the transmitter output. Such a device will increase the isolation by 20 to 30 dB and prevent harmful intermodulation to occur (e.g.: AmphenolProcom PRO-IS-150-S1).**

The power levels of radios connected to antenna 4, 5, 9 and 10 should be reduced according to the following table. However, based on the measurements (Stellendam, August ’22) the isolation between antenna 5 and marine receive antennas is slightly better than simulations showed, hence it may run at a similar power level as marine radio 1.

Table 4.12 Recommended output power levels of marine radio’s

System	TX antenna nr.	Maximum Power [W / dBm]
Marine radio 1	**4**	**8 / +39**
Marine radio 2	**5**	**3 / +35**
Marine radio 3 (ECW)	**9**	**5 / +37**
Marine radio 4 (ECW)	**10**	**8 / +39**
Marine radio 1&2, Ch 90L	**4 & 5**	**3 / +35**
AIS	**13**	**12.5 / +41**

4.6.2 TETRA

No detrimental effect of the TETRA transmissions are to be expected on any of the systems installed on the tower. A check on the RF-input filter specifications of the BAT receivers is advised.

4.6.3 LoRa and SDNS

The isolation between LoRa and SDNS amounts more than 31 dB. The frequency difference is more than 200 MHz and RF output power of LoRa systems low (500 mW). Hence, degradation of the SDNS reception is not expected.

5 Antenna patterns and simulated coverages

In this chapter the coverage areas have been calculated for Marine, AIS, TETRA, LoRa RTK and SDNS. The purpose of the marine radio and AIS-systems is to cover the wind turbine park with adequate signal levels including an area of 10 NM around it.[9] The height of the ship antenna used in the simulations has been changed to 4 metres, instead of 6 metres as in the previous reports. This has been done in order to comply with IMO resolution A.801[10]. Compared to former reports a slight decrease of the simulated coverage area will occur.

For marine and AIS, the coverage maps show that at all transmitter power levels (i.e.: 3 W (Channel 90L), 8 W and 12 W power levels) the signal strength inside the wind park area is well above -80 dBm, which is a very solid and save level. In most cases up to 10 NM *outside* the wind park a signal level of at least -100 dBm is still obtained. The marine standard dictates that Marine radios still provide adequate quality audio levels at -100 dBm signal levels (an audio SINAD of 20 dB), hence provide adequate margin for proper communication with the HKWA base station.

5.1 HKWA wind park dimensions

Hollandse Kust West Alpha comprises of lot 6, see Figure 5.1.

Figure 5.1 HKWA wind turbine park, showing the required 10NM zone outside its perimeters. The longest distance from the OSS towards the North-Eastern tip inside the wind park is 15 km.

[9] MEMO: Functionele eisen van de nautische sensoren voor de windenergiegebieden Hollandse Kust west, Ten Noorden van de Wadden en IJmuiden Ver, pag. 10-12, Rijkswaterstaat Zee en Delta, 31 maart 2022.

[10] 801(19) Provision of radio services for the Global Maritime Distress and Safety System (MSC.199(80)) - Netherlands Regulatory Framework (NeRF) – Maritime (overheid.nl)

5.2 Required coverage for Marine and AIS radio's

The assumption has been made that Marine coverage should be close to 100% within the boundaries of the wind park. The required receiver sensitivity for marine radio's is -101 dBm (20 dB SINAD)[11]. Cable and connector losses are crossed out against the typical 2 dBi antenna gain. Coverages are calculated at -100, -90 and -80 dBm receiver signal levels.

Ship transmitters are expected to be running at full power, i.e. 25…40 W, while the transmit power at HKWA will be limited to a level which does not cause degradation to other receivers in the mast. The minimum required signal strength at the edges of the wind park shall be ≥ -90 dBm at the input of the receiver in order to have a sufficient signal safety margin of 10 dB (according to the simulations the signal levels should in most cases be better than -80 dBm).

Based on simulations in Q1 of 2023, power reductions for several transmitters had to be applied in order to prevent desensitization of other receivers operating in the marine radio band. The addition of marine radio for Ecowende requires a new set of calculations to be performed. Subsequent Interference measurements in Stellendam are not possible since the platform is build-up now and will be released from the yard soon (July 2023).

The calculated isolation between the various antennas (chapter 4) shows that the transmit powers have to be reduced to prevent desensitization of other marine- and AIS-systems, taking into account the minimum signal level requirements across the wind turbine park.

For all channels, except 90L, the maritime radio transmitter coverage ranges have been calculated according to the simulated reduced power levels according to Table 4.12.

The coverage for channel 90L is shown in separate plots, as the maximum power for this specific channel 90L is limited to +5 dBW ERP (dictated by license).

5.2.1 Individual antenna coverages at VHF (Marine and AIS)

Calculations have been performed regarding the coverages of the VHF systems. The VHF-antennas, as provided in table 1, have been simulated.

The communication platform has its “Platform North” positioned 25º east of Geographic north. The presented coverage areas in this document have been modified in such a way that they align with true geographical North.

[11] EN301929, par. 9.4.3

5.2.2 Antenna 1, TenneT, Marine RX-antenna 159MHz, 16 m up in the mast (61 m a.s.l.)

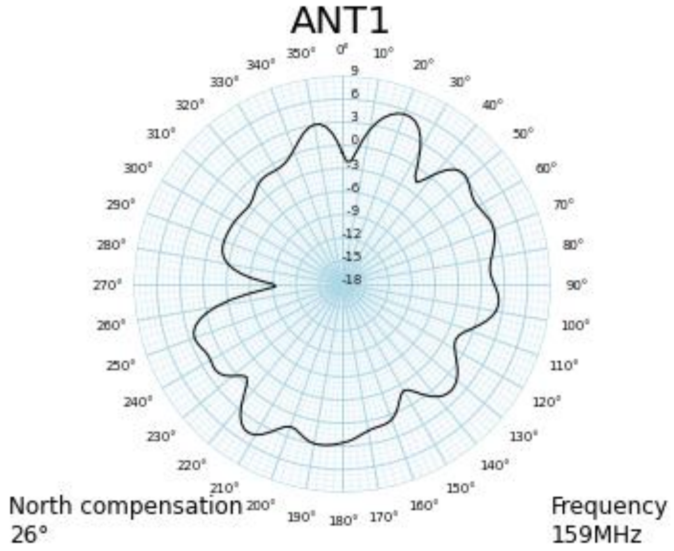

Figure 5.2 Antenna pattern. 0° is geographic north.

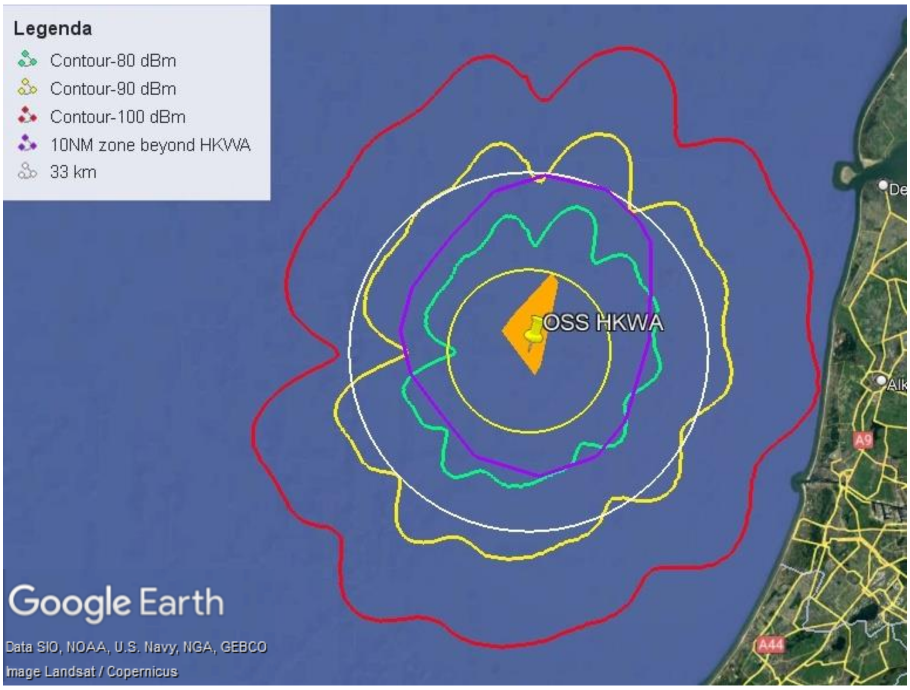

Figure 5.3 Reception range on generic marine channels. Ship's transmitter power set to +16 dBW and antenna height is 4 m a. s.l.. Receive antenna at HKWA is at 61 m.

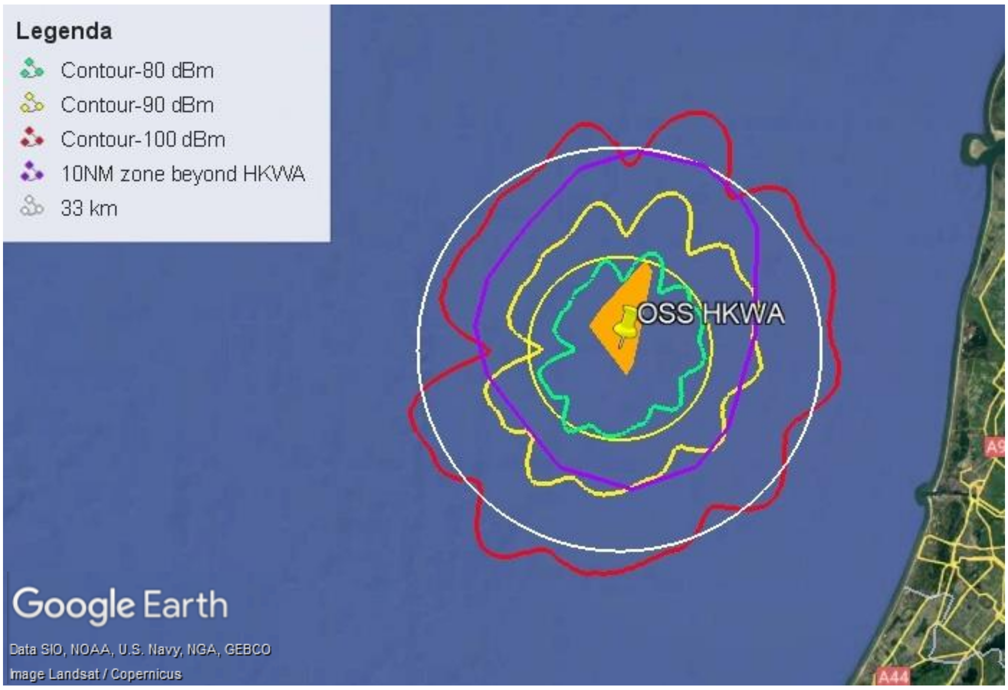

Figure 5.4 Reception range on channel 90L. Ship's transmitter power set to +5 dBW and antenna height is 4 m a.s.l. Receive antenna at HKWA is at a height of 61 m.

5.2.3 Antenna 2, TenneT, Marine RX-antenna 159 MHz, 16 m up in the mast (61 m a.s.l.)

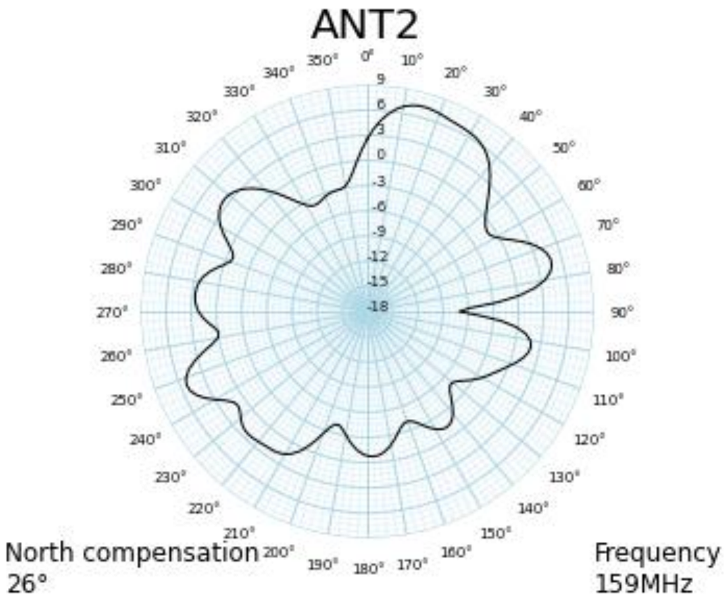

Figure 5.5 Antenna pattern. 0° is geographic north

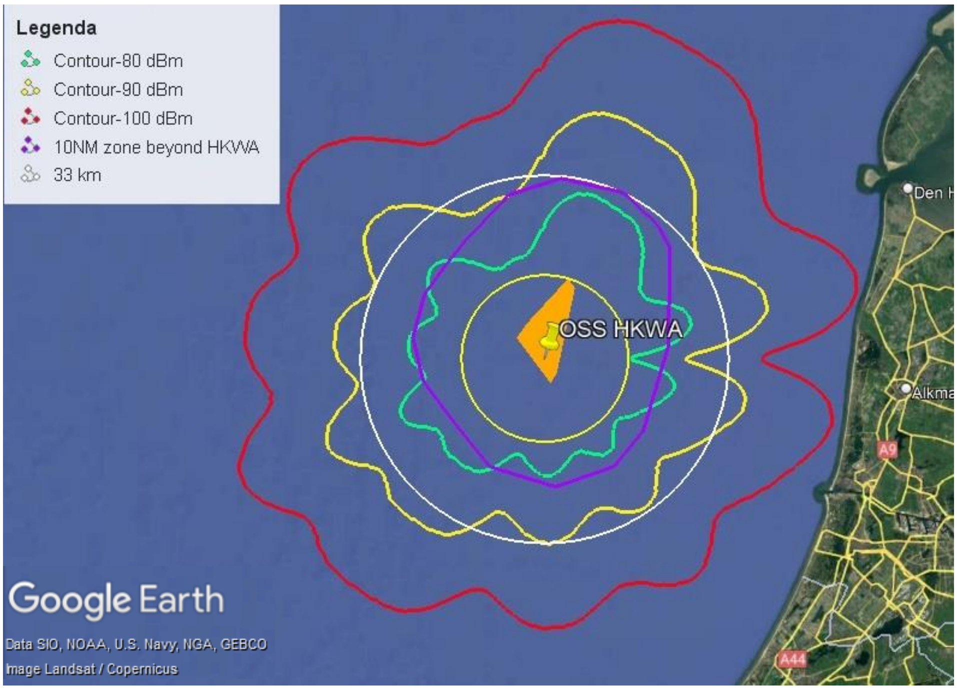

Figure 5.6 Reception range on general marine channels. Ship's transmitter power set to +16 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

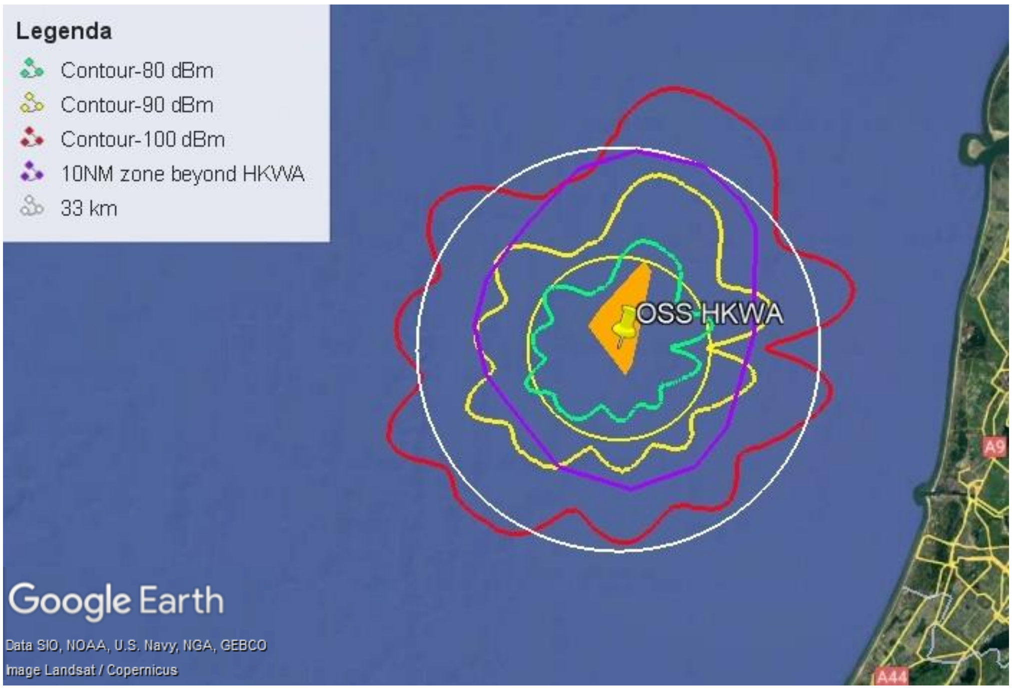

Figure 5.7 Reception range on channel 90L. Ship's transmitter power set to +5 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

5.2.4 *Antenna 3, TenneT, Marine RX-antenna 159 MHz, 16 m up in the mast (61 m a.s.l.)*

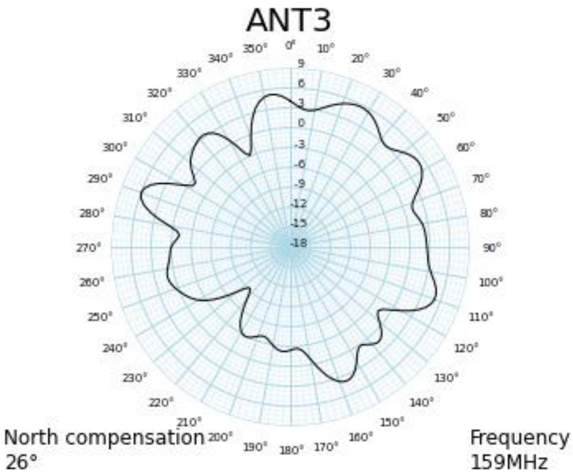

Figure 5.8 Antenna pattern. 0° is geographic north

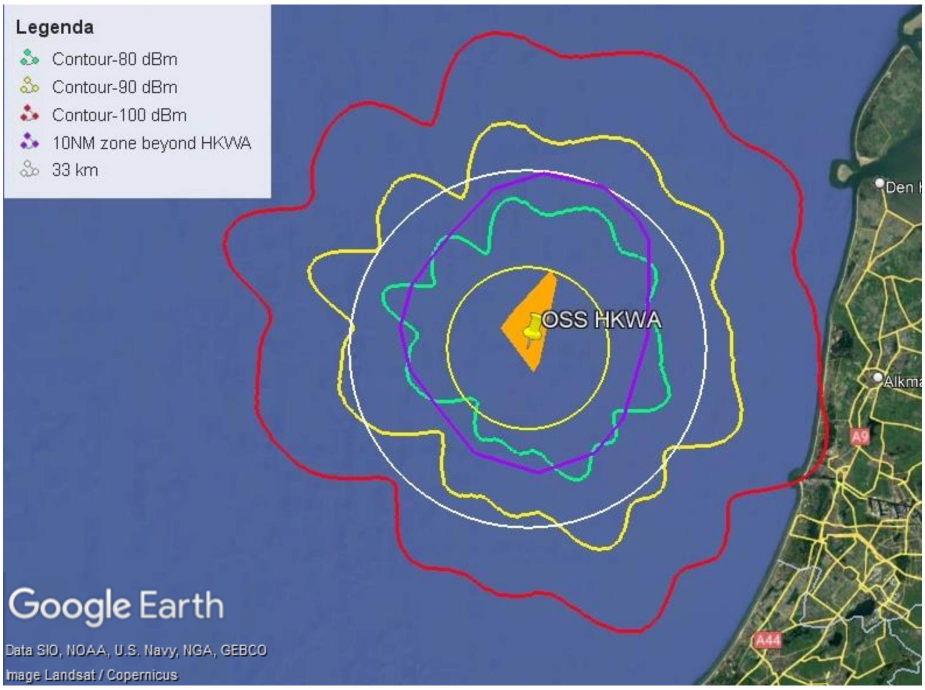

Figure 5.9 Reception range on general marine channels. Ship's transmitter power set to +16 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

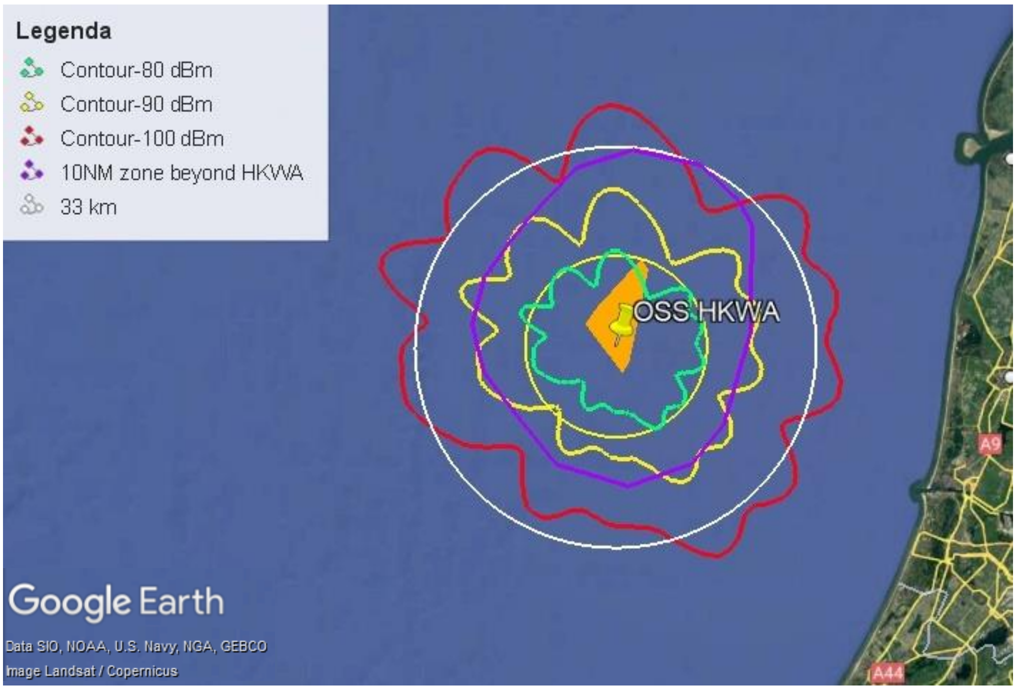

Figure 5.10 Reception range on channel 90L. Ship's transmitter power set to +5 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

5.2.5 Antenna 4, TenneT, Marine TX-antenna 159MHz, 5 m up in the mast (50 m a.s.l.).

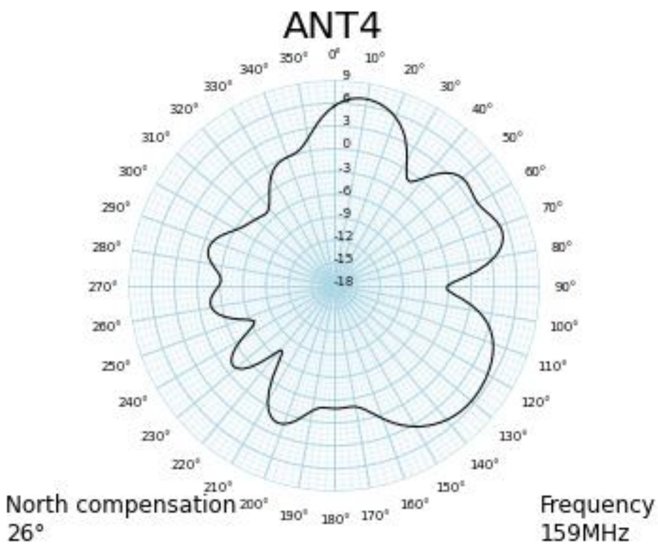

Figure 5.11 Antenna pattern. 0° is geographic north

Antenna 4 is assigned to marine VHF radio but has a minimum decoupling of 54 dB with antenna 3 (Table 4.1). In order to prevent desensitization effects the maximum power level for the generic marine channels has initially been reduced from +16 dBW to +9 dBW.

Coverages for 9 dBW and +5 dBW (channel 90L) are presented in Figure 5.12 and Figure 5.13.

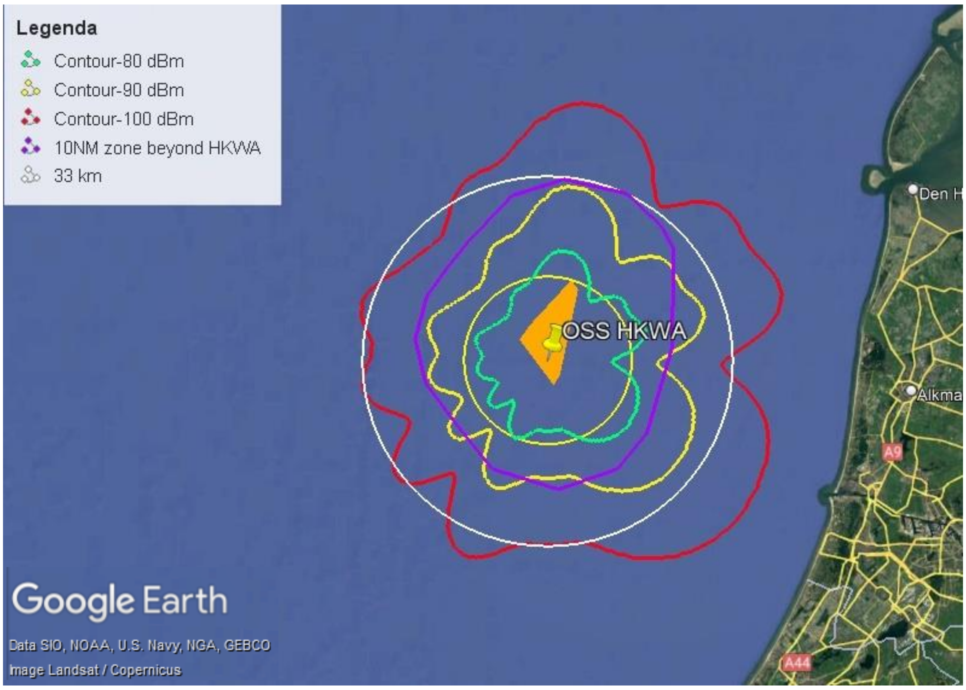

Figure 5.12 Transmission range on general marine channels. HKWA transmitter power set to +9 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

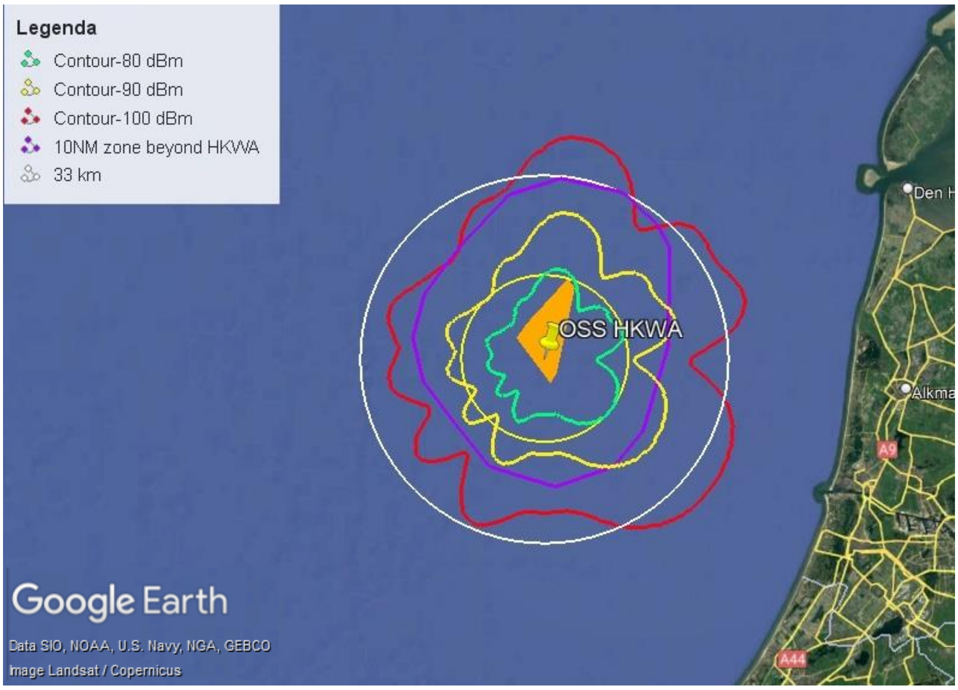

Figure 5.13 Transmission range using channel 90L. HKWA transmitter power set to +5 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

5.2.6 *Antenna 5, TenneT, Marine TX-antenna 159 MHz, 5 m up in the mast (50 m a.s.l.)*

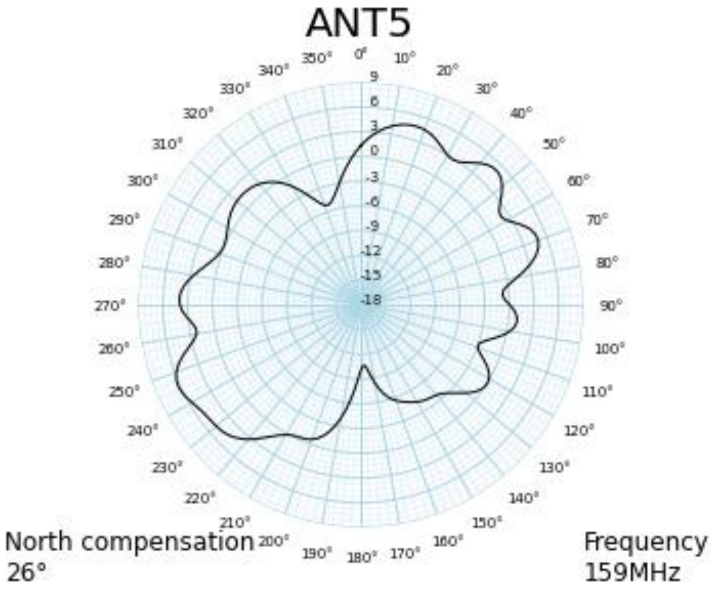

Figure 5.14 Antenna pattern. 0° is geographic north

The lowest simulated decoupling level between transmit antenna 5 and other VHF receivers (Marine and AIS) equals 50 dB as indicated in Table 4.2

Because of this an 11 dB transmit power reduction is applied when calculating antenna 5 coverages (illustrated in **Error! Reference source not found.**). There is n o margin for further power reductions as -100 dBm contour is already dips below the 10 NM perimeter in the north west.

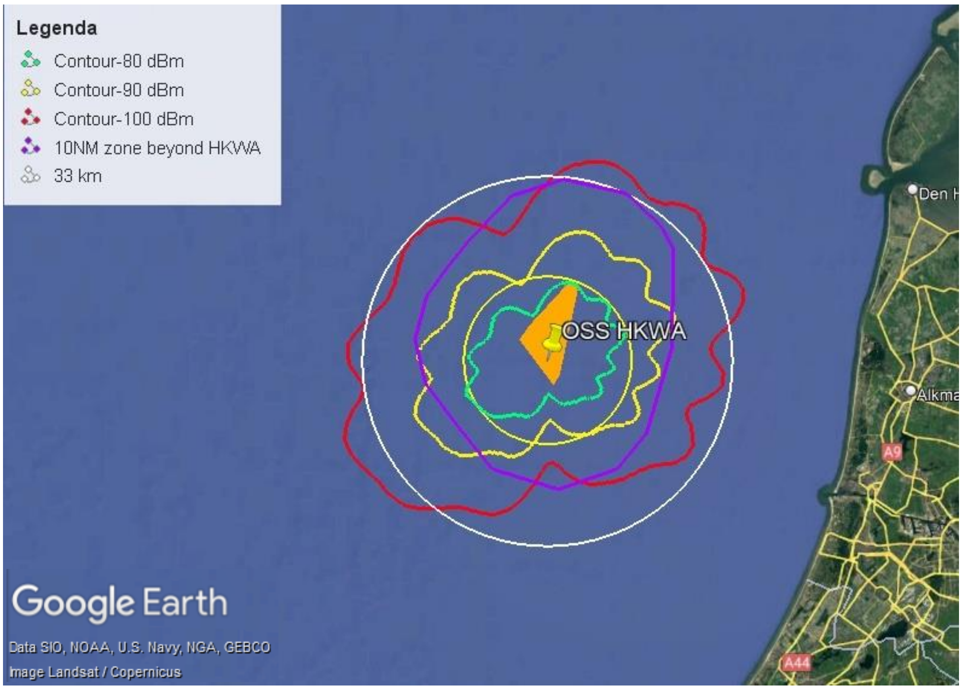

Figure 5.15 Transmission range using generic channels and channel 90L. HKWA transmitter power set to +5 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

5.2.7 Antenna 6, Ecowende, Marine RX-antenna 159 MHz, deck 5 (16 m up in the mast, 61 m a.s.l.)

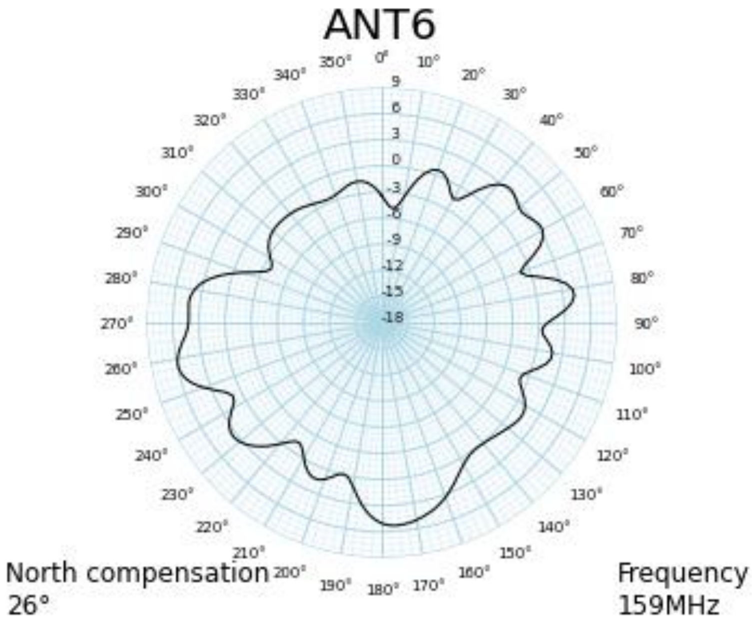

Figure 5.16 Antenna pattern. 0° is geographic north

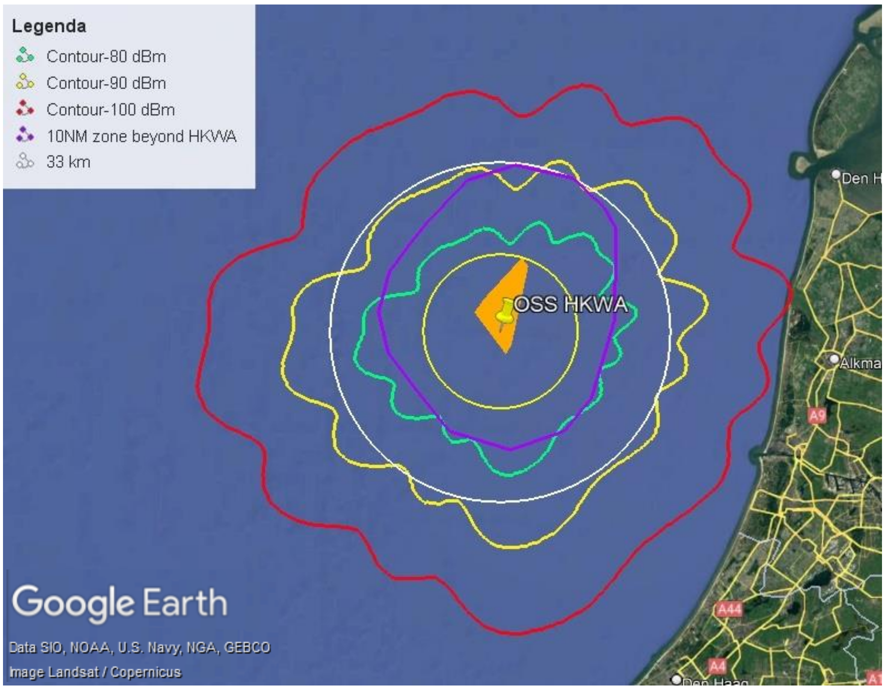

Figure 5.17 Reception range on general marine channels. Ship's transmitter power set to +16 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

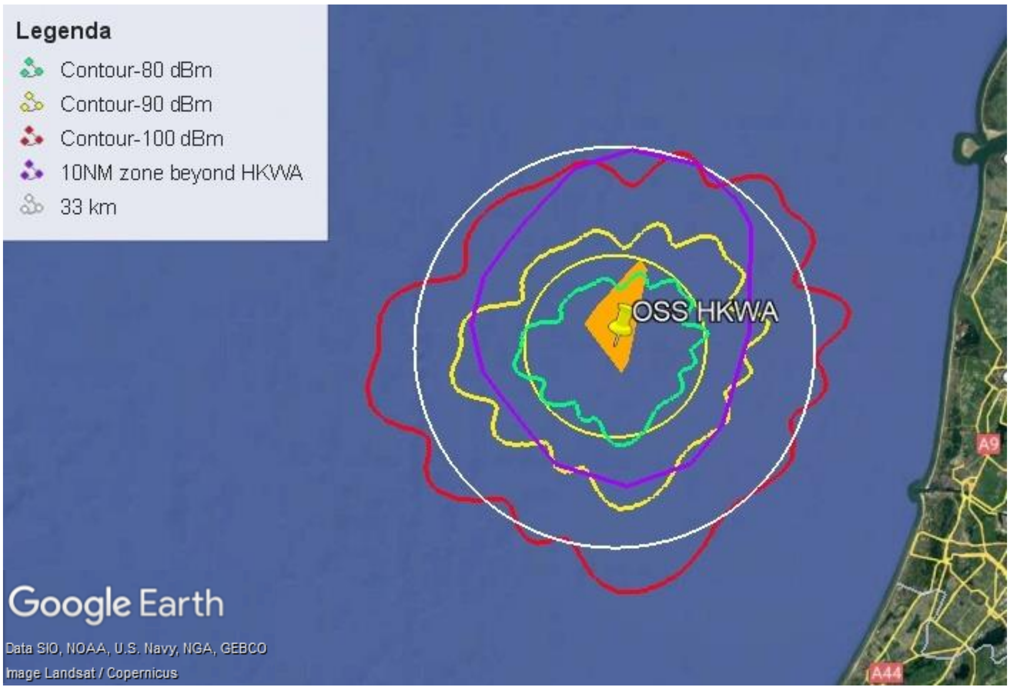

Figure 5.18 Reception range channel 90L. Ship's transmitter power set to +5 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

5.2.8 *Antenna 7, Ecowende, Marine RX-antenna 159 MHz, deck 5 (16 m up in the mast, 61 m a.s.l.)*

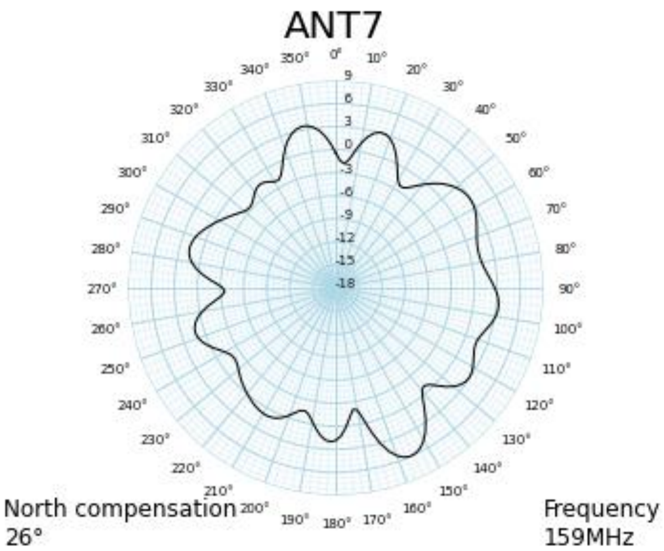

Figure 5.19 Antenna pattern. 0° is geographic north

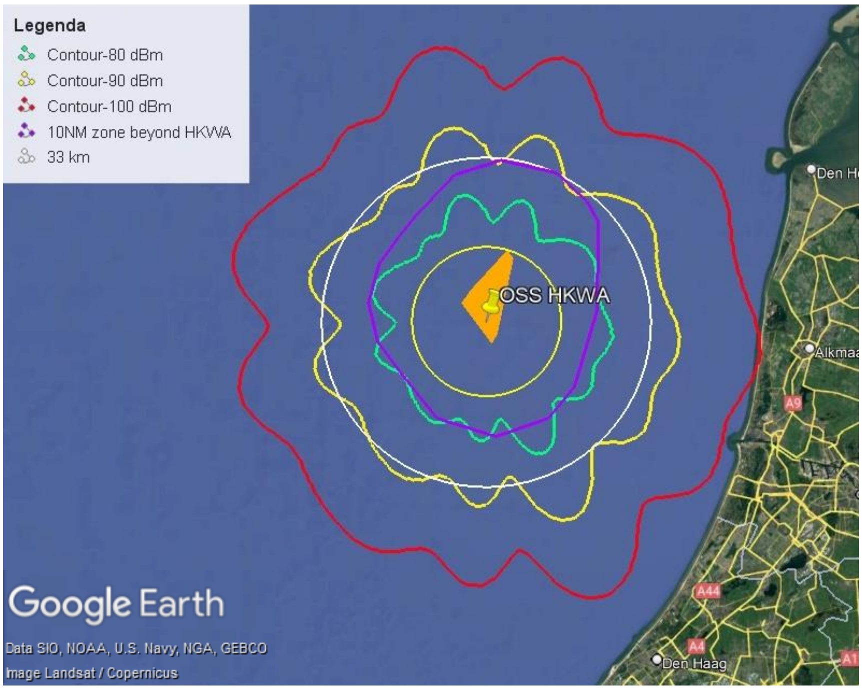

Figure 5.20 Reception range on general marine channels. Ship's transmitter power set to +16 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m.

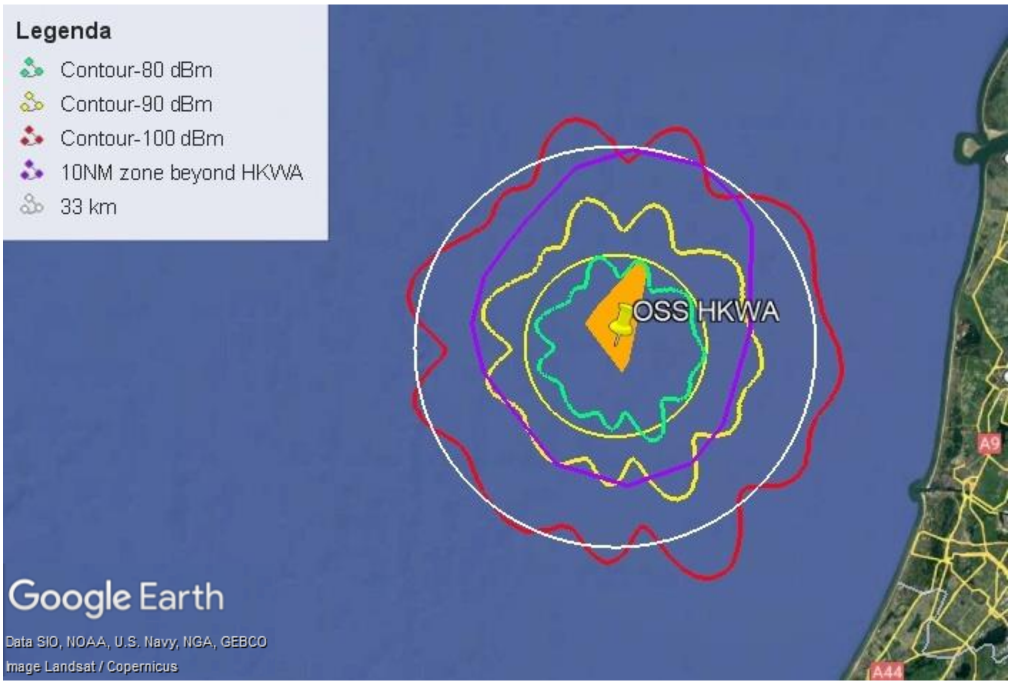

Figure 5.21 Reception range on channel 90L. Ship's transmitter power set to +5 dBW and antenna height is 4 m a.s.l.. Receive antenna at HKWA is at a height of 61 m..

5.2.9 *Antenna 9, Ecowende, Marine TX-antenna 159 MHz, deck 1 (5 m up in the mast, 50 m a.s.l.)*

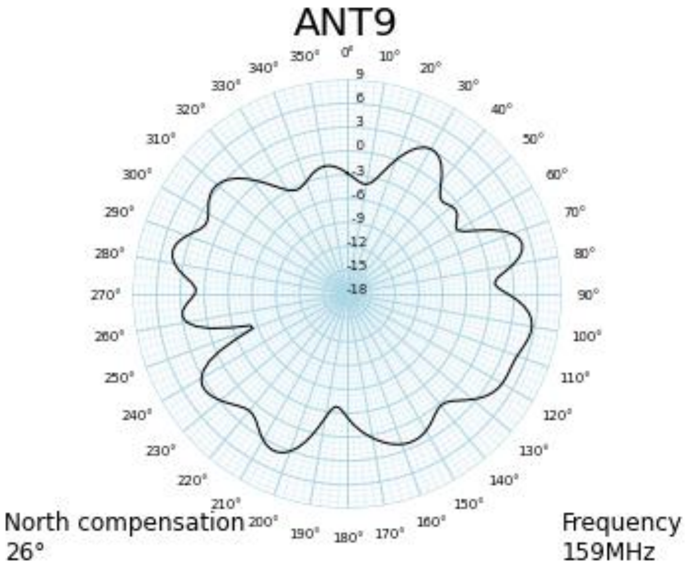

Figure 5.22 Antenna pattern. 0° is geographic north

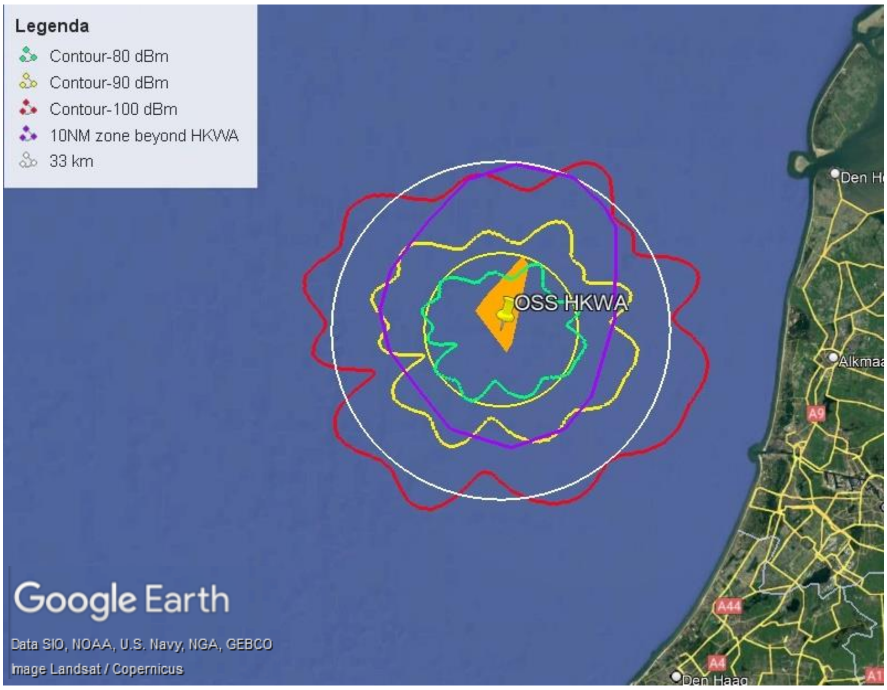

Figure 5.23 Transmission range using general marine channels. HKWA transmitter power set to +7 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

Antenna 9 is assigned to marine VHF radio but has a minimum decoupling of 52 dB with antenna 3 (Table 4.3). In order to prevent desensitization effects the maximum power level for the generic marine channels has initially been reduced from +16 dBW to +7 dBW.

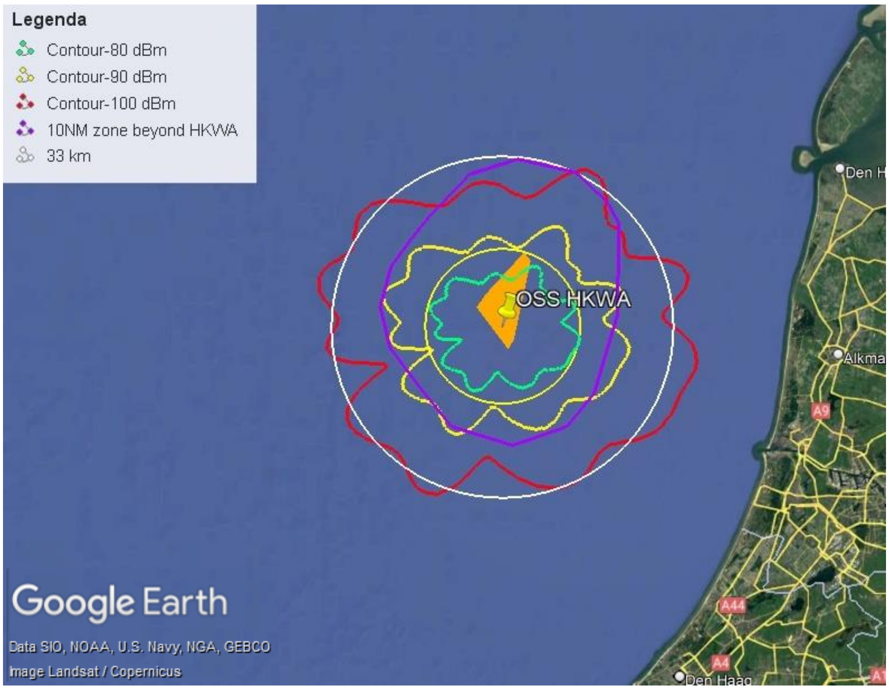

Figure 5.24 Transmission range using channel 90L: HKWA transmitter power set to +5 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

5.2.10 Antenna 10, Ecowende, Marine TX-antenna 159 MHz, deck 1 (5 m up in the mast, 50 m a.s.l.)

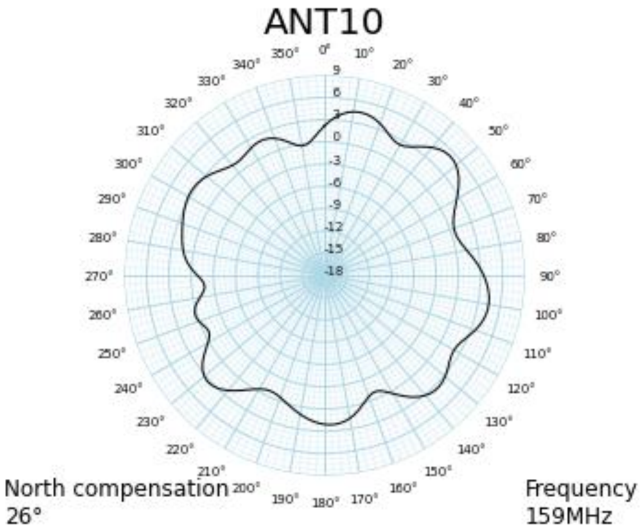

Figure 5.25 Antenna pattern. 0° is geographic north

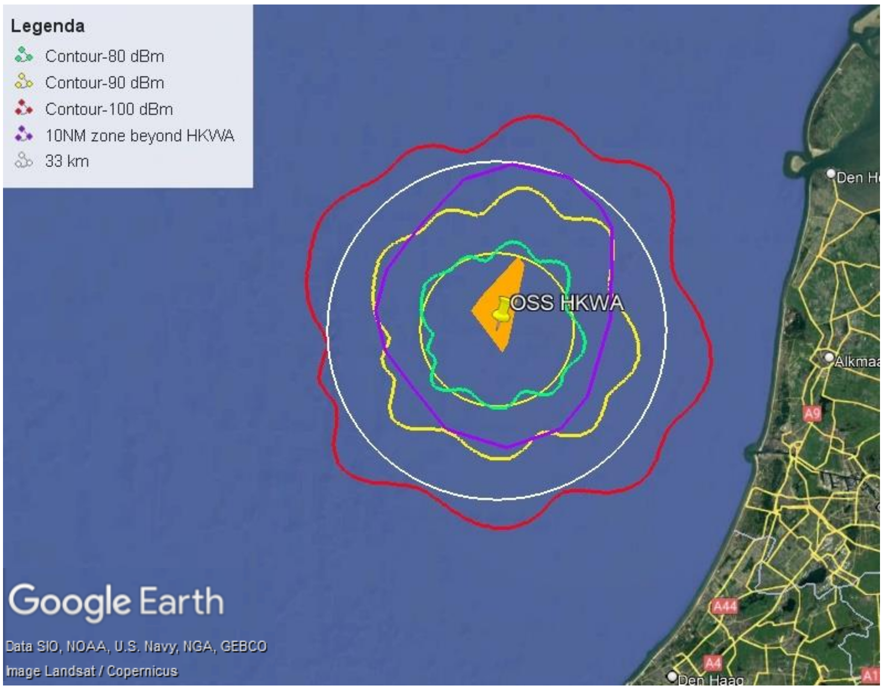

Figure 5.26 Transmission range using general marine channels. HKWA transmitter power set to +9 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

Antenna 10 is assigned to marine VHF radio but has a minimum decoupling of 54 dB with antenna 14 (Table 4.4). In order to prevent desensitization effects the maximum transmission power level for the generic marine channels is reduced from +16 dBW to +9 dBW.

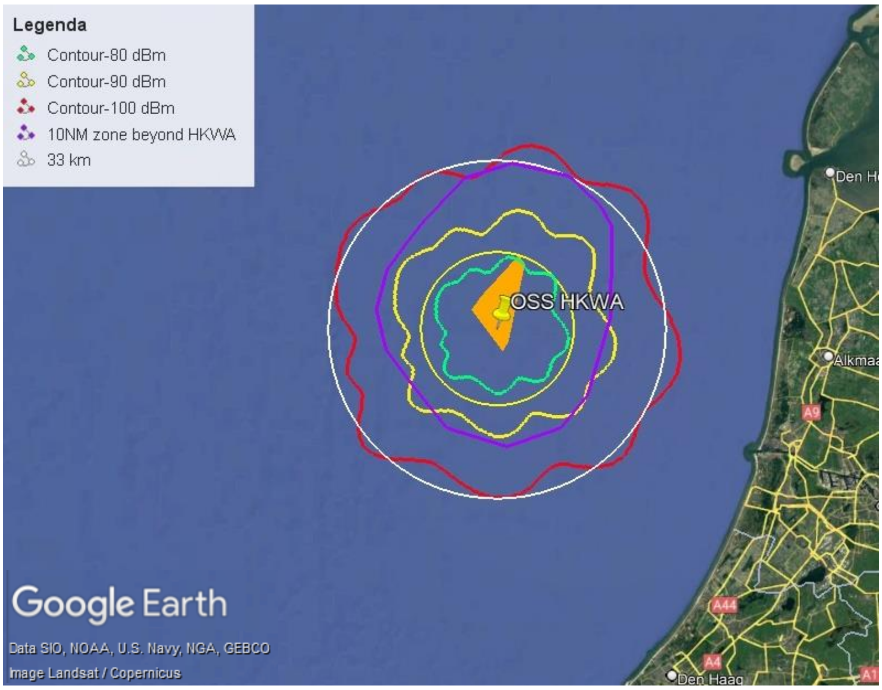

Figure 5.27 Transmission range using channel 90L: HKWA transmitter power set to +5 dBW and antenna height is 50 m a.s.l.. Ship receive antenna height is 4 m.

5.2.11 Antenna 13, RWS, AIS1 TX-antenna, 162 MHz, 5 m up in the mast (50 m a.s.l.)

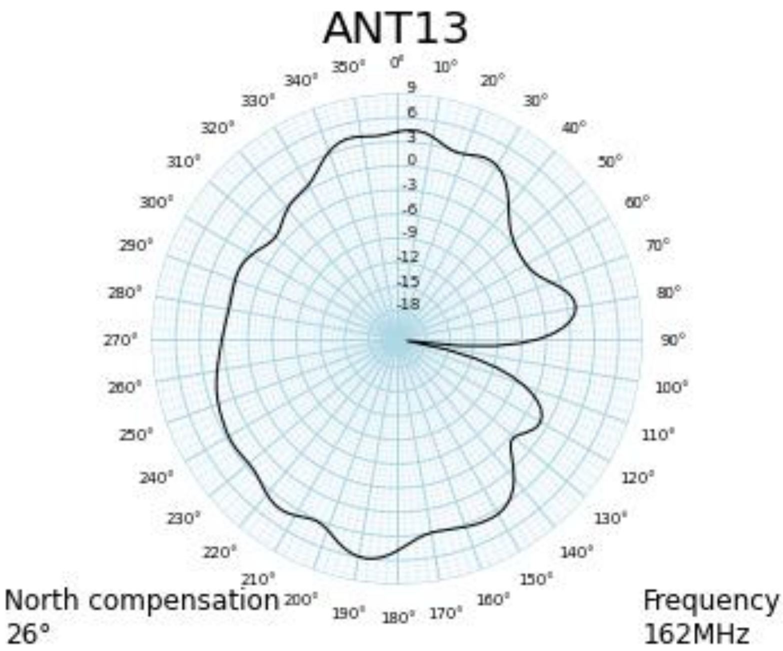

Figure 5.28 Antenna pattern. 0° is geographic north

All the AIS coverages are based on the default power levels for AIS-A at sea: +11 dBW (12.5 W). The performed simulations assume a ship antenna height of 4 m a.s.l..

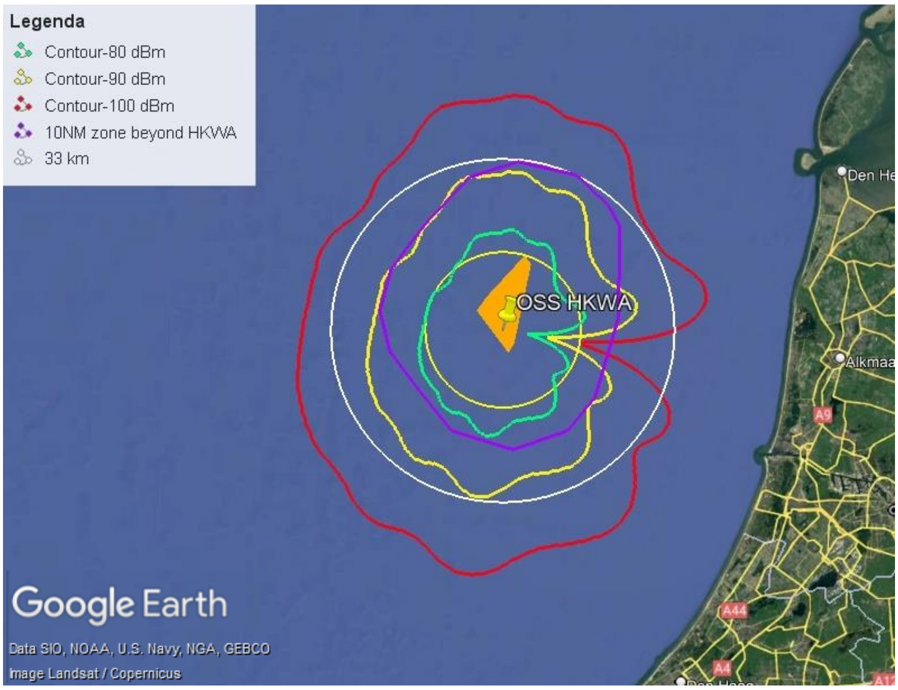

Figure 5.29 Transmission range of HKWA AIS transmitter power set to +11 dBW and antenna height of 50 m a.s.l.. Ship receive antenna height is 4 m.

5.2.12 Antenna 14, RWS AIS1 RX-antenna, 162 MHz, 16 m up in the mast (61 m a.s.l.)

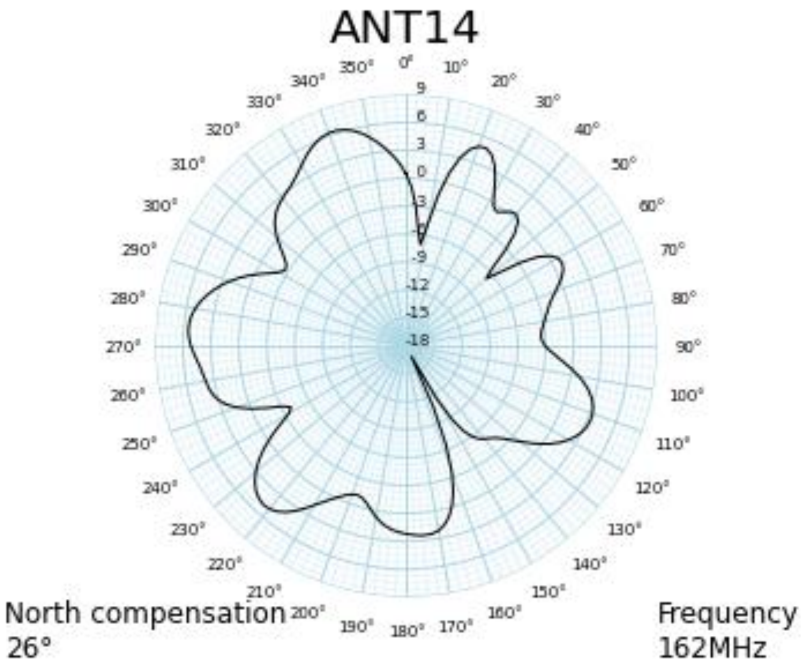

Figure 5.30 Antenna pattern. 0° is geographic north

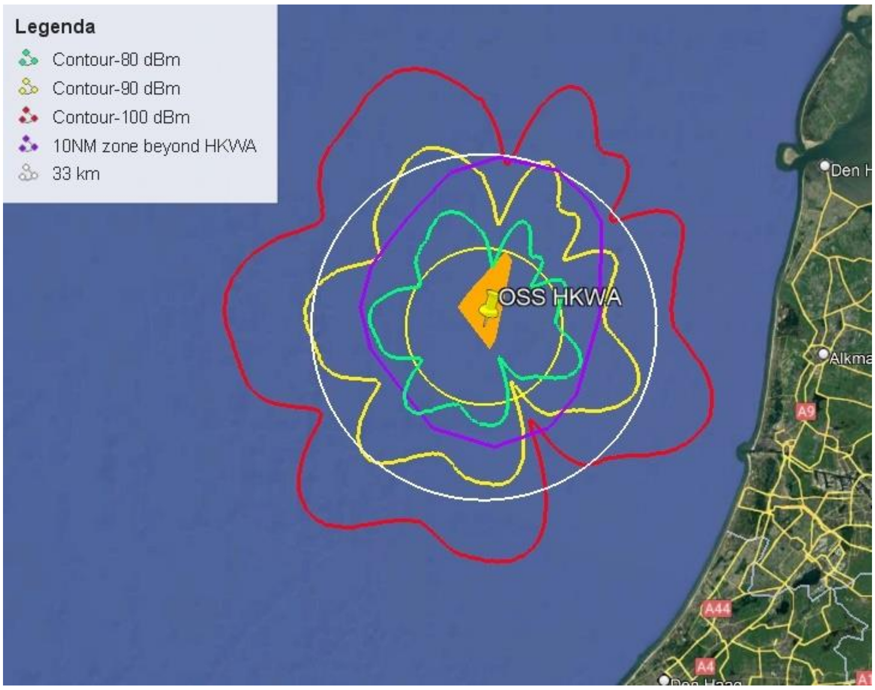

Figure 5.31 Reception range of HKWA AIS receive antenna. Coverage based on +11 dBW ship transmit power. Ships antenna height is 4 m a.s.l. Receive antenna at HKWA is at 61 m a.s.l..

5.3 TETRA coverage

5.3.1 TETRA simulation conditions

At time of writing (May 2022) the exact type of UHF maintenance communication application was not known. I.e. the obvious choices of TETRA or DMR had still to be decided upon. In order to perform an initial simulation, TETRA was chosen by RWS as the operational maintenance communication solution.

TETRA has been specifically designed for land based operation in urban areas. Most of the available data regarding sensitivity is based on multipath, shadowing and moving vehicles, which is contrary to the more or less static conditions in a marine environment. The land based values are likely too strict for a marine environment. In Table 5.1. the so called Static and Dynamic sensitivity levels are given according to the TETRA standard and values of a randomly chosen handheld transceiver. The required signal levels for TETRA of a previous WPO are roughly 10 dB higher, which translates to a smaller coverage area at those boundary levels. In practice it is likely that the operational area will be much larger, given the 10 dB margin.

Table 5.1 Sensitivity reference levels according to the ETSI standard, a regular Motorola Handheld and the requirements of a previous WPO.

Reference	EN 300 392-2 V2.3.2	Motorola MPT3000	Requirements of a previous WPO.
Static, MS sensitivity (C/I=19 dB)	-112 dBm		
Dynamic, MS sensitivity (C/I=19 dB)	-103 dBm		
Static Sensitivity (handheld)		-116 dBm	
Dynamic Sensitivity (handheld)		-107 dBm	
Handheld, 99% of time and place			-95 dBm
Handheld, 99% of time and place, including 6 dB body loss			-89 dBm
Base Station, 99% of time and place,			-95 dBm

TETRA may be used in TMO (i.e.: via the base station on the platform) or in DMO (point-to-point) mode. The simulated coverages, assume a handheld height of 2.5 m. The handheld antenna gain is set to 0 dBi. DMO mode is not required by Ecowende.

The coverage are calculated for reception signal levels of -89 for the hand held and -95 dBm at the HKWA base station. Transmit power of the hand held is assumed to be +5 dBW and a 6 dB loss due to the presence of the human body is incorporated. Hence, an isotropic radiated power of -1 dBW will be used. The TETRA base station transmit power is set to +12.15 dBW EIRP. These power and reception levels will be used throughout the subsequent TETRA coverage plots.

5.3.2 Antenna 17, TETRA1 RX-antenna, 415/425 MHz, 11 m up in the mast (56 m a.s.l.)

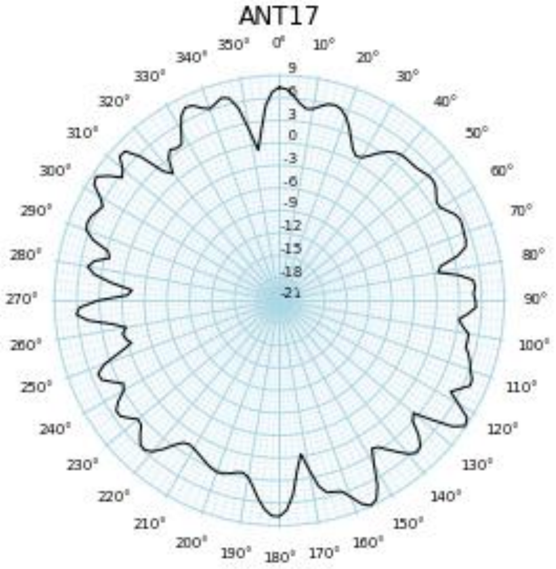

Figure 5.32 TETRA RX-antenna pattern. 0° is geographic north

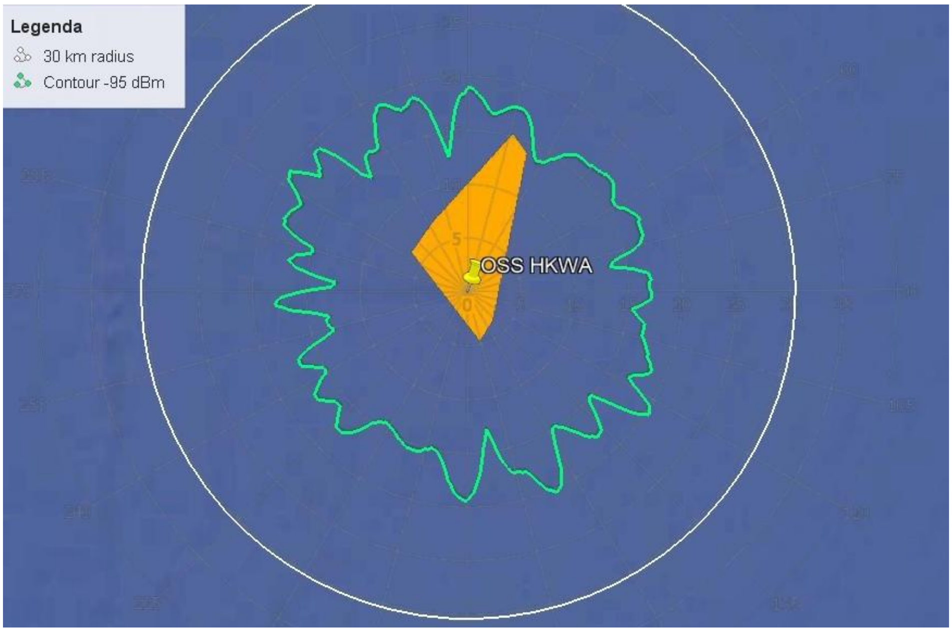

Figure 5.33 Coverage based on handheld situated at 2.5 m a.s.l.. Base station height is 56 m a.s.l..

5.3.3 Antenna 18, TETRA1 RX- and TX-antenna, 415/425 MHz, 6 m up in the mast (51 m a.s.l.)

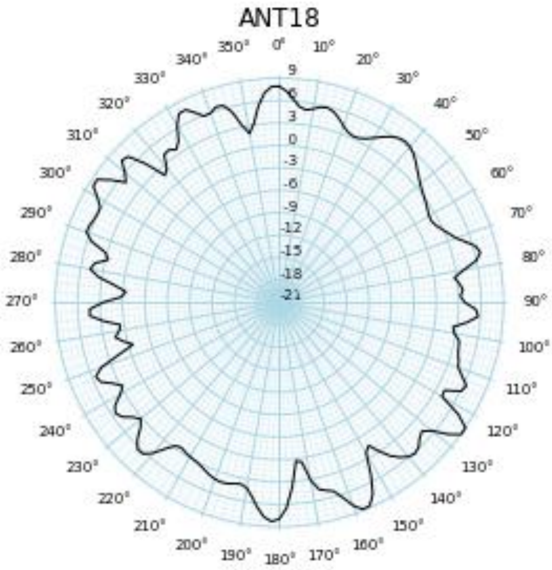

Figure 5.34 TETRA1 RX&TX-antenna pattern. 0° is geographic north.

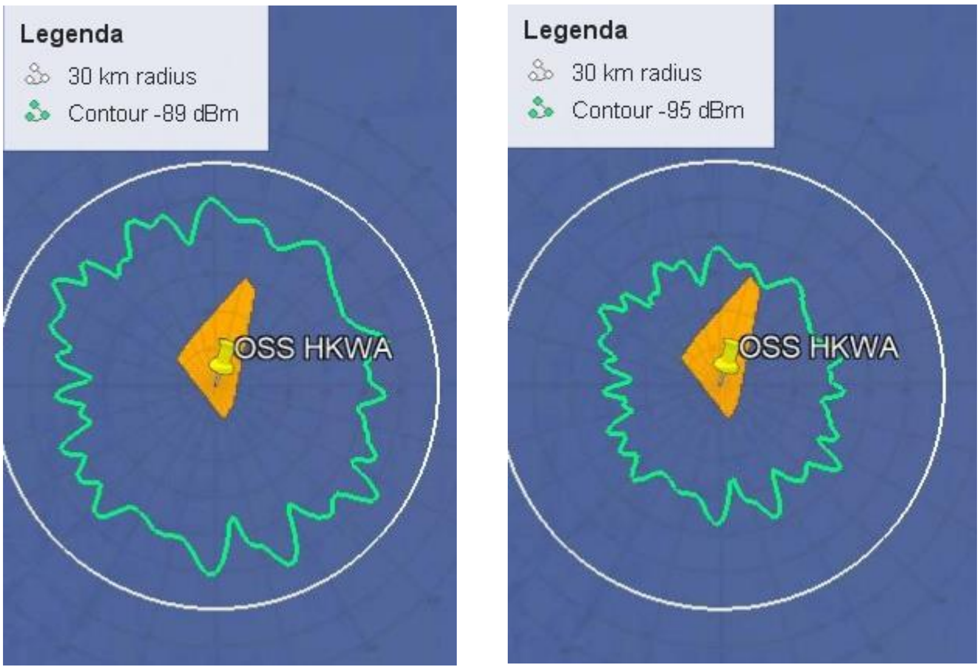

Figure 5.35 Left hand side: Coverage based on the TETRA 1 base station. Right hand side: Coverage based on handheld, using antenna 18. Base station antenna height is 51 m, handheld is situated at 2.5 m height a.s.l..

5.3.4 *Antenna 20, TETRA2 RX-antenna, 415/425 MHz, 11 m up in the mast (56 m a.s.l.)*

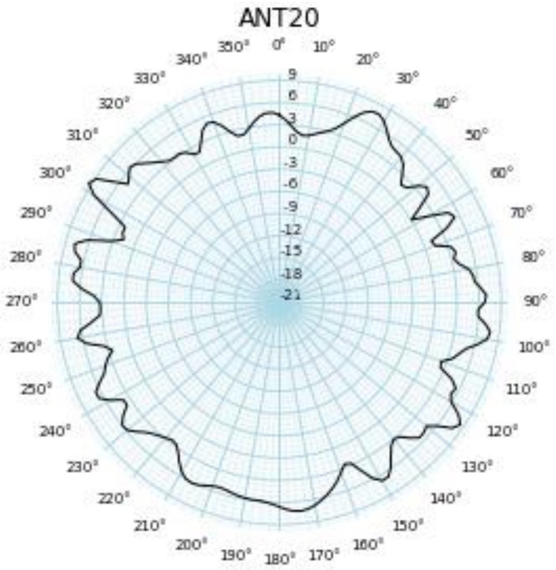

Figure 5.36 TETRA2 RX-antenna pattern. 0° is geographic north.

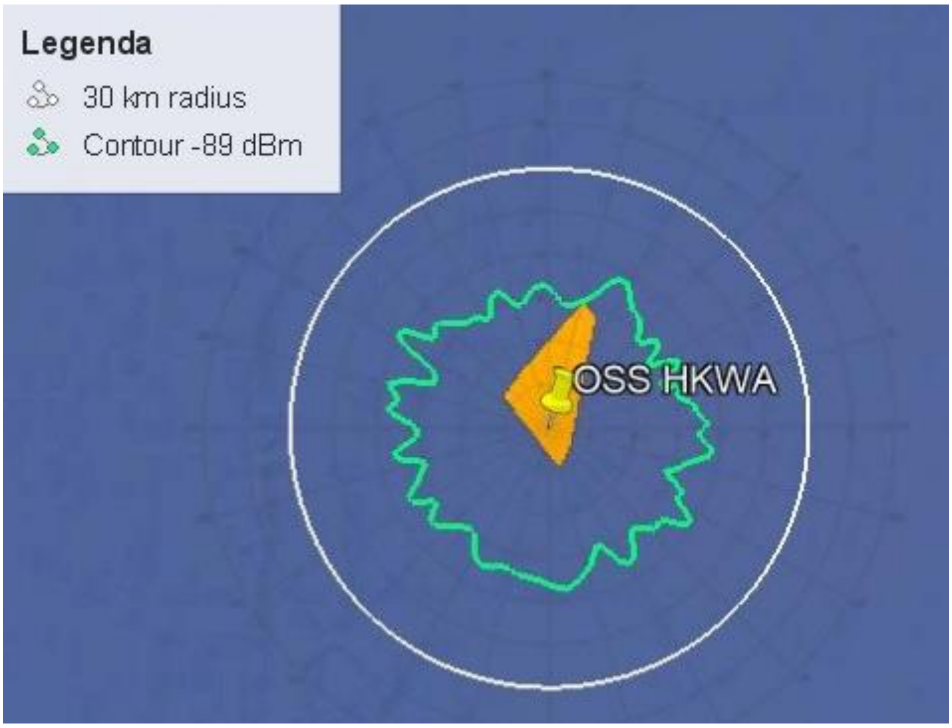

Figure 5.37 Coverage based on handheld situated at 2.5 m a.s.l.. Base station antenna height is 56 m a.s.l..

5.3.5 Antenna 28, TETRA2 RX- and TX-antenna, 415/425 MHz, 6 m up in the mast (51 m a.s.l.)

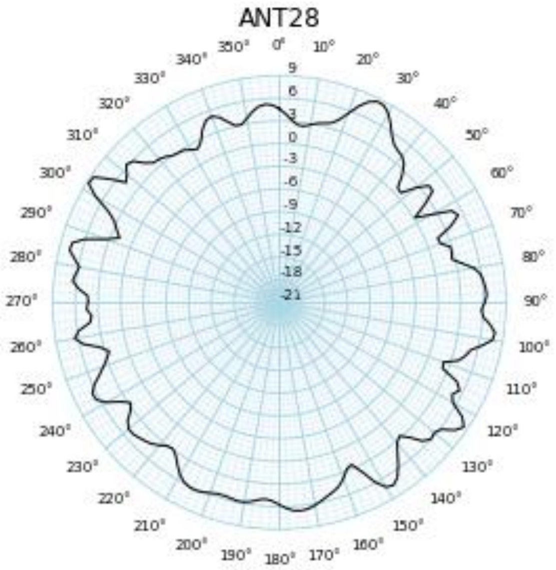

Figure 5.38 TETRA2 RX&TX-antenna pattern. 0° is geographic north.

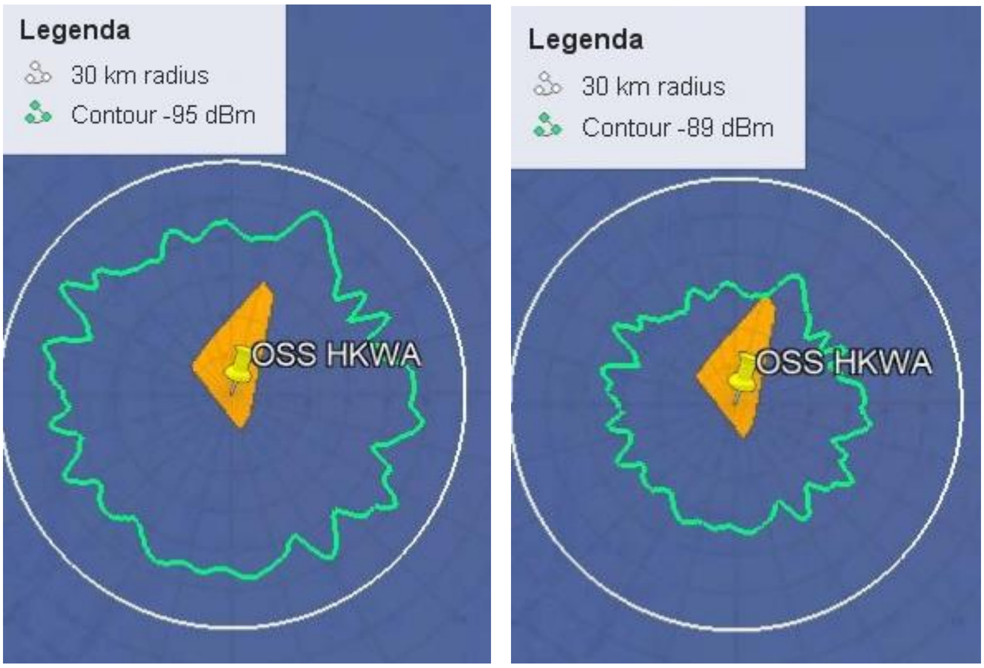

Figure 5.39 Left hand side: Coverage based on the TETRA 2 base station. Right hand side: Coverage based on handheld, using antenna 28. Base station antenna height is 51 m, handheld is situated at 2.5 m height a.s.l..

5.4 LoRa coverage

5.4.1 Antenna 25, LoRa 1, TRX-antenna, 868 MHz, 8 m up in the mast (53 m a.s.l.)

Long Range technology (LoRa) uses low data rates in a very effective way, which enable a very high link margin. In spite of the low utilised transmit power level of an IoT device (+14 dBm), long communication ranges may be achieved. The minimum usable receiver sensitivity is approximately -148 dBm. Two coverage ranges have been simulated, based on -148 and -138 dBm signal levels. The higher level simulates a 10 dB margin in order to cope with multipath and possible blocking effects. For reception at the platform an omni directional antenna with 4 dBi gain is used in the simulations. The usual antenna gain of the remote, and often battery powered, IoT device is set to 0 dBi. The height of the IoT device is assumed to be 2.5 m a.s.l..

Regarding the LoRa coverage plots, a word of caution should be noted. As the calculated ranges are well beyond line of sight, it is likely that the actual operating distances may be somewhat shorter than simulated. Weather induced propagation effects may start to take influence the signal strength during certain time intervals. It is advised to use a shorter maximum range than simulated (10 km shorter than plotted is a safe estimate). The anticipated coverage over land will be much shorter as the effects of the dunes and other (man-made) obstacles could not be taken into account in the simulations.

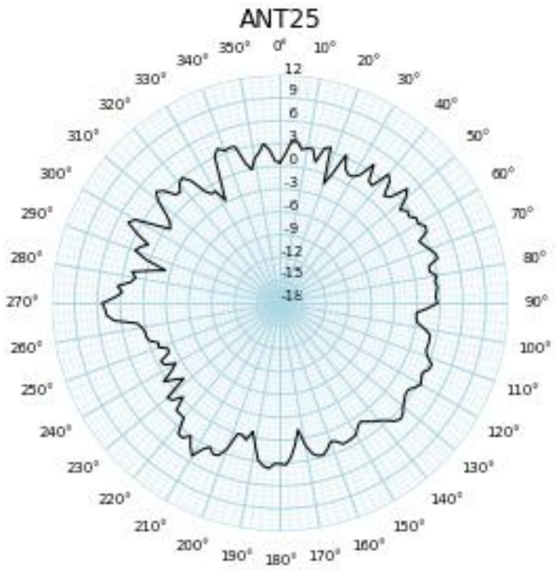

Figure 5.40 LoRa RWS antenna pattern. 0° is geographic north.

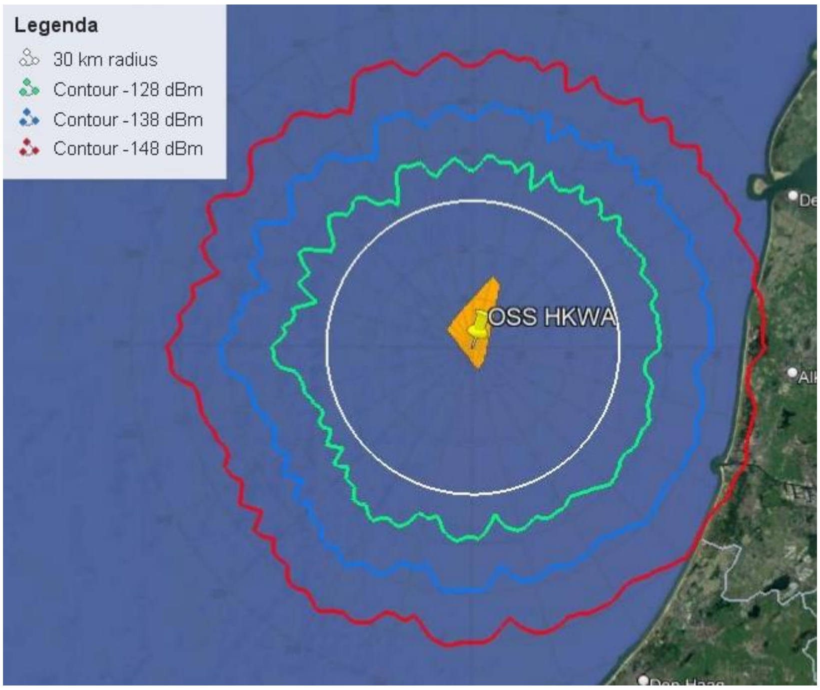

Figure 5.41 Transmit power of the LoRa remote device is set to +14 dBm with its antenna at 2.5. m a.s.l.. The heigh of the receive antenna at the HKWA OSS is 53.2 m, its gain +4 dBi.

5.4.2 Antenna 12, LoRa EXT, TRX-antenna, 868 MHz, 8 m up in the mast (53 m a.s.l.).

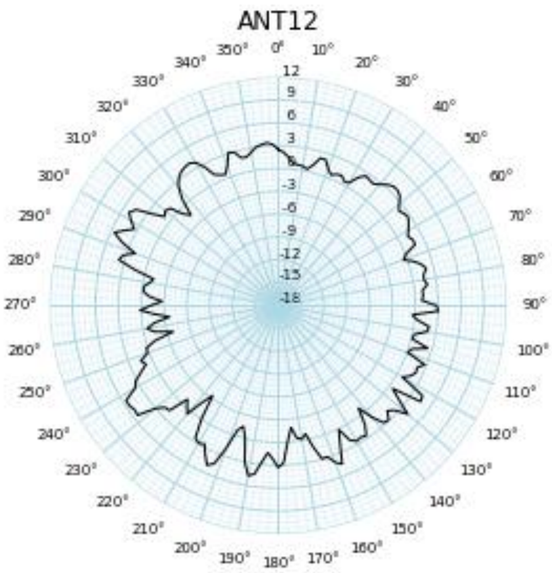

Figure 5.42 LoRa EXT antenna pattern. 0° is geographic north.

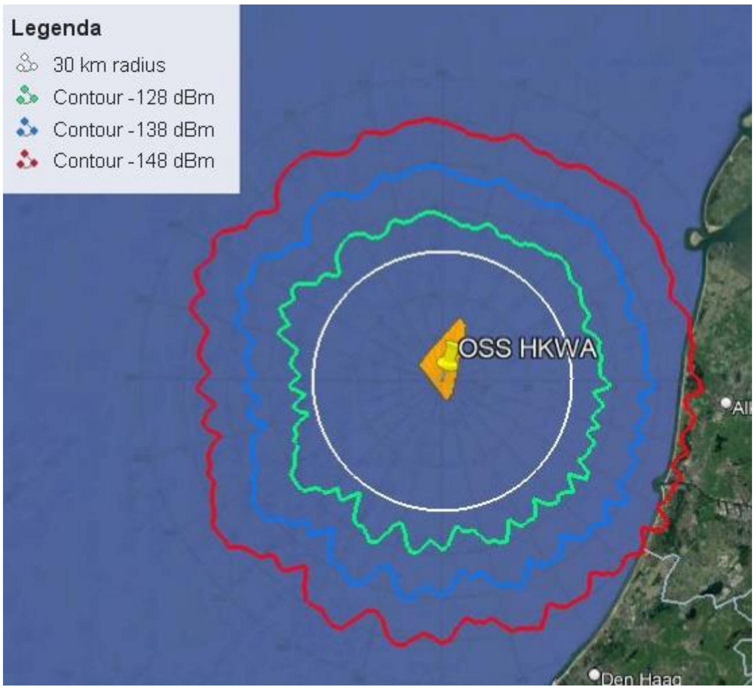

Figure 5.43 Transmit power of the LoRa remote device is set to +14 dBm with its antenna at 2.5. m a.s.l.. The heigh of the receive antenna at the HKWA OSS is 53.2 m, its gain +4 dBi.

5.5 SDNS coverage

The coverages as outlined in Figure 5.45, are based on a minimum reception sensitivity level of -90 dBm, and planes flying at an altitude of 500 ft. Transmitter power levels of **37.5, 75 and 125 Watt** are used. These power levels are based on the lowest transmit power levels for small aircraft (75 W) up to main stream airplanes which run 250 W transmitters. A line loss of 3 dB has been incorporated, hence the lower power levels used in the simulations.
TERPEM and Free Space propagation models have been used to estimate the range. Calculations based on Free Space produced detection ranges in excess of 100 km. Although this might be true in some cases, the more conservative range predictions of TERPEM are presented in the plots.

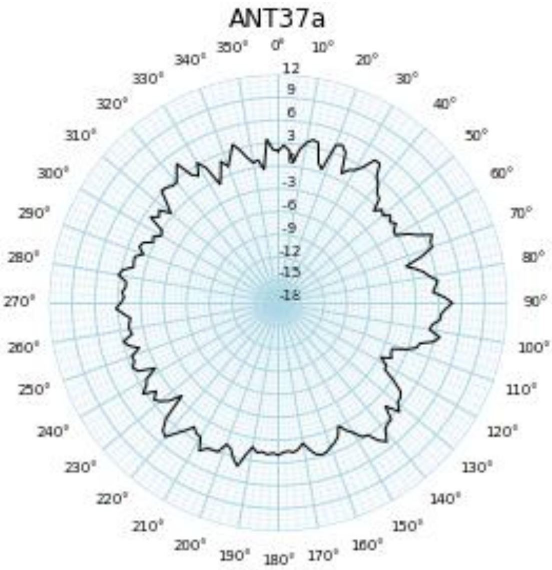

Figure 5.44 SDNS receive antenna pattern. 0° is geographic north.

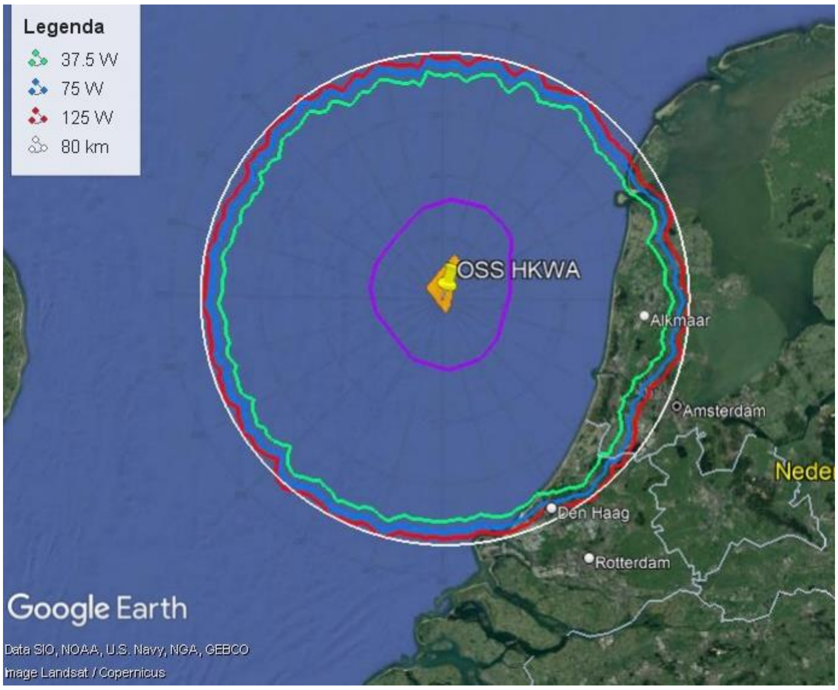

Figure 5.45 Reception coverage of the SDNS antenna at 53 m a.s.l., for an airplane flying at a height of 153 metres (500 feet) and 3 different transmit power levels

6 Conclusions

The communication mast provides about 16 metres of vertical space to install antennas for communication, navigation, RADAR and various sensors. Regarding the communication and navigation part (Marine radio, AIS and TETRA), the vertical separation sets certain limits to the maximum isolation between the various antennas which may be achieved, unless very drastic and expensive measures are considered, which are out of scope (e.g. a much taller mast, or metal isolation disks between the various antennas). Hence, the isolation between some antennas may not satisfy the required value to transmit at full power without loss of sensitivity of systems operating in the same frequency band.

The height of the communication mast on the platform is such that even with limited power of marine radio's the required communication range will be achieved. The full 40 Watts of marine radios is not required to compensate for over the horizon signal loss as may be applicable for communication between ships. A slight decrease of power level for Marine radio's will still both satisfy the wind park area + 10 NM communication range with ships as well prevent desensitisation of systems operating in the same frequency band. Hence, simultaneous operation of systems operating in the same VHF-band is possible with little or no hindrance.

Simulations have been conducted which showed that in some cases up to 11 dB of power reduction of the marine radio's was required to prevent desensitisation of a neighbouring system. Subsequent coverages calculations at these deprecated power levels, show that coverage of the wind park at -80 dBm signal levels, as well as a the required 10 NM outside the wind park area is possible, except for antenna 5. After the addition of antennas for Ecowende the results of the VHF-system interference tests in Stellendam became invalid. The actual maximum power level could not be verified at the mock-up in Stellendam as the set-up had been dismantled.

It is recommended that during the offshore interference campaign it is investigated whether a higher power level of the transmitter connected to antenna 5 is possible without unacceptable interference levels on any of the other VHF marine radio and AIS receivers. This should also be considered for antenna 9.

The simulated coverage areas are based on the signal levels as required by the standard. In practice the sensitivity of marine radio receivers is often 10 to 15 dB better than deemed necessary by the standard, hence the reception range may be significantly larger than the simulated ranges.
Radio contacts outside the simulated signal range may be prone to interference from the co-sited marine and AIS transmitters present on the OSS.

The isolation between transmitters operating in the VHF band, showed rather low levels, sometimes as little as 23 dB. This is due to limitations in the available positions on the mast were antennas could be allocated, which would provide sufficient coverage. The low decoupling levels may produce intermodulation effects in the power amplifiers of the effected transmitters, but can be countered by implementing RF-isolators.

Non-interference operation is only possible if the recommendations regarding reduced power levels and the inclusion of RF-isolators in the marine- and AIS-transmitter coax lines are observed.

6.1.1 AIS and marine radios

RF-isolators[12] are recommended to be inserted at the transmitter outputs of all marine and AIS-radios.

In order to prevent interference to other VHF systems, it is strongly advised to follow the advised power output levels as shown in Table 6.1. Based on the interference measurements conducted in Stellendam (August 2022), the power level of the transmitter 2 requires less attenuation and may be set to the same level as transmitter 1.

Table 6.1: Recommended maximum power level for attached marine radio's

System	Antenna nr.	Maximum Power (W / dBm)
Marine radio 1	4	12 / 41
Marine radio 2	5	12 / 41

6.1.2 TETRA

No detrimental effect of the TETRA transmissions are to be expected on any of the systems installed on the tower.

6.1.3 BAT-receivers

A check on the RF input filter specifications of the BAT SDR-receivers has been conducted. In August 2022[13] measurements were performed in Stellendam which involved the addition of RF input filters and the coexistence with maritime transmissions. Without RF-filters significant degradation of the BAT-receiver sensitivity occurred during maritime radio transmissions. When RF-filters were inserted in the reception line most of the degradation effects disappeared, but noise ingress from antenna 4 remained. This effect has been deemed acceptable and may be further mitigated if other BAT reception antennas are used to replace the Yagis from Sirio (WY140-6).

6.1.4 LoRa and SDNS

The isolation between LoRa and SDNS amounts more than 31 dB. The frequency difference is more than 200 MHz and RF output power of LoRa systems low (500 mW). Hence, degradation of the SDNS reception is not expected.

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[12] Single stage isolator, 5 MHz bandwidth,Tunable, 138-174 MHz – Sinclair Technologies (sinctech.com), Raditek Coaxial Isolators and Coaxial Circulators (100MHz-199MHz) | Raditek

[13] Interference measurements HKWA mast at Stellendam, TNO, R. Kruize, P.C. Hoefsloot

7 Appendix 1: Isolation between all antennas

The simulated isolation values between all antennas (i.e. also between receive-receive and transmit-transmit antennas) are presented in the tables.

Table 7.1 Isolation between RX antenna 1 and all other antennas (159 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	0	
ANT2	Marine RX	35	40
ANT3	Marine RX	30	32
ANT4	Marine TX	63	52
ANT5	Marine TX	51	45
ANT6	Marine RX	29	
ANT7	Marine RX	18	
ANT9	Marine TX	55	
ANT10	Marine TX	56	
ANT13	AIS1 TX	61	58
ANT14	AIS1 RX	29	38
ANT17	TETRA1 RX	62	
ANT18	TETRA1 TX&RX	71	
ANT20	TETRA2 RX	66	
ANT21	GPS, TETRA1	88	
ANT22	GPS, TETRA2	89	
ANT23	GPS, AIS1	120	
ANT25	LoRa	93	54
ANT28	TETRA2 TX&RX	79	
ANT12	LoRa (EXT)	100	
ANT37a	SDNS	101	
ANT37b	SDNS, GPS	103	
ANT40	BAT	44	
ANT41	BAT	41	95 (incl BPF)
ANT42	BAT	76	
ANT43	BAT	58	90 (incl BPF)
ANT44	BAT	57	
ANT45	BAT	52	78 (incl BPF)
ANT47[14]	BAT, GPS		
ANT48	BAT, GPS		

[14] GPS antennas 47 and 48 were added to the mast design by RWS in December ’22, hence were not incorporated in the simulations. Antennas 6, 7, 9 and 10 were added in June ’23. At the same time antennas 15, 24 and 29 were removed.

Table 7.2 Isolation between RX antenna 2 and all other antennas (159 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	34	40
ANT2	Marine RX	0	
ANT3	Marine RX	21	31
ANT4	Marine TX	53	56
ANT5	Marine TX	70	56
ANT6	Marine RX	31	
ANT7	Marine RX	55	
ANT9	Marine TX	76	
ANT10	Marine TX	69	
ANT13	AIS1 TX	54	57
ANT14	AIS1 RX	50	23
ANT17	TETRA1 RX	63	
ANT18	TETRA1 TX&RX	79	
ANT20	TETRA2 RX	71	
ANT21	GPS, TETRA1	91	
ANT22	GPS, TETRA2	103	
ANT23	GPS, AIS1	101	
ANT25	LoRa	95	56
ANT28	TETRA2 TX&RX	81	
ANT12	LoRa (EXT)	92	
ANT37a	SDNS	101	
ANT37b	SDNS, GPS	119	
ANT40	BAT	40	
ANT41	BAT	37	75 (incl BPF)
ANT42	BAT	55	
ANT43	BAT	51	90 (incl BPF)
ANT44	BAT	52	
ANT45	BAT	71	95 (incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.3 Isolation between RX antenna 3 and all other antennas (159 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	30	31
ANT2	Marine RX	22	32
ANT3	Marine RX	0	
ANT4	Marine TX	58	56
ANT5	Marine TX	64	58
ANT6	Marine RX	29	
ANT7	Marine RX	21	
ANT9	Marine TX	54	
ANT10	Marine TX	67	
ANT13	AIS1 TX	56	56
ANT14	AIS1 RX	28	34
ANT17	TETRA1 RX	67	
ANT18	TETRA1 TX&RX	88	
ANT20	TETRA2 RX	62	
ANT21	GPS, TETRA1	91	
ANT22	GPS, TETRA2	86	
ANT23	GPS, AIS1	98	
ANT25	LoRa	88	
ANT28	TETRA2 TX&RX	83	
ANT12	LoRa (EXT)	87	
ANT37a	SDNS	93	
ANT37b	SDNS, GPS	100	
ANT40	BAT	37	
ANT41	BAT	46	95 (incl BPF)
ANT42	BAT	76	
ANT43	BAT	51	95 (incl BPF)
ANT44	BAT	43	
ANT45	BAT	43	85 (incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.4 Isolation between TX antenna 4 and all other antennas (159 MHz).

Antenna nr.	**Application**	**Isolation [dB]**	
		Simulated	**Measured**
ANT1	Marine RX	60	52
ANT2	Marine RX	58	56
ANT3	Marine RX	63	56
ANT4	Marine TX	0	
ANT5	Marine TX	50	42
ANT6	Marine RX	55	
ANT7	Marine RX	66	
ANT9	Marine TX	67	
ANT10	Marine TX	23	
ANT13	AIS1 TX	26	42
ANT14	AIS1 RX	80	57
ANT17	TETRA1 RX	66	
ANT18	TETRA1 TX&RX	42	
ANT20	TETRA2 RX	63	
ANT21	GPS, TETRA1	81	
ANT22	GPS, TETRA2	89	
ANT23	GPS, AIS1	89	
ANT25	LoRa	65	29
ANT28	TETRA2 TX&RX	55	
ANT12	LoRa (EXT)	74	
ANT37a	SDNS	76	
ANT37b	SDNS, GPS	79	
ANT40	BAT	57	
ANT41	BAT	54	100 (incl BPF)
ANT42	BAT	59	
ANT43	BAT	59	100 (incl BPF)
ANT44	BAT	54	
ANT45	BAT	58	80 (incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.5 Isolation between TX antenna 5 and all other antennas (159 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	50	56
ANT2	Marine RX	58	56
ANT3	Marine RX	58	56
ANT4	Marine TX	41	42
ANT5	Marine TX	0	
ANT6	Marine RX	90	
ANT7	Marine RX	65	
ANT9	Marine TX	43	
ANT10	Marine TX	44	
ANT13	AIS1 TX	23	27
ANT14	AIS1 RX	53	58
ANT17	TETRA1 RX	65	
ANT18	TETRA1 TX&RX	43	
ANT20	TETRA2 RX	70	
ANT21	GPS, TETRA1	92	
ANT22	GPS, TETRA2	111	
ANT23	GPS, AIS1	112	
ANT25	LoRa	73	51
ANT28	TETRA2 TX&RX	53	
ANT12	LoRa (EXT)	75	
ANT37a	SDNS	68	
ANT37b	SDNS, GPS	72	
ANT40	BAT	56	
ANT41	BAT	54	90(incl BPF)
ANT42	BAT	59	
ANT43	BAT	61	90(incl BPF)
ANT44	BAT	54	
ANT45	BAT	53	90(incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.6 Isolation between RX antenna 6 and all other antennas (159 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	31	
ANT2	Marine RX	33	
ANT3	Marine RX	30	
ANT4	Marine TX	57	
ANT5	Marine TX	66	
ANT6	Marine RX	0	
ANT7	Marine RX	26	
ANT9	Marine TX	98	
ANT10	Marine TX	60	
ANT13	AIS1 TX	51	
ANT14	AIS1 RX	26	
ANT17	TETRA1 RX	61	
ANT18	TETRA1 TX&RX	78	
ANT20	TETRA2 RX	63	
ANT21	GPS, TETRA1	40	
ANT22	GPS, TETRA2	41	
ANT23	GPS, AIS1	91	
ANT25	LoRa	91	
ANT28	TETRA2 TX&RX	86	
ANT12	LoRa (EXT)	119	
ANT37a	SDNS	98	
ANT37b	SDNS, GPS	108	
ANT40	BAT	44	
ANT41	BAT	45	
ANT42	BAT	37	
ANT43	BAT	36	
ANT44	BAT	46	
ANT45	BAT	44	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.7 Isolation between RX antenna 7 and all other antennas (159 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	19	
ANT2	Marine RX	68	
ANT3	Marine RX	21	
ANT4	Marine TX	65	
ANT5	Marine TX	58	
ANT6	Marine RX	26	
ANT7	Marine RX	0	
ANT9	Marine TX	67	
ANT10	Marine TX	54	
ANT13	AIS1 TX	66	
ANT14	AIS1 RX	29	
ANT17	TETRA1 RX	87	
ANT18	TETRA1 TX&RX	73	
ANT20	TETRA2 RX	67	
ANT21	GPS, TETRA1	81	
ANT22	GPS, TETRA2	97	
ANT23	GPS, AIS1	90	
ANT25	LoRa	94	
ANT28	TETRA2 TX&RX	82	
ANT12	LoRa (EXT)	104	
ANT37a	SDNS	96	
ANT37b	SDNS, GPS	113	
ANT40	BAT	44	
ANT41	BAT	52	
ANT42	BAT	49	
ANT43	BAT	55	
ANT44	BAT	50	
ANT45	BAT	54	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.8 Isolation between TX antenna 9 and all other antennas (159 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	54	
ANT2	Marine RX	66	
ANT3	Marine RX	52	
ANT4	Marine TX	20	
ANT5	Marine TX	42	
ANT6	Marine RX	78	
ANT7	Marine RX	56	
ANT9	Marine TX	0	
ANT10	Marine TX	30	
ANT13	AIS1 TX	28	
ANT14	AIS1 RX	55	
ANT17	TETRA1 RX	61	
ANT18	TETRA1 TX&RX	63	
ANT20	TETRA2 RX	78	
ANT21	GPS, TETRA1	90	
ANT22	GPS, TETRA2	91	
ANT23	GPS, AIS1	83	
ANT25	LoRa	70	
ANT28	TETRA2 TX&RX	54	
ANT12	LoRa (EXT)	73	
ANT37a	SDNS	91	
ANT37b	SDNS, GPS	81	
ANT40	BAT	52	
ANT41	BAT	55	
ANT42	BAT	59	
ANT43	BAT	54	
ANT44	BAT	57	
ANT45	BAT	63	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.9 Isolation between TX antenna 10 and all other antennas (159 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	77	
ANT2	Marine RX	58	
ANT3	Marine RX	77	
ANT4	Marine TX	23	
ANT5	Marine TX	26	
ANT6	Marine RX	64	
ANT7	Marine RX	55	
ANT9	Marine TX	33	
ANT10	Marine TX	0	
ANT13	AIS1 TX	38	
ANT14	AIS1 RX	54	
ANT17	TETRA1 RX	61	
ANT18	TETRA1 TX&RX	41	
ANT20	TETRA2 RX	79	
ANT21	GPS, TETRA1	84	
ANT22	GPS, TETRA2	90	
ANT23	GPS, AIS1	>100	
ANT25	LoRa	69	
ANT28	TETRA2 TX&RX	42	
ANT12	LoRa (EXT)	70	
ANT37a	SDNS	90	
ANT37b	SDNS, GPS	87	
ANT40	BAT	55	
ANT41	BAT	55	
ANT42	BAT	79	
ANT43	BAT	57	
ANT44	BAT	51	
ANT45	BAT	62	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.10 Isolation between TX/RX antenna 12 and other antennas (868 MHz). As a subsection of the tower had to be used, no simulations could be performed on more distant positioned antennas.

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX		
ANT2	Marine RX		
ANT3	Marine RX		
ANT4	Marine TX	63	
ANT5	Marine TX	44	
ANT13	AIS1 TX	69	
ANT14	AIS1 RX		
ANT17	TETRA1 RX	64	
ANT18	TETRA1 TX&RX	57	
ANT20	TETRA2 RX	89	
ANT21	GPS, TETRA1	57	
ANT22	GPS, TETRA2	70	
ANT23	GPS, AIS1	59	
ANT25	LoRa	43	
ANT28	TETRA2 TX&RX	51	
ANT12	LoRa (EXT)	0	
ANT37a	SDNS	40	
ANT37b	GPS	61	
ANT40	BAT		
ANT41	BAT		
ANT42	BAT		
ANT43	BAT		
ANT44	BAT		
ANT45	BAT		
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.11 Isolation between TX antenna 13 and all other antennas (162 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	56	58
ANT2	Marine RX	70	57
ANT3	Marine RX	67	56
ANT4	Marine TX	31	42
ANT5	Marine TX	36	27
ANT6	Marine RX	59	
ANT7	Marine RX	54	
ANT9	Marine TX	22	
ANGT10	Marine TX	32	
ANT13	AIS1 TX	0	
ANT14	AIS1 RX	67	53
ANT17	TETRA1 RX	69	
ANT18	TETRA1 TX&RX	45	
ANT20	TETRA2 RX	68	
ANT21	GPS, TETRA1	117	
ANT22	GPS, TETRA2	93	
ANT23	GPS, AIS1	89	
ANT25	LoRa	107	47
ANT28	TETRA2 TX&RX	59	
ANT12	LoRa (EXT)	80	
ANT37a	SDNS	91	
ANT37b	SDNS, GPS	82	
ANT40	BAT	54	
ANT41	BAT	48	90 (incl BPF)
ANT42	BAT	78	
ANT43	BAT	46	85 (incl BPF)
ANT44	BAT	62	
ANT45	BAT	67	95 (incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.12 Isolation between RX antenna 14 and all other antennas (162 MHz)

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	25	38
ANT2	Marine RX	22	23
ANT3	Marine RX	33	34
ANT4	Marine TX	73	57
ANT5	Marine TX	60	58
ANT6	Marine RX	29	
ANT7	Marine RX	31	
ANT9	Marine TX	56	
ANGT10	Marine TX	51	
ANT13	AIS1 TX	62	53
ANT14	AIS1 RX	0	
ANT17	TETRA1 RX	73	
ANT18	TETRA1 TX&RX	80	
ANT20	TETRA2 RX	61	
ANT21	GPS, TETRA1	85	
ANT22	GPS, TETRA2	96	
ANT23	GPS, AIS1	90	
ANT25	LoRa	86	56
ANT28	TETRA2 TX&RX	74	
ANT12	LoRa (EXT)	88	
ANT37a	SDNS	107	
ANT37b	SDNS, GPS	109	
ANT40	BAT	43	
ANT41	BAT	44	85 (incl BPF)
ANT42	BAT	44	
ANT43	BAT	45	100 (incl BPF)
ANT44	BAT	42	
ANT45	BAT	56	95 (incl BPF)
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.13 Isolation between RX antenna 17 and all other antennas (420 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	58	
ANT2	Marine RX	69	
ANT3	Marine RX	61	
ANT4	Marine TX	76	
ANT5	Marine TX	61	
ANT13	AIS1 TX	65	
ANT14	AIS1 RX	66	
ANT17	TETRA1 RX	0	
ANT18	TETRA1 TX&RX	54	
ANT20	TETRA2 RX	26	
ANT21	GPS, TETRA1	54	
ANT22	GPS, TETRA2	52	
ANT23	GPS, AIS1	59	
ANT25	LoRa	74	
ANT28	TETRA2 TX&RX	47	
ANT12	LoRa (EXT)	72	
ANT37a	SDNS	74	
ANT37b	SDNS, GPS	103	
ANT40	BAT	44	
ANT41	BAT	62	
ANT42	BAT	55	
ANT43	BAT	61	
ANT44	BAT	60	
ANT45	BAT	42	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.14 Isolation between RX&TX antenna 18 and all other antennas (420 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	65	
ANT2	Marine RX	75	
ANT3	Marine RX	79	
ANT4	Marine TX	44	
ANT5	Marine TX	28	
ANT13	AIS1 TX	34	
ANT14	AIS1 RX	92	
ANT17	TETRA1 RX	52	
ANT18	TETRA1 TX&RX	0	
ANT20	TETRA2 RX	58	
ANT21	GPS, TETRA1	74	
ANT22	GPS, TETRA2	90	
ANT23	GPS, AIS1	89	
ANT25	LoRa	67	
ANT28	TETRA2 TX&RX	26	
ANT12	LoRa (EXT)	58	
ANT37a	SDNS	75	
ANT37b	SDNS, GPS	73	
ANT40	BAT	82	
ANT41	BAT	58	
ANT42	BAT	67	
ANT43	BAT	68	
ANT44	BAT	57	
ANT45	BAT	60	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.15 Isolation between RX TETRA2 antenna 20 and all other antennas (420 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	58	
ANT2	Marine RX	67	
ANT3	Marine RX	60	
ANT4	Marine TX	62	
ANT5	Marine TX	67	
ANT13	AIS1 TX	76	
ANT14	AIS1 RX	83	
ANT17	TETRA1 RX	26	
ANT18	TETRA1 TX&RX	56	
ANT20	TETRA2 RX	0	
ANT21	GPS, TETRA1	53	
ANT22	GPS, TETRA2	62	
ANT23	GPS, AIS1	56	
ANT25	LoRa	87	
ANT28	TETRA2 TX&RX	68	
ANT12	LoRa (EXT)	88	
ANT37a	SDNS	71	
ANT37b	SDNS, GPS	80	
ANT40	BAT	55	
ANT41	BAT	55	
ANT42	BAT	57	
ANT43	BAT	54	
ANT44	BAT	59	
ANT45	BAT	49	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.16 Isolation between TX/RX antenna 25 and other antennas (868 MHz). As a subsection of the tower had to be used, no simulations could be performed on more distant positioned antennas.

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX		76
ANT2	Marine RX		84
ANT3	Marine RX		69
ANT4	Marine TX	65	85
ANT5	Marine TX	56	70
ANT13	AIS1 TX	56	70
ANT14	AIS1 RX		59
ANT17	TETRA1 RX	56	
ANT18	TETRA1 TX&RX	55	
ANT20	TETRA2 RX	69	
ANT21	GPS, TETRA1	63	
ANT22	GPS, TETRA2	59	
ANT23	GPS, AIS1	59	
ANT25	LoRa	0	
ANT28	TETRA2 TX&RX	52	
ANT12	LoRa (EXT)	42	
ANT37a	SDNS	44	
ANT37b	SDNS, GPS	54	
ANT40	BAT		
ANT41	BAT		75
ANT42	BAT		
ANT43	BAT		85
ANT44	BAT		
ANT45	BAT		87
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.17 Isolation between RX&TX TETRA2 antenna 28 and all other antennas (420 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	74	
ANT2	Marine RX	72	
ANT3	Marine RX	67	
ANT4	Marine TX	38	
ANT5	Marine TX	34	
ANT13	AIS1 TX	29	
ANT14	AIS1 RX	75	
ANT17	TETRA1 RX	58	
ANT18	TETRA1 TX&RX	26	
ANT20	TETRA2 RX	65	
ANT21	GPS, TETRA1	77	
ANT22	GPS, TETRA2	108	
ANT23	GPS, AIS1	78	
ANT25	LoRa	76	
ANT28	TETRA2 TX&RX	0	
ANT12	LoRa (EXT)	61	
ANT37a	SDNS	61	
ANT37b	SDNS, GPS	70	
ANT40	BAT	74	
ANT41	BAT	57	
ANT42	BAT	56	
ANT43	BAT	60	
ANT44	BAT	62	
ANT45	BAT	68	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.18 Isolation between RX antenna 37a and all other antennas (1090 MHz). As a subsection of the tower had to be used, no simulations could be performed on more distant positioned antennas in the same mast.

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT4	Marine TX	57	
ANT5	Marine TX	52	
ANT13	AIS1 TX	69	
ANT17	TETRA1 RX	60	
ANT18	TETRA1 TX&RX	54	
ANT20	TETRA2 RX	52	
ANT21	GPS, TETRA1	59	
ANT22	GPS, TETRA2	68	
ANT23	GPS, AIS1	64	
ANT25	LoRa	54	
ANT28	TETRA2 TX&RX	48	
ANT12	LoRa (EXT)	41	
ANT37b	SDNS, GPS	21	

Table 7.19 Isolation between TX/RX antenna 40 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	35	
ANT2	Marine RX	35	
ANT3	Marine RX	38	
ANT4	Marine TX	48	
ANT5	Marine TX	43	
ANT13	AIS1 TX	54	
ANT14	AIS1 RX	41	
ANT17	TETRA1 RX	56	
ANT18	TETRA1 TX&RX	82	
ANT20	TETRA2 RX	60	
ANT21	GPS, TETRA1	80	
ANT22	GPS, TETRA2	80	
ANT23	GPS, AIS1	83	
ANT25	LoRa	117	
ANT28	TETRA2 TX&RX	92	
ANT12	LoRa (EXT)	84	
ANT37a	SDNS	102	
ANT37b	SDNS, GPS	101	
ANT40	BAT	0	
ANT41	BAT	41	
ANT42	BAT	44	
ANT43	BAT	35	
ANT44	BAT	40	
ANT45	BAT	51	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.20 Isolation between TX/RX antenna 41 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	52	55
ANT2	Marine RX	36	39
ANT3	Marine RX	59	55
ANT4	Marine TX	51	65
ANT5	Marine TX	56	55
ANT13	AIS1 TX	43	50
ANT14	AIS1 RX	44	44
ANT17	TETRA1 RX	59	
ANT18	TETRA1 TX&RX	67	
ANT20	TETRA2 RX	70	
ANT21	GPS, TETRA1	81	
ANT22	GPS, TETRA2	77	
ANT23	GPS, AIS1	106	
ANT25	LoRa	91	
ANT28	TETRA2 TX&RX	79	
ANT12	LoRa (EXT)	80	
ANT37a	SDNS	75	
ANT37b	SDNS, GPS	79	
ANT40	BAT	42	
ANT41	BAT	0	
ANT42	BAT	44	
ANT43	BAT	51	63
ANT44	BAT	37	
ANT45	BAT	36	56
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.21 Isolation between TX/RX antenna 42 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	45	
ANT2	Marine RX	49	
ANT3	Marine RX	49	
ANT4	Marine TX	47	
ANT5	Marine TX	64	
ANT13	AIS1 TX	49	
ANT14	AIS1 RX	45	
ANT17	TETRA1 RX	68	
ANT18	TETRA1 TX&RX	80	
ANT20	TETRA2 RX	59	
ANT21	GPS, TETRA1	104	
ANT22	GPS, TETRA2	90	
ANT23	GPS, AIS1	82	
ANT25	LoRa	85	
ANT28	TETRA2 TX&RX	70	
ANT12	LoRa (EXT)	82	
ANT37a	SDNS	81	
ANT37b	SDNS, GPS	86	
ANT40	BAT	57	
ANT41	BAT	42	
ANT42	BAT	0	
ANT43	BAT	57	
ANT44	BAT	73	
ANT45	BAT	38	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.22 Isolation between TX/RX antenna 43 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured
ANT1	Marine RX	38	50
ANT2	Marine RX	39	55
ANT3	Marine RX	61	53
ANT4	Marine TX	64	54
ANT5	Marine TX	47	60
ANT13	AIS1 TX	48	50
ANT14	AIS1 RX	48	54
ANT17	TETRA1 RX	64	
ANT18	TETRA1 TX&RX	68	
ANT20	TETRA2 RX	56	
ANT21	GPS, TETRA1	89	
ANT22	GPS, TETRA2	83	
ANT23	GPS, AIS1	73	
ANT25	LoRa	93	
ANT28	TETRA2 TX&RX	76	
ANT12	LoRa (EXT)	115	
ANT37a	SDNS	90	
ANT37b	SDNS, GPS	94	
ANT40	BAT	37	
ANT41	BAT	48	63
ANT42	BAT	40	
ANT43	BAT	0	
ANT44	BAT	38	
ANT45	BAT	33	55
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.23 Isolation between TX/RX antenna 44 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated	Measured)
ANT1	Marine RX	57	
ANT2	Marine RX	45	
ANT3	Marine RX	44	
ANT4	Marine TX	56	
ANT5	Marine TX	45	
ANT13	AIS1 TX	49	
ANT14	AIS1 RX	54	
ANT17	TETRA1 RX	70	
ANT18	TETRA1 TX&RX	71	
ANT20	TETRA2 RX	58	
ANT21	GPS, TETRA1	92	
ANT22	GPS, TETRA2	90	
ANT23	GPS, AIS1	99	
ANT25	LoRa	86	
ANT28	TETRA2 TX&RX	74	
ANT12	LoRa (EXT)	87	
ANT37a	SDNS	97	
ANT37b	SDNS, GPS	117	
ANT40	BAT	51	
ANT41	BAT	36	
ANT42	BAT	40	
ANT43	BAT	38	
ANT44	BAT	0	
ANT45	BAT	56	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

Table 7.24 Isolation between TX/RX antenna 45 and all other antennas (150 MHz).

Antenna nr.	Application	Isolation [dB]	
		Simulated (magnitude)	Simulated (real)
ANT1	Marine RX	47	42
ANT2	Marine RX	63	55
ANT3	Marine RX	39	47
ANT4	Marine TX	43	42
ANT5	Marine TX	48	54
ANT13	AIS1 TX	49	61
ANT14	AIS1 RX	43	54
ANT17	TETRA1 RX	50	
ANT18	TETRA1 TX&RX	65	
ANT20	TETRA2 RX	61	
ANT21	GPS, TETRA1	98	
ANT22	GPS, TETRA2	79	
ANT23	GPS, AIS1	85	
ANT25	LoRa	104	
ANT28	TETRA2 TX&RX	78	
ANT12	LoRa (EXT)	88	
ANT37a	SDNS	118	
ANT37b	SDNS, GPS	136	
ANT40	BAT	40	
ANT41	BAT	35	56
ANT42	BAT	36	
ANT43	BAT	33	55
ANT44	BAT	54	
ANT45	BAT	0	
ANT47	BAT, GPS		
ANT48	BAT, GPS		

8 Appendix 2: Antenna positions (locations and angles)

All positions and angles are based on Bracket dimensions of 1 and 1.5 m.

Green line = 1 m Bracket

Orange line = 1.5 m Bracket

Direction of BAT-antennas

Bold dimensions in [mm]

Decks are counted from Bottom to Top. HKWA has 6 decks, similar to the earlier platforms HKZ and Borssele.

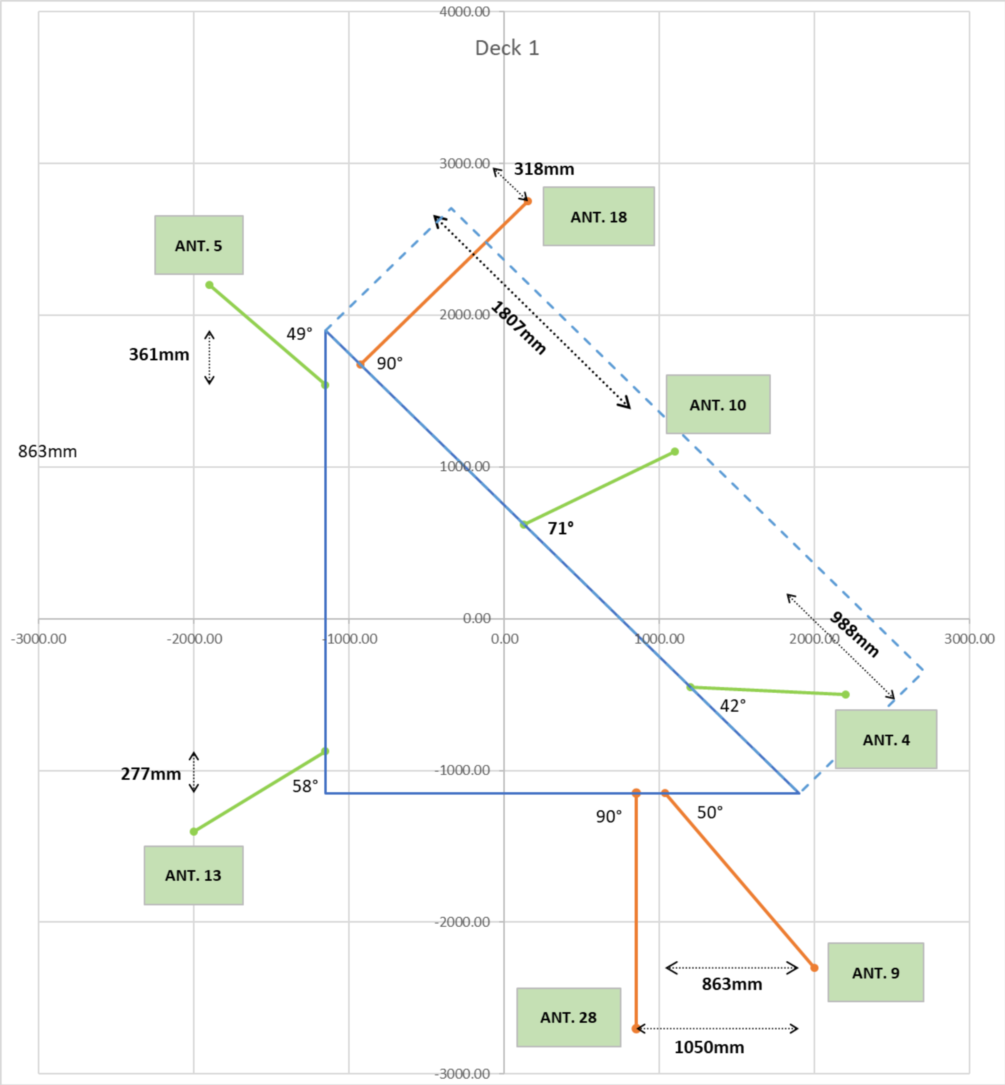

Figure 8.1 Bracket mounting dimensions and positions, deck 1

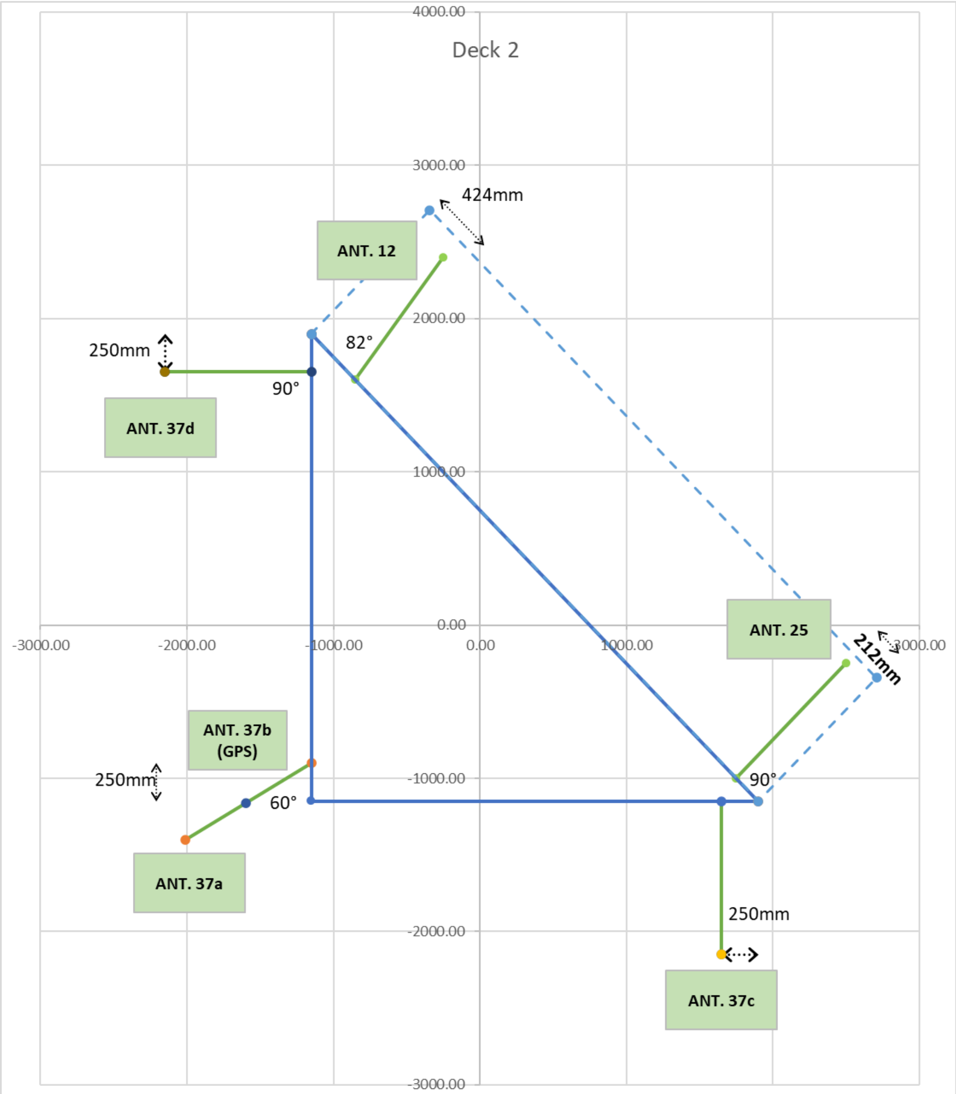

Figure 8.2 Bracket mounting dimensions and positions, deck 2

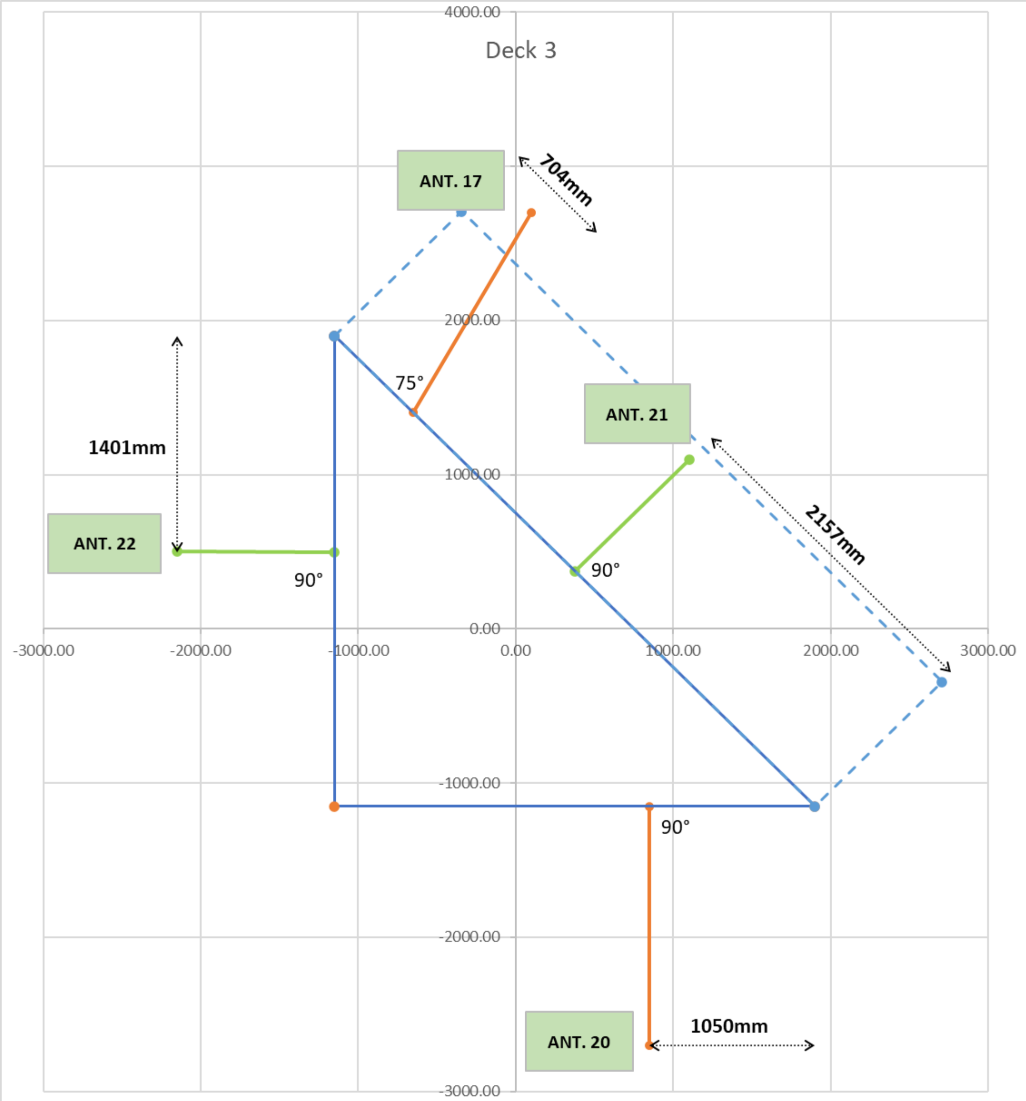

Figure 8.3 Bracket mounting dimensions and positions, deck 3

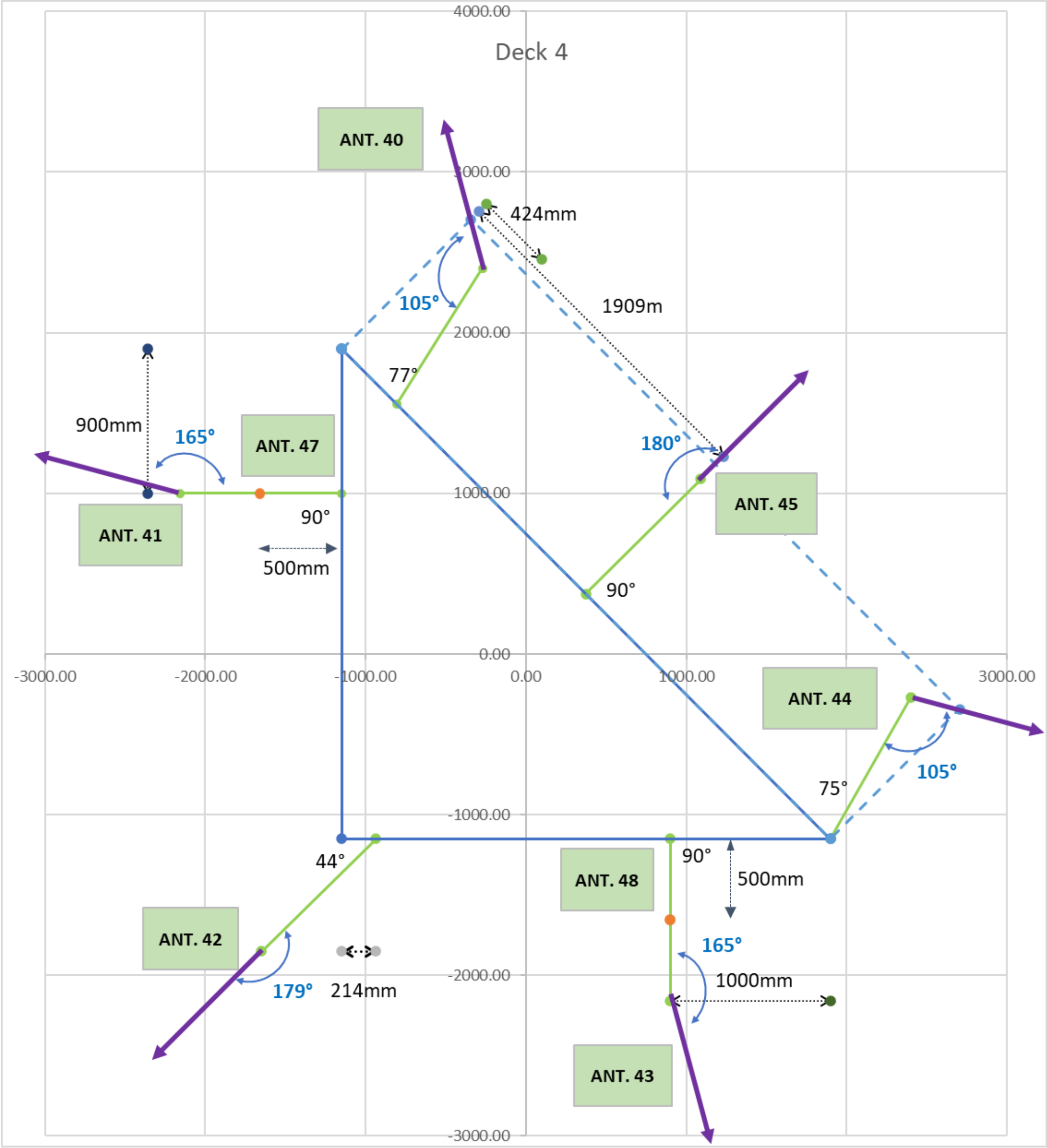

Figure 8.4 Bracket mounting dimensions and positions, deck 4

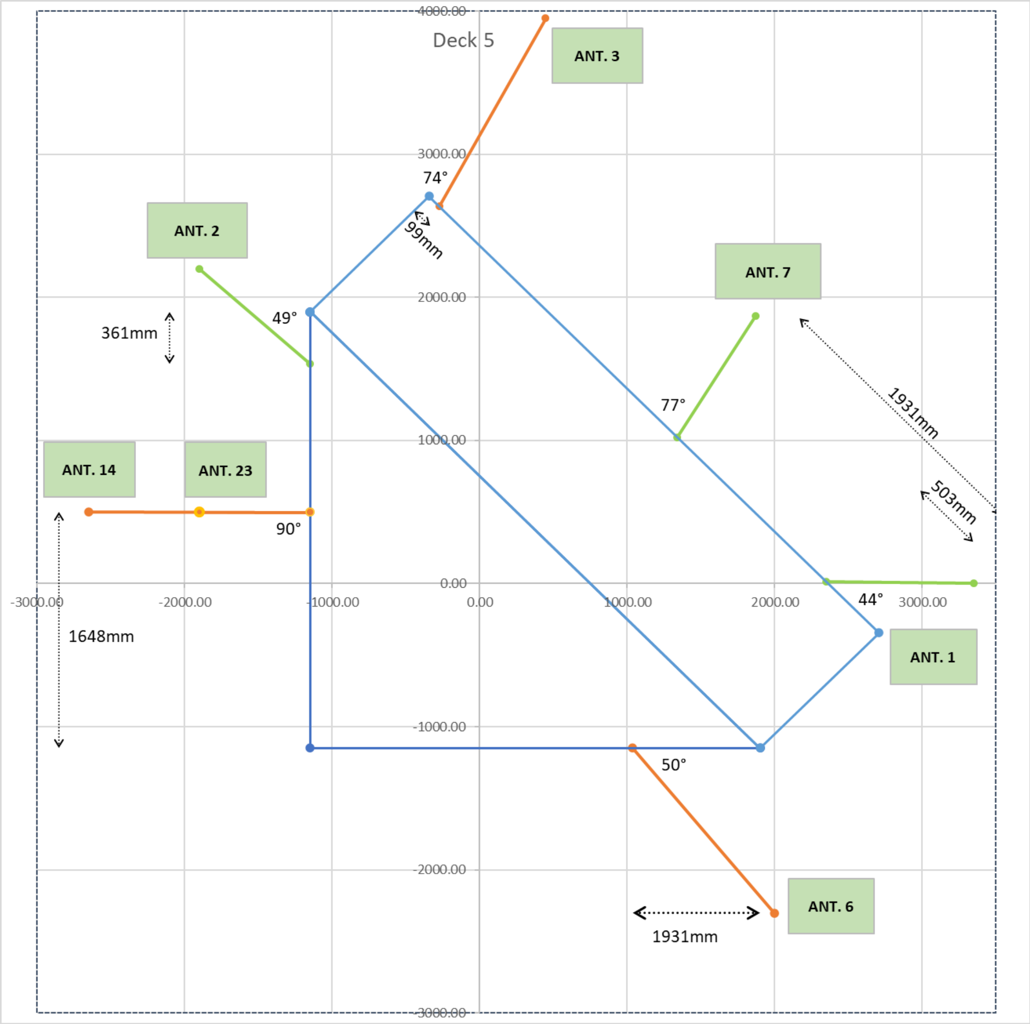

Figure 8.5 Bracket mounting dimensions and positions, deck 5

9 Appendix 3: Radiation Hazards

The occurrence of an electromagnetic (EM) field near an antenna is a logical consequence from transmissions. Very high and extended exposure to electromagnetic fields may be harmful.
Exposure human safety levels to EM fields is divided into two categories: Civilian population and “workers”. Both frequency dependent levels are displayed in Figure 9.4 through Figure 9.6. The field strength levels for workers are designated as Action Levels.
Electronic equipment needs to comply with electromagnetic field strength levels of 10 V/m. The applicable field strength contours are plotted in Figure 9.7 through Figure 9.9.

The European commission has published a document[15] which advices on the maximum exposure levels for the frequency spectrum ranging from 1 Hz up to 300 GHz. In the document Exposure (ELVs) and Activation levels (ALs) levels are described. ELVs focus on health effects (sensory and tissue). The ALs are a subset ensuring safe limits which will not result in ill health effects. Those ALs are shown in Table 9.1, and apply to the communication and navigation systems in the HKWA mast. Exposure levels are defined as averaged over a 6 minute time interval.

Table 9.1 Electric field levels for civilian population (Reference Levels) and workers (Action Levels[16]).

Freq. range	**Electric Field strength [V/m]**	
	Civilian population (Reference Levels)	**Workers (Action Levels)**
10 – 400 MHz	28	61
400 – 2000 MHz	1,375 x $\sqrt{freq}[MHz]$	$3 \times 10^{-3} \times \sqrt{freq}[Hz]$
2 – 300 GHz	61	140

Figure 9.4, 9.2 and 9.3 show the Action Level contours (i.e. according to Table 9.1) as they may occur on the HKWA mast under *operational*[17] power level conditions:

- 12.5 Watt for marine radios and AIS
- 500 mW for LoRa
- 1.1 Watt for RTK and
- 10 Watt for TETRA.

The “balloons” show the contours of the frequency specific field strength levels.

[15] DIRECTIVE 2013/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2013

[16] Table B1 from DIRECTIVE 2013/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2013

[17] The marine transmitters run at a limited power level, as advised in this report, the so called “Operational Power Levels”.

9.1 Civilian population maximum field strength levels (28 V/m)

The views on the masts are taken slightly from *above*.

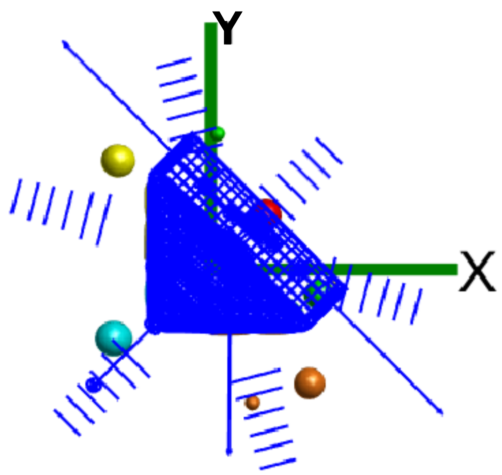

Figure 9.1 Top View. Reference Level field strength limits under operational conditions

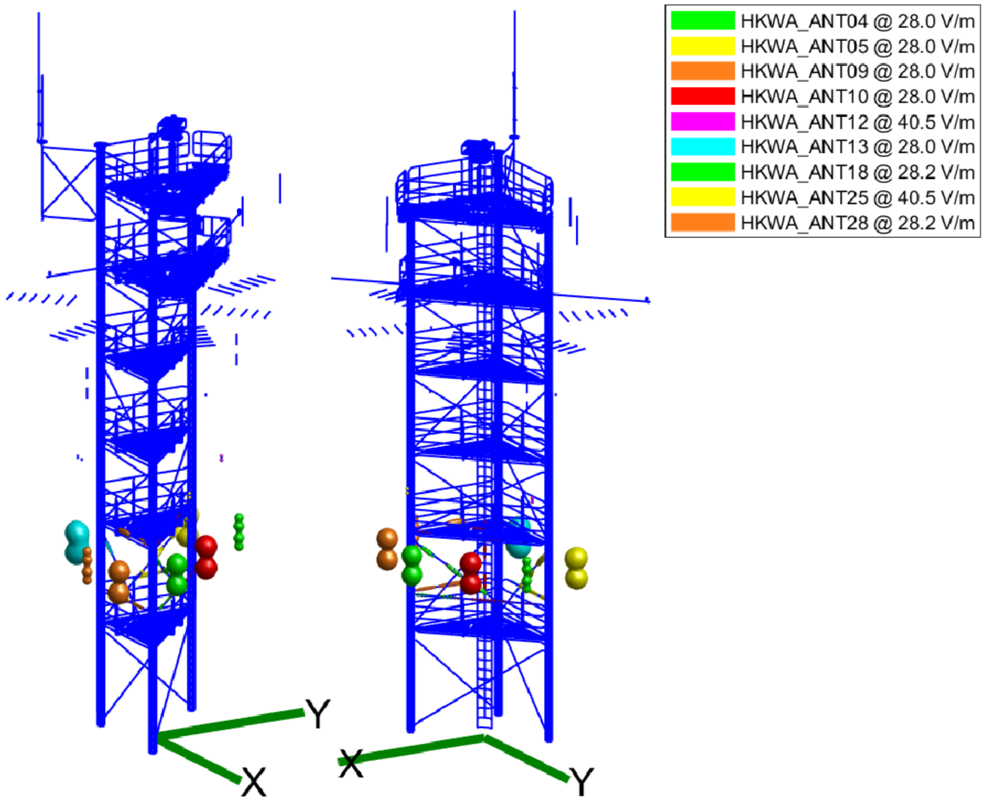

Figure 9.2 Side views. Reference Level field strength limits under operational conditions

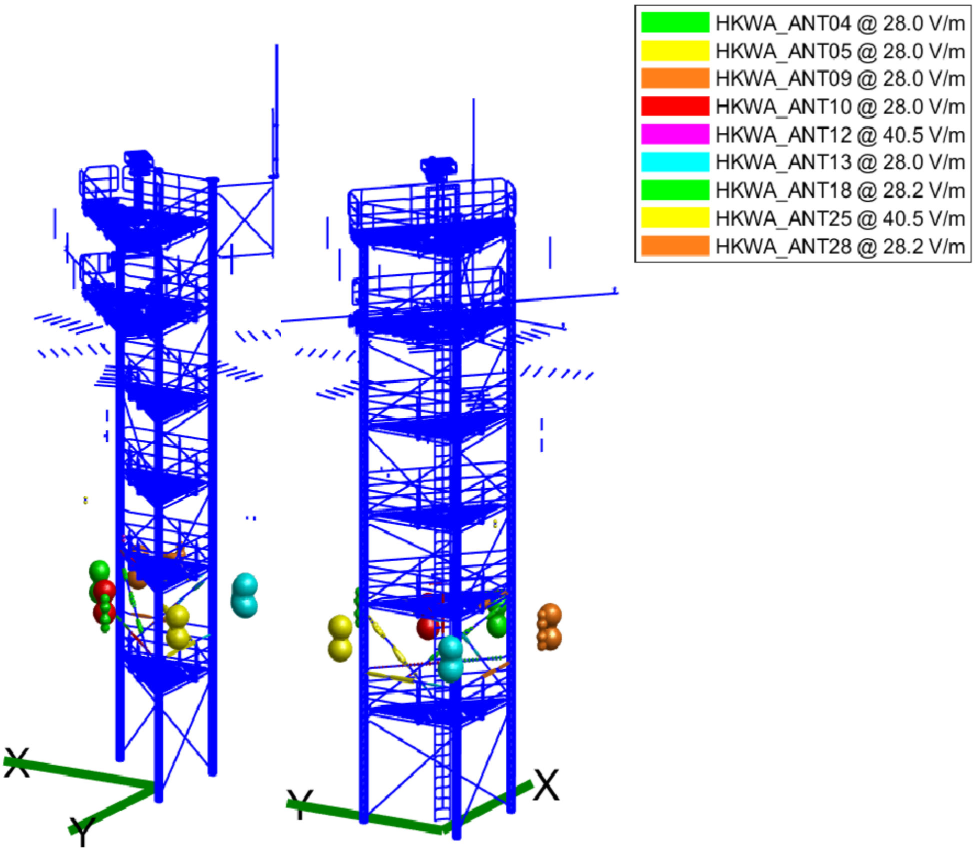

Figure 9.3 Side views. Reference Level field strength limits under operational conditions

9.2 Action Levels, applicable to workers (≈ 61 V/m)

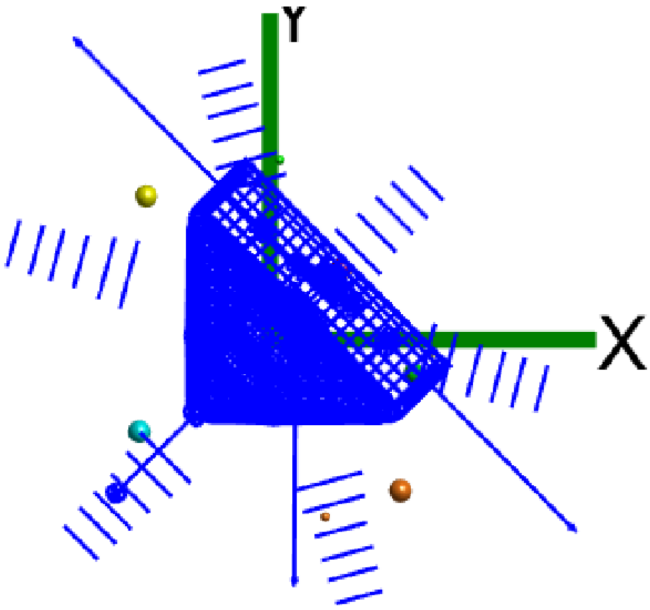

Figure 9.4 Top View. Action Level field strength limits under operational conditions

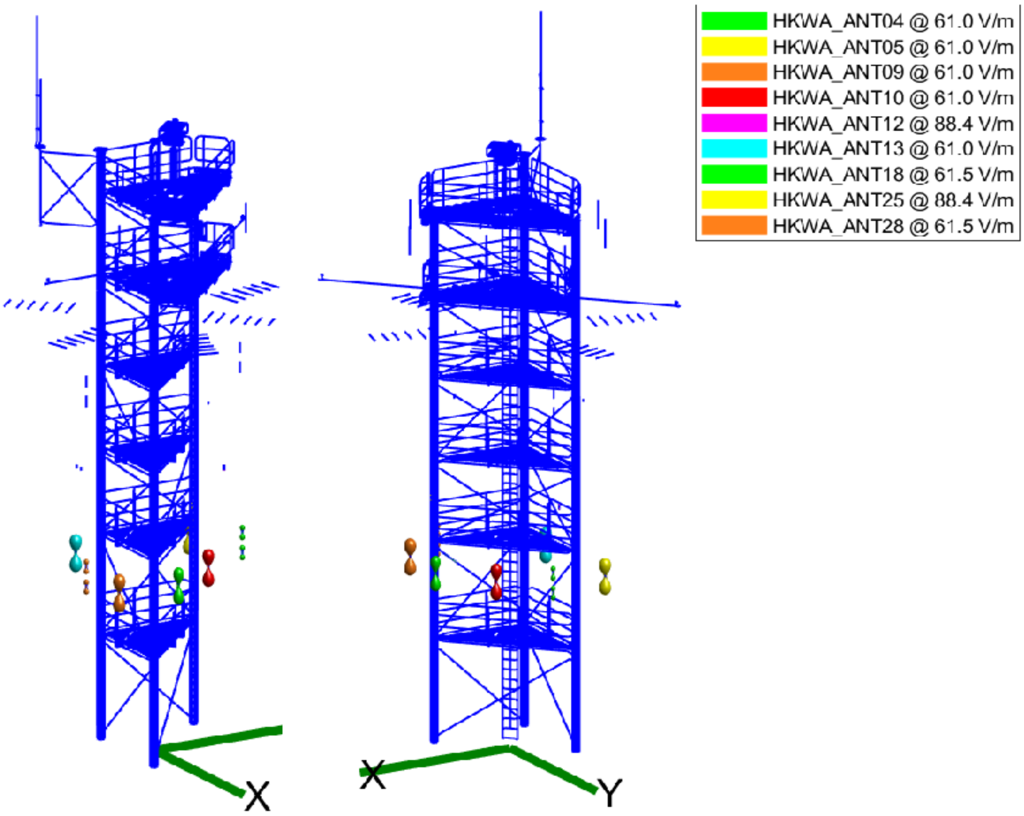

Figure 9.5 Side views. Action Level field strength limits under operational conditions

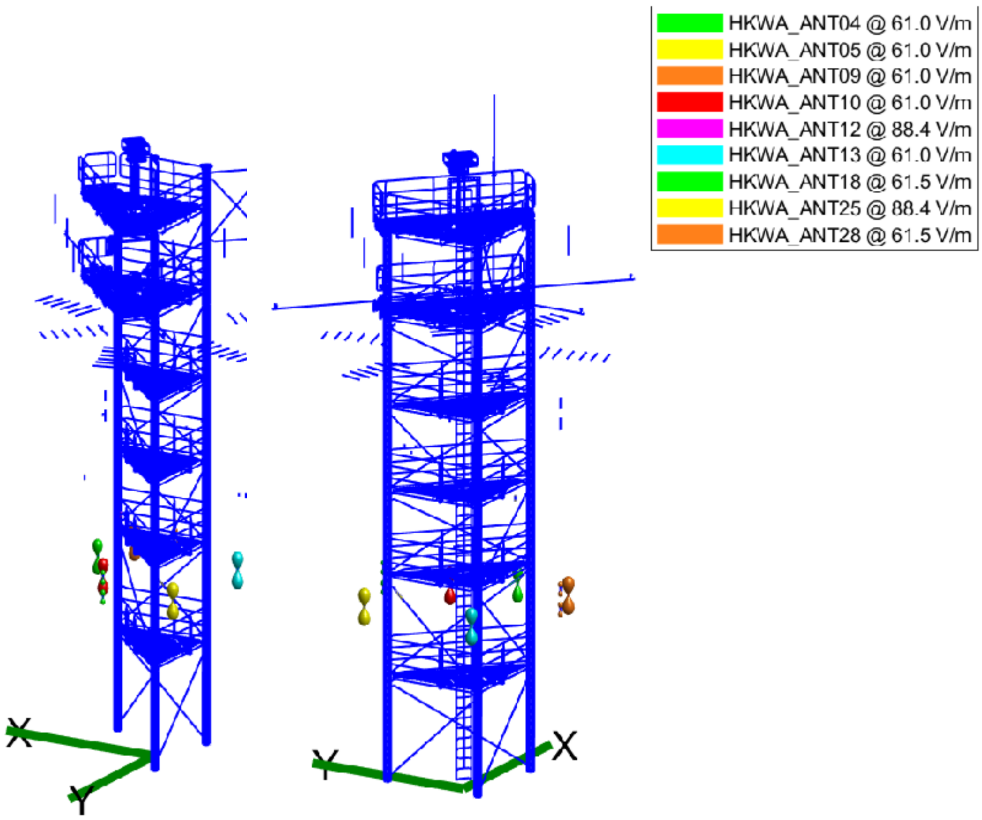

Figure 9.6 Side views. Action Level field strength limits under operational conditions

9.3 Equipment EMC levels

Contours are drawn for a specified electric field strength of 10V/m.

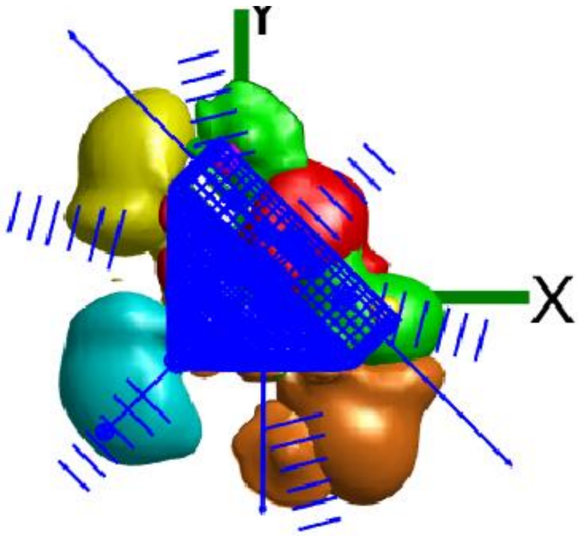

Figure 9.7 Top View. 10 V field strength limits under operational conditions

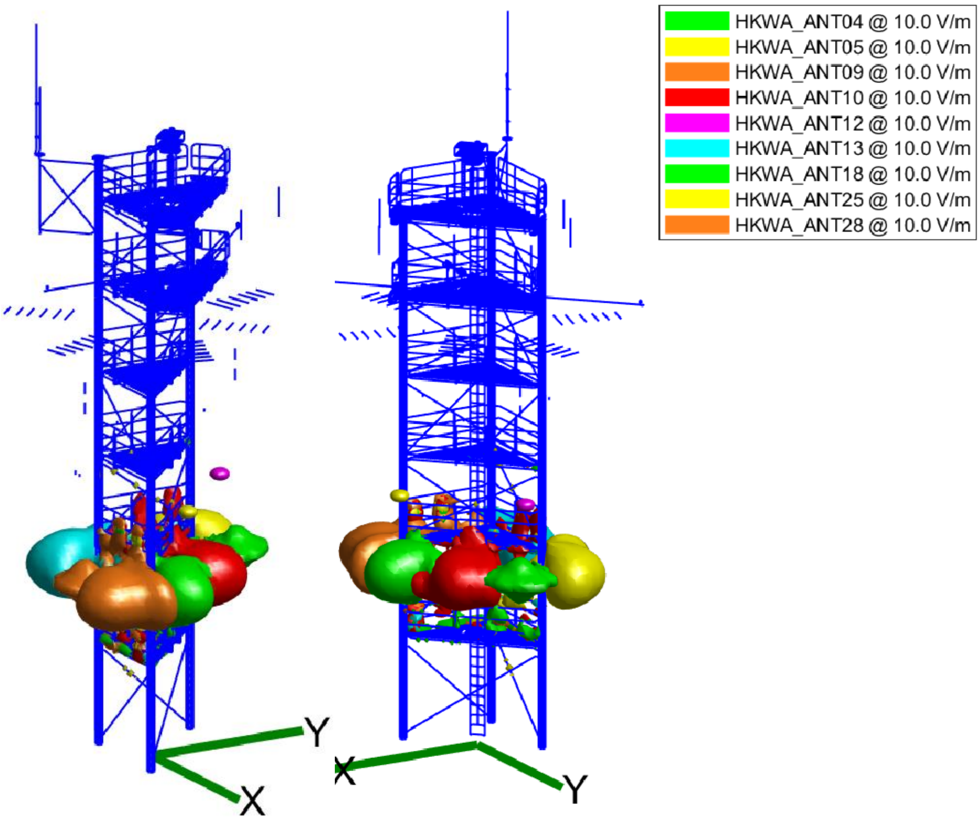

Figure 9.8 Side views. 10 V/m field strength limits under operational conditions

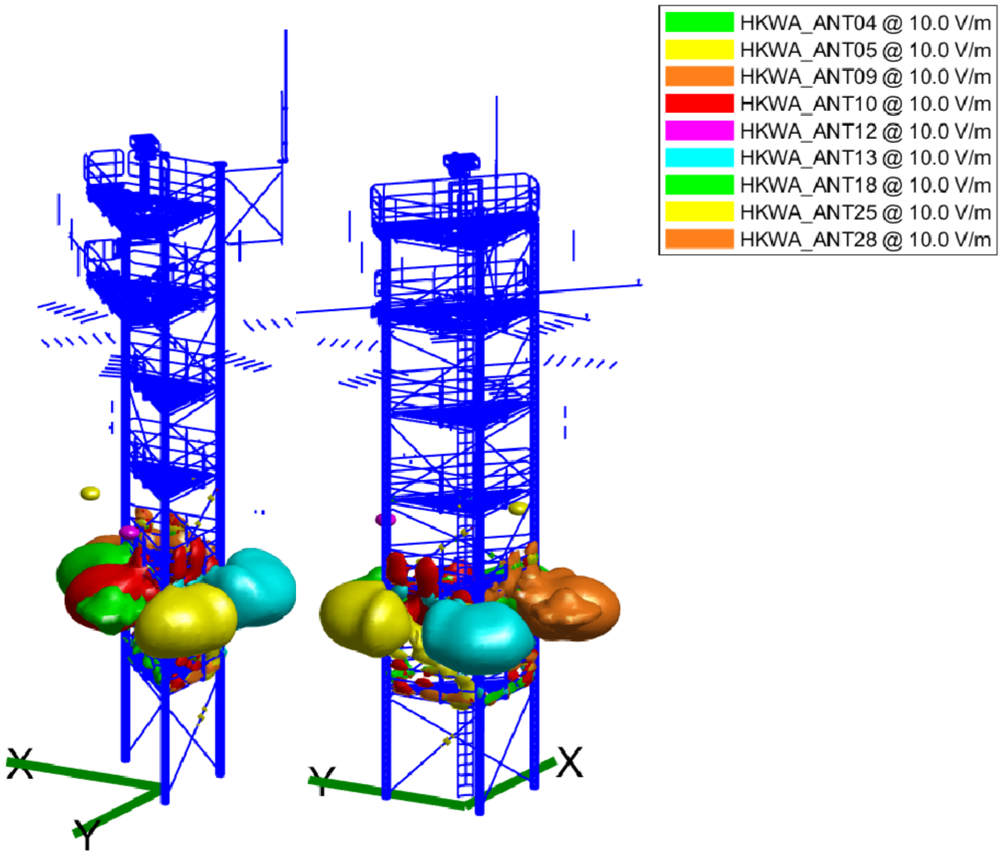

Figure 9.9 Side views. 10V/m field strength limits under operational conditions