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Date:	2017-06-27		
Page:	1/20		

<u>Executive Summary</u>

The Reserved Matters Planning condition is as detailed in italics below

No development relating to the erection of the converter station buildings shall take place until details setting out how the converter station buildings will be designed and implemented to ensure that any electromagnetic disturbance arising from the use of the site does not prevent radio and telecommunications equipment or other equipment outside the site from operating as intended, has been submitted to and approved in writing by the local planning authority. The development shall be undertaken strictly in accordance with the approved details. REASON: To prevent radio frequency interference to users of surrounding land and buildings.

This report describes the mitigation proposals which will be implemented to ensure compliance with the above condition.

In summary, a combination of enhanced building shielding and electrical filtering equipment, will be used to achieve this condition.

Further reassurance will take the form of on-site measurement during early convertor operation to reaffirm compliance.

If the requirements for radio interference are not met, IFA2 with its Contractor shall perform the necessary modification to fulfil these requirements.

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1 Radio and Telecommunications Interference

1.1 Introduction and Background

1.1.1 General

The source of electromagnetic disturbances comes from the switching action taking place in the HVDC converter valves. From this source the electromagnetic disturbances can spread to the outside world in two ways:-

1) by direct electromagnetic radiation from the valve circuitry acting as an antenna or,

2) by conduction of disturbance currents to high voltage equipment and high voltage buses in connected switchyards, inducing them so, that they function as antennas and in this way can cause electromagnetic radiation.

1.1.2 Specific Frequencies Generated by the Converter

1.1.2.1 Typical Spectral Behavior of an HVDC MMC

For a HVDC Modular Multi-level Converter (MMC), which is the type of HVDC converter that will be present at Daedalus, emitted-field disturbance is emitted mainly in the frequency range below 10 MHz.

The emission spectrum is similar to any switched power electronic device, as explained below. Station resonances cause a cluster of resonance peaks to appear between approximately 1 MHz and 4 MHz.

Converter-generated disturbances above 30 MHz are not possible to detect around a HVDC converter station as the fields are already below the levels that can be measured without the converter station in operation and are not possible to measure at practical measuring distances. This means that the converter cannot cause any interference to radio systems operating above 30 MHz.

Between 10 and 30 MHz, standing very near (< 30 m) to the installation with a measuring instrument, some low level emission could be detected at a standard HVDC Light converter station, with outdoor electrical switchgear and without enhanced building screening; in the case that disturbances from other sources are not dominating. In that case, it would be impossible to distinguish HVDC emissions from the background emissions.

A more technically detailed description of the spectral behavior can be found in the Appendix 1.

1.2 Mitigation Method

1.2.1 Emission Limits

1.2.1.1 Radiated Emissions

For standard HVDC stations, the standard limit to apply is Limit 2 (marked with red in Table 1) in the CIGRÉ publication TB 391 (Guide for

Measurement of Radio Frequency Interference from HV and MV Substations), [1]. The limit applies at a measurement distance of 200 m from nearest energized part of a substation. Emissions at 200 m from the substation must then not exceed this limit, measured by an EMI receiver specified as per CISPR 16-1-1, [2]. The quasi-peak detector is a standard detector used in RFI measurements.

Table F.1: Overview of proposed limits for MV and HV substations and lines, CISPR 16 Bandwidths

DEFINITIONS	PROPOSED LIMITS IN [dBμV/m]						
Frequency ranges, frequency in [MHz]	0.009 – 0.1	0.1 - 0.15	0.15 - 1	1 - 30	30 -230	230 - 1000	1000 - 18000
Limit 1 and Reference Substations and lines, $U \leq 30$ kV	30 - 20·log(f)	30 - 20·log(f)	30 - 20·log(f)	30 - 8.8·log(f)	30	37	60
Limit 2; Substations 30 kV $< U \leq$ 620 kV	60 – 20·log(f)	50 - 30·log(f)	50 - 30·log(f)	50 – 10·log(f)	35	37	55
Limit 3; Substations $U >$ 620 kV	50 - 35·log(f)	60 - 25·log(f)	60 - 25·log(f)	60 - 17·log(f)	35	37	55
Limit 4; Lines $U >$ 30 kV	45 – 22·log(f)	45 - 22·log(f)	45 - 22·log(f)	45 - 18·log(f)	30	37	60
Bandwidth	200 Hz	200 Hz	9 kHz	9 kHz	120 kHz	120 kHz	1 MHz
Detector	Quasi-peak	Quasi-peak	Quasi-peak	Quasi-peak	Quasi-peak	Quasi-peak	Peak

NOTES: log(f) is $^{10}\log(f)$ with f in [MHz]
The reference is the limit at the location of the radio receivers as per Appendix B.
The measurement distances are defined in Appendix D

Table 1

The frequency range 1000 – 18000 MHz is not included as this frequency range is usually not applied for standard HVDC installations.

Based on measurement results presented in the attached (APPENDIX 2) document “2015-019-TR-005 NatGrid Daedlus RF Emission (Issue 1)”, [3], where the Reference or Limit 1 (marked with blue in Table 1, also called ‘at the receiver’ limit) was recommended for Daedalus converter station instead of the standard limit for a substation of this type, Limit 2. Limit 1 is a much stricter limit.

Daedalus converter station will comply with emission levels as per the strict Limit 1 in TB 391. In addition, the measurement distance shall, for frequencies above 30 MHz, not be 200m but instead 30m from the installation. The difference between the standard limit values (Limit 2) and the limit values for Daedalus (Limit 1) is shown in Figure 1. It can be seen that requirements have been strengthened significantly for Daedalus compared to a standard HVDC converter station. In order to fulfil this strict limit, extra efficient electromagnetic shielding is needed (see 1.3).

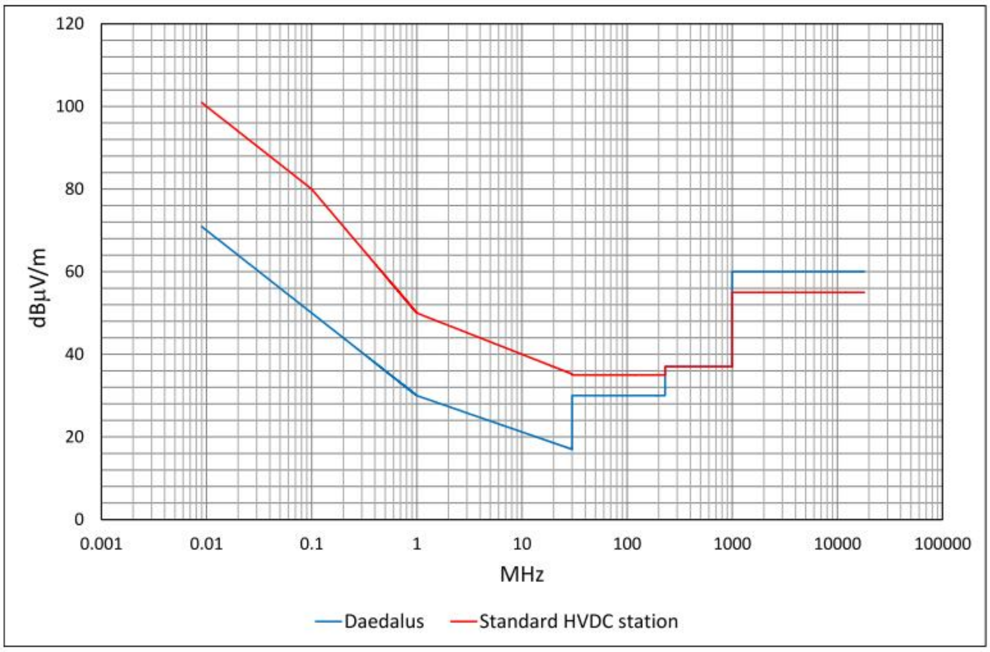

Figure 1

1.2.1.2 Conducted Emissions

For conducted emissions, the limit is aimed to protect the power line carrier communication in use on the AC grid. There is no such communication installed on the Daedalus AC side, but some communication exist on remote stations. The limit therefore applies at Chilling substation, which is connected to Daedalus via a several km long 400 kV AC cable.

The required limit for power line carrier interference is – 10 dBm in the frequency range 70 kHz to 700 kHz.

1.2.2 General Description

The standard method used in basic design for reducing direct radiation by the valve circuitry is by placing the valve inside a building and making this building act as an electromagnetic shield, i.e. it is designed in such a way, that the radiation is attenuated by the surrounding metallic building. This is commonly referred to as a Faraday Cage. A faraday cage is a broadband mitigation method as it provides attenuation across a wide frequency range.

The standard method to reduce conducted disturbances is to install a certain amount of low-pass filters. These filters allow the energy at power frequency to pass but attenuate the high frequency disturbances that could affect radio and telecommunication systems. In addition to low-pass filters, broadband high frequency damping circuits are installed.

By combining shielding of the buildings and filtering, electromagnetic disturbances can be contained within the buildings. The buildings are designed to handle the contained levels and thus no interference, neither to internal systems, nor to systems in the outside world will occur.

1.3 Extended Mitigation Methods at Daedalus

1.3.1 General

At Daedalus, additional shielding and filtering above the standard method will be applied. All equipment will be placed in metallic enclosures or buildings, which means that equipment cannot function as antennas. They are placed within Faraday Cages. In addition to this, extra filtering compared to the basic design normally used has been installed in order to increase attenuation of conducted disturbances in a wide frequency range.

At Daedalus, on top of the extra shielding and filtering mentioned above, further shielding has been applied, where the valve, i.e. the source, has an extra shield inside the normal shielding. This additional element is not strictly required but has been applied to give additional reassurance on emissions.

Thus, by applying these extra measures in Daedalus, the aim is to reduce the electromagnetic disturbances to levels below the existing background disturbance level already present at site. In practice this means that nearby residents, industries or airfield operations will not notice any difference in disturbance levels after the installation of the HVDC converter station compared to before.

1.3.2 Specific Measures

In order to comply with Limit 1 (see Table 1) as recommended in the consultant report [3], some specific measures were outlined in a preliminary assessment. The measures and the implementation during detailed design is presented in Table 2 below.

Preliminary Assessment	Implementation
Reinforcement of walls and ceilings of Valve Hall, Reactor Hall and DC Hall with a shell consisting minimum 1.5-2.0 mm sheets of steel that are welded together. This shell must be weather protected by the outer walls and coated with corrosion protection. In the Reactor Hall, there must be Aluminum sheets between the phase reactors and steel sheets in order to provide eddy current magnetic shielding to prevent thermal overload of the sheet steel.	The inner shield will consist of 2 mm thick Aluminum and the outer shield will consist of 0.8 mm Steel sandwich element which are connected with rivets or self-drilling screws. Welding will not be necessary. 2.0 mm Steel thickness can, according to ABB electromagnetic experts, be reduced to 0.8 mm without losing shielding efficiency even at 9 kHz.
Connecting GIS tubes must be reinforced with a sheet steel shell as well to avoid common mode emissions from the tubes at low frequencies.	Implemented with 0.8 mm thick stainless sheet steel.
The wall steel shell and the steel shell surrounding GIS tubes must be welded to the earthing grid at points that are no further than 0.6 m from each other.	The distance 0.6 m may be subject to change during detailed design.
The ceiling steel sheets shall be connected to the wall steel sheets by welding points no further than 0.6 m from each other	The distance 0.6 m may be subject to change during detailed design.
All sandwich steel elements ('PAROC') must have screws at each 0.1 m and connections to the ground grid similar to the steel sheet shell mentioned above	The distance 0.1 m may be subject to change during detailed design.
All doors and other openings in the buildings must have EMC sealing in the form of EMC gaskets	Some doors might not, from mechanical reasons, be suitable for EMC gasket sealing. In those cases another shielding solution, defined during the detailed design phase, will be implemented

Table 2

1.4 Studies, Shielding and Filter Design

The design of the filters is performed using a high frequency model of the station, i.e., the station is modeled including the behavior of the station equipment at high frequencies. A margin is always assumed for all design to eliminate any inaccuracies.

The physical filter equipment is tested and adjusted by the sub-suppliers in their factory to ensure performance and the filter equipment is approved by ABB before it is installed at site.

The shielding design is part of the civil works. Strict design rules related to EMC performance are internal requirements to the civil design departments. During the entire construction phase, including site works, compliance of these design rules will be checked.

1.5 Verification of Performance

During the commissioning phase, when the station is ready to be energised, measurements of disturbance levels around the station are performed in order to verify compliance with requirements.

2 Electric and Magnetic Fields

2.1 Introduction

In general, the exposure to electric and magnetic fields (EMF) will be limited to provide protection against adverse health effects. Electric fields are produced by voltage and magnetic fields by current. To limit the EMF exposure, considerations have been taken in the early design phase, in regards of, e.g., the layout design, the exposure scenario (access during operation), etc.

2.2 Mitigation Methods at Daedalus

For the IFA2 project, the EMF requirements stated in “E2.1-a.i Converter System Basis of Design”, together with the revision in “TB233 EMF requirements” (see chapter 5.2 in the Appendix) will be applicable i.e. for electric field levels, requirements given in clause 11.1 and for magnetic field levels, requirements stated in 11.2 will apply.

At Daedalus, all high voltage equipment is placed in metallic enclosures or buildings, which means that the high field area is confined inside the buildings.

The field levels are calculated conservatively in a scenario where there are no building structures around the high voltage bus-work, see Figure 2, 3 and 4.

From the results, we can see that the maximum field levels at the fence line are around 2 kV/m (power frequency electric field), 5 uT (power frequency magnetic field) and 5 kV/m (static electric field), much below the public exposure limit of 9 kV/m (power frequency electric field), 360uT (power frequency magnetic field) and 25kV/m (static electric field).

After taking consideration of the shielding and attenuation effects of the buildings, the field levels at the fence line will be even lower.

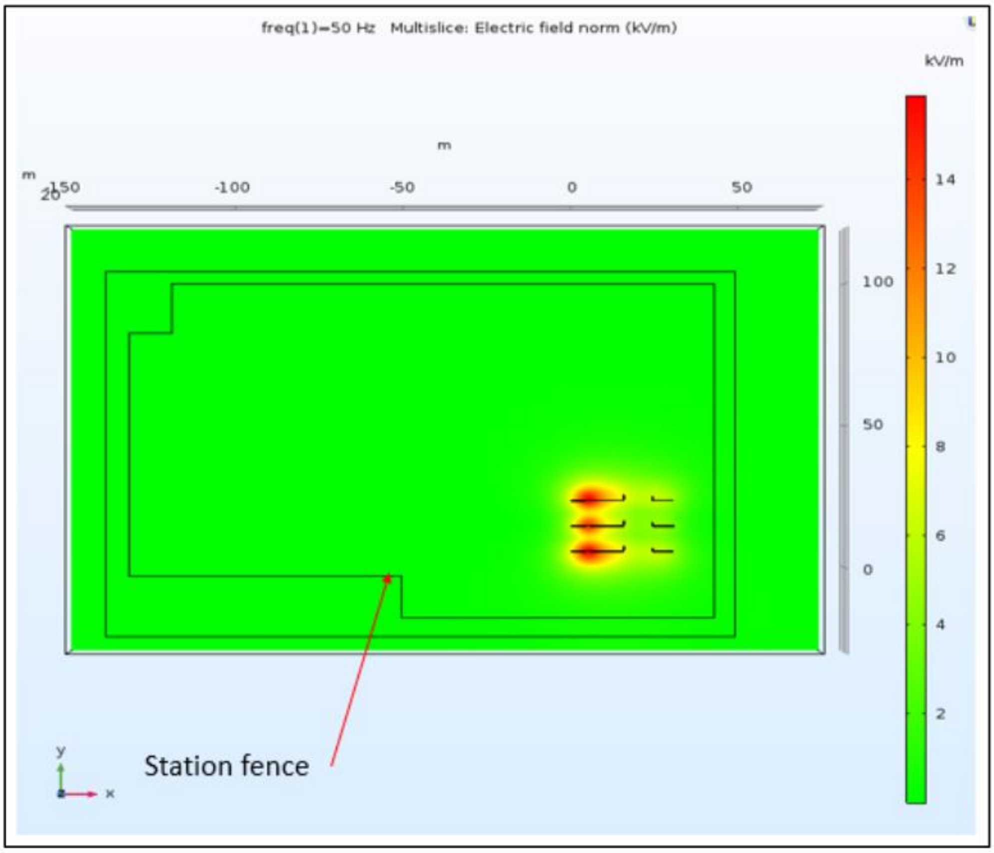

Figure 2, Electric Field

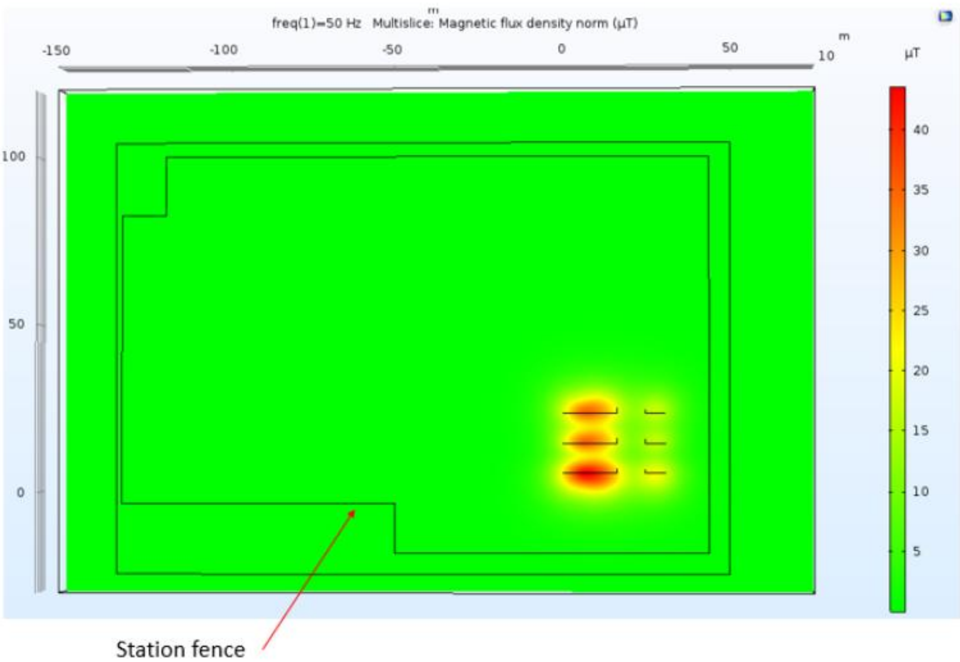

Figure 3, Magnetic Field

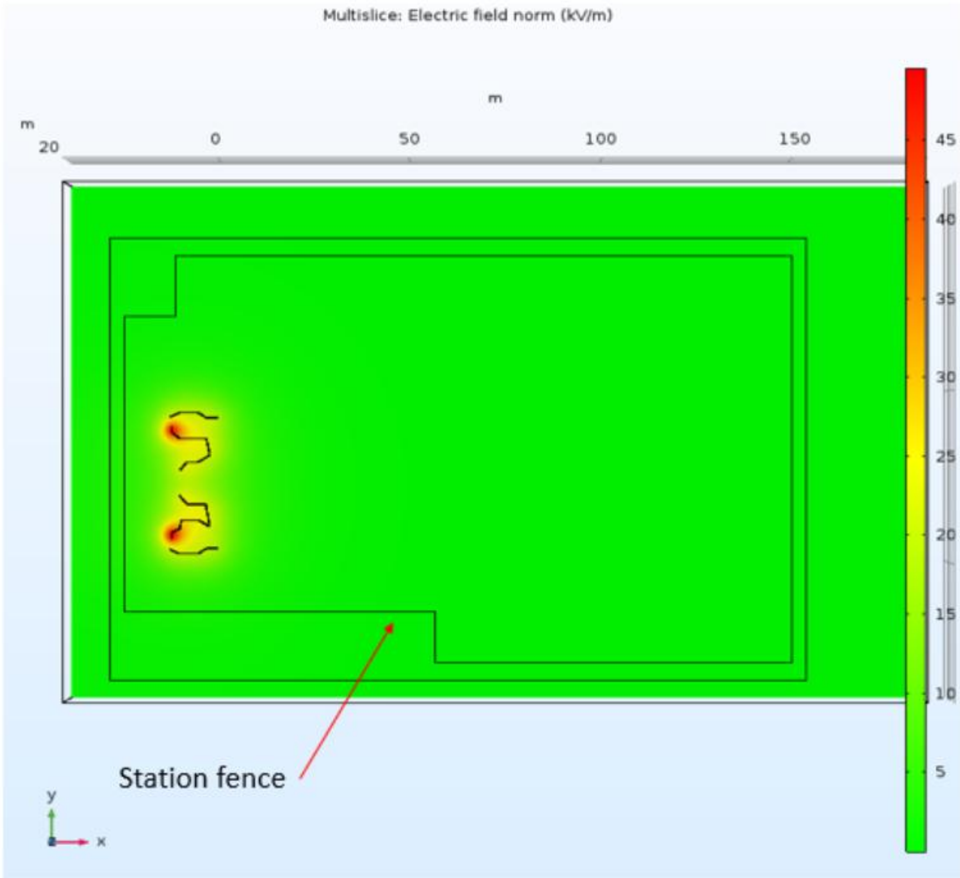

Figure 4, Static Field

Therefore, the EMF exposure level to the public outside the fence is far below the required exposure limits as stated above.

For the control of the occupational exposure during operation, no personnel are allowed to enter the converter reactor hall and valve hall. For the AC hall and DC hall where personnel can enter during operation, to ensure that the field exposed to the personnel is lower than the requirement, 2,5m high pedestals will be added to the equipment where necessary, and in addition, fences will be adopted to keep personnel a sufficient distance from the high field area.

The requirements contained in clause 11.2.1.1 and 11.2.1.2 of "E2.1-a.i Converter System Basis of Design" and revision in "TB233 EMF requirements" shall take precedence if these contradict with the requirements given in clause 11.2.

Furthermore, a detailed study will be carried out to ensure that the field level in the accessible area is lower than the requirements.

2.3 Verification of Performance

During commissioning phase, measurements of electric and magnetic field both inside and around the station will be performed in order to verify the compliance with the requirements.

2.4 Conclusion

In regards to EMF exposure to the operational staff at site, special considerations are taken in the design phase and a detailed study will be carried out to ensure that the field level at the accessible areas is lower than the required exposure limit.

In regards of EMF exposure to the public outside of the station fence, the field levels will be below the required exposure limit, as all high voltage equipment is place in metallic enclosures or buildings.

EMF measurements both inside and around the station will be performed to verify the compliance with the requirements.

3 References

[1] CIGRÉ - Technical Brochure No 391, "Guide for Measurement of Radio Frequency Interference from HV and MV Substations", Joint Working Group C4.202, August 2009.

[2] IEC - CISPR 16-1-1, "Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus", Edition 2.2, 2007-10

[3] LSA Electromagnetics Limited, "RF Survey Test Report for IFA2 Development at Solent Airport", Issue 1, 7 March 2017

4 Revision History

Rev.	Prepared	Approved
C	Olof Andersson, 2017-08-21	
Revision text: - Report updated based on RoR received 17th of August 2017		
B	Olof Andersson, 2017-08-07	Alberto Persico, 2017-08-07
Revision text: - Report updated based on RoR received 4th of August 2017		
A	Olof Andersson, 2017-07-20	Olof Andersson, 2017-07-21
Revision text: - Report updated based on RoR received 14th of July 2017		
-	Olof Andersson, 2017-06-27	Olof Andersson, 2017-06-29
Revision text: - First Issue		

5 APPENDIX 1

5.1 Explanation of Spectral Behavior

The following explanation is provided for why converter-generated disturbances are low (or can be safely assumed to be low) above 10 MHz, is only intended to illustrate the principle. One must keep in mind the many complicating factors such as the interaction of sources via near-fields, large and complex radiating structures with many propagation paths, station equipment resonances, propagation over ground etcetera, so an exact spectrum is not possible to provide. During detailed engineering, an assessment by calculations will be provided in a technical study, the HF Study (see clause 1.4 Studies, Shielding and Filter Design above). This assessment is used for filter design.

What can be provided, however, is an expected worst case spectrum

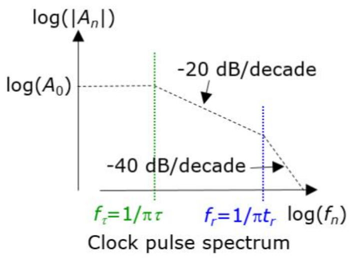

Figure 1

It can be seen from Figure 1 that the pulse spectrum for any random pulse is dependent on the duty cycle and the pulse rise time $t_{r.}$ The rise and fall time of the voltage pulse (in HVDC converter stations) as well as the shape vary between commutations. Both the rise and fall times as well as the shape of the pulse depend on the type of switch (IGBT or diode controlled) or the cell current. The rise and fall time vary between 1 µs to several µs.

1 µs = 1/1000000 s.

For 1 µs rise time, the approximate breakpoint frequency occurs at 1/π*1 µs = 300 kHz (approx.).Thus the effective voltage source spectrum of a pulse decays at a rate of -20 dB/decade till 300 kHz.

Now combining the spectrum of this voltage pulse with the emission properties of magnetic dipoles (or with another name magnetic loop antennas), as the radiating portion of HV switchyards are bus systems with shunt elements forming loops, the spectrum content of the emitted radiation can be estimated. Figure 2 shows the magnetic dipole radiation efficiency. Here λ = wavelength and d = measuring distance.

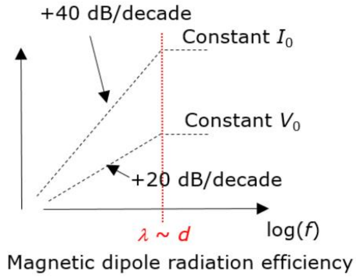

Figure 2

By combining figures 1 and 2, the expected qualitative spectrum can be obtained.

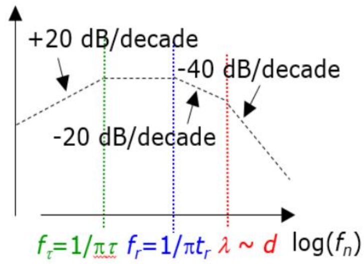

Figure 3

Figure 3 shows the effective spectrum thus obtained for a driving voltage V_0. It is seen from Figure 3 that the effective voltage spectrum decays linearly with frequency above the breakpoint frequency f_r, calculated earlier to be 300 kHz. Above this breakpoint frequency, the spectrum decays at the rate of -40 dB/decade. Thus at 10 MHz, the spectrum has decayed to a great extent and this is primarily why it is hard to measure any radiated field emission above 10 MHz – it is typically 'buried' in the background noise, especially at sites with high background levels, such as industrial or residential areas with a concentration of household/industrial electric and electronic equipment or near HV switchyards or overhead lines where partial discharge generated disturbances will dominate the background emission at frequencies above 10 MHz. At certain sites and during certain weather conditions, the latter disturbance type can dominate background also below 10 MHz.

What complicates the matter somewhat are station resonances. In a large and complex installation such as an HVDC converter station, there will be interactions between capacitance and inductance as in any electric circuit. It is very hard to predict the exact behavior of this interaction for higher frequencies, i.e. frequencies well above the power system harmonic spectrum (f > 150 kHz), as stray inductances and capacitances starts to come into play more and more. Such stray inductances and capacitances can only be estimated and this makes the circuit complex to analyze.

This means that the exact location of resonance peaks in the emitted spectra from HVDC stations is not possible to exactly foresee. Based on experience from earlier installations, it is anyway possible to know an approximate frequency range for such resonance peaks. These peaks are usually the parts of the emitted field spectra that have the potential to exceed emission limits. The basic behavior of the HVDC converter generated disturbance spectrum is still as seen in Figure 3, but the envelope will be modified by resonance peaks. The above is a complication, but it can be handled by applying broadband mitigation methods thus eliminating the need for knowing the exact resonance frequencies. The HF design can be performed anyway.

In the emitted field disturbance spectra from standard HVDC converter installations, during measurements, a cluster of resonance peaks usually appearing between 1 MHz and 4 MHz has been observed. It is believed that due to the combination of physical size and type of HV equipment usually installed, the majority of resonances will occur between 1 MHz and 4 MHz with a variation stretching down to approximately 0.5 MHz and up to 5 MHz.

However it should be noted, that all of the above refers to a standard converter installation. Daedalus station has a non-standard design as it is so heavily shielded with all HV equipment placed inside metallic buildings. Resonances therefore might appear outside the frequency ranges given above. However, as all radiating parts of Daedalus are built in, efficient attenuation is provided and overall emission levels will be extremely low. The attenuation effect of electromagnetic shielding has been explained in sections 1.2.2 and 1.3.

5.2 TB233 EMF requirements

IFA2 HVDC Interconnector
Bravo Solution Reference: 15 353
Tender Bulletin Form

IFA2 HVDC INTERCONNECTOR

TENDER BULLETIN FORM

IFA2 Ref:	TB233
Description	EMF requirements
From:	A d'AUBIGNY
Date:	10/10/2016

Dear Sirs,

Tenderers to note the following amendment (in red) to section 11 of E2.1-a.i Converter System Basis of Design which:

- will be incorporated in the revised Converter Specifications ahead of any Contract being awarded.

11. ELECTRIC AND MAGNETIC FIELDS

11.1. Electric Field Prescriptions

In UK, the electric field should follow prescription made in 1999/519/CE Directive [14] for public limitation and 2013/35/UE [15] inside the substation where the presence of workers is expected.

In France, Directive 1999/519/CE shall apply for public limitation and Directive 2004/40/CE shall apply for ~~public~~ workers limitation.

Static electric field outside the Converter Stations in areas accessible to the public shall be lower than 25 kV/m.

11.2. Magnetic field prescriptions

The magnetic field function of frequency should satisfy the equation:

$$\sum_{f=1Hz}^{f=150kHz} \frac{B_f}{B_{Lf}} \leq 1$$

Where:

- B_f is the magnetic induction at the frequency f
- B_{Lf} is the reference level of the magnetic induction at the frequency f :
  - Inside the Station where workers can access, action levels of the European recommendation 2013/35/UE table B2 "Magnetic flux density low" shall be taken into account for UK.
    For France, Directive 2004/40/CE shall apply.
  - Outside the Station reference levels of the European recommendation 1999/519/CE [14] table 2 shall be taken into account.

In case public visit the Converter Station, they should not access to an area where magnetic field is above the public limitation. Therefore a visual boundary should be visible as a warning (to indicate 100 µT) for

Page 1 of 3

public people. The method of identifying the boundaries shall be provided to the Employer for review and acceptance.

For the GB side, the magnetic field shall be limited corresponding to the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines.

11.2.1. GB Requirements - Magnetic fields requirements

Where the sections below contradict the requirements contained in 11.2, the requirements in section 11.2.1.1 and 11.2.1.2 shall take precedence.

11.2.1.1. OCCUPATIONAL EXPOSURE- TO APPLY INSIDE THE SITE BOUNDARY

In normal operational conditions, it shall not be necessary for staff to enter any area where the limits given in the table below for time-varying fields can be exceeded.

The Contractor shall provide plans showing areas (if any) where this magnetic field level is exceeded for operation of the converter station at any maximum continuous operating point for all of the site layouts listed in the Enquiry document and proposals for any barriers necessary.

11.2.1.2. PUBLIC EXPOSURE

Outside of the boundary fence, in normal operational conditions, it shall not be possible for members of the public to enter any area where the limits given in the table below for time-varying1 fields are exceeded. If operational constraints or significant additional costs would be incurred to achieve this, the Contractor shall notify the Employer and act on any instructions given.

Public Exposure Limits	
	External field strength corresponding to the basic restriction
Magnetic field	360 µT
Electric field	9 kV/m^{-1}
Occupational Exposure Limits	
	External field strength corresponding to the basic restriction
Magnetic field	6000 µT
Electric field	20 kV/m^{-1}

The Contractor shall provide plans and magnetic field plots to demonstrate the criterion above has been met for the STATCOM installation. To enable the Employer to assess the impact of staff with medical devices these plots shall additionally show the 100 µT contour. This is not, however, a limit that shall be applied to the design.

11.3. Performance verification - EMF

The Contractor shall propose a method to verify the Magnetic and Electrical field performance.

Regards,

The IFA 2 Project.

6 APPENDIX 2

Document “2015-019-TR-005 NatGrid Daedalus RF Emission (Issue 1)”.

LSA Electromagnetics Limited
5 Balidon Place, Yeovil
Somerset, BA20 2FY

RF Survey Test Report for IFA2 Development at Solent Airport

Reference: LSAEM/2015/019/TR/005

Issue 1

7 March 2017

Commercial in Confidence

Author:

....

Michael Airey
E3 Consultant

CUSTOMER DETAILS

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31 Homer Road
Solihull
B91 3LT

CUSTOMER REFERENCE

Purchase Order Number: PO3200632776

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DOCUMENT HISTORY

Issue	Date	Comment
1	7 Mar 2017	First format issue.

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1 Introduction

National Grid IFA2 Ltd (NGIL) is proposing to construct a 1000 MW high voltage direct current (HVDC) electricity interconnector between the French and British transmission systems, at Chilling, Hampshire in the United Kingdom (UK) and Tourbe, Normandy in France. The IFA2 project consists of two converter stations of similar construction, one sited in each country, connected by over-land and subsea HVDC cables. High voltage alternating current (HVAC) cables connect each Voltage Source Converter (VSC) station to the transmission network substations.

The alternating current (AC) electricity of the sending country is converted to direct current (DC) electricity at the converter station and then transmitted to the receiving country's converter station, where it is converted back to AC and supplied to the receiving transmission system. The interconnector is reversible and capable of importing and exporting electricity depending on requirements at any given time.

NGIL intends to construct the UK converter station in close proximity to Solent Airport, formerly RNAS Daedalus. This will include a VSC converter station and both HVAC and HVDC cables routes leading from the site to the coastline, these cables will traverse the airfield and therefore aircraft may either taxy or operate close to the cables. More details of the proposed installation are provided in [1].

National Grid (NG) has contracted LSA Electromagnetics ('LSAEM') to undertaken measurements of the ambient Radio Frequency (RF) environment at Solent Airport.

2 Background

The development of IFA2 introduces a risk of electromagnetic interference (EMI) to users of the RF spectrum in the proximity of the converter station. The European Electromagnetic Compatibility (EMC) Directive 2014/30/EU [2] places a legal requirement on NGIL as the operator of the converter station to ensure that such interference does not occur.

The prime method to manage the risk of EMI is to specify of limit for the level of EMI emissions that can be tolerated from the converter station and several limits have been proposed that are based on a report by the Council on Large Electric Systems (Cigré), Report 391 [3]:

- The standard Cigré proposed limit for HV converter stations that was originally adopted for IFA2 [1], as shown in Table 1; and
- The Cigré limit for the location of potential victim receivers to the EMI from the converter station, as shown in Table 2.

The term f refers to the emission frequency and is measurement in MHz and these limits are shown in Figure 1.

Table 1: Standard Cigré Limit for Converter Station Emissions

Frequency Range (MHz)	Electric Field Strength (dBµV/m)
0.009 – 0.1	$60 - 20log_{10}(f)$
0.1 – 0.15	$50 - 30log_{10}(f)$
0.15 – 1.0	$50 - 30log_{10}(f)$
1.0 – 30	$50 - 10log_{10}(f)$

Frequency Range (MHz)	Electric Field Strength (dBµV/m)
30 – 230	35
230 – 1000	37
1000 – 18000	55

Table 2: Cigré Limit for Converter Station Emissions at Location of Receivers

Frequency Range (MHz)	Electric Field Strength (dBµV/m)	Bandwidth
0.009 – 0.15	$30 - 20log_{10}(f)$	200 Hz
0.15 – 1.0	$30 - 20log_{10}(f)$	9 kHz
1.0 – 30	$30 - 8.8log_{10}(f)$	9 kHz
30 – 230	30	120 kHz
230 – 1000	37	120 kHz
1000 – 18000	60	1 MHz

Comparing the limits in Figure 1, it is apparent that the standard limit proposed by Cigré permits a higher level of emissions and that these are measured 200 m from the installation. The main rationale for specifying the limit at a 200 m distance is that:

- RF receivers would not be located closer than this distance (referred to as the 'respect distance' in the Cigré report [3]) from the installation; and
- Measurement of the emissions at smaller distance lead to sampling of the emissions from proximate parts of the installation rather than measuring overall emissions.

The adoption of the standard proposed Cigré limit would permit an EMI level higher than this limit at smaller distances. An estimate of the limit that would result at 60 m from the converter station is shown by the dashed purple curve in Figure 1, with an increase of 10.5 dB. The 200 m measurement distance proposed by Cigré [3] differs from that of typical EMI emissions measurement techniques that typically employ distances of up to 10 m. For example test methods for aircraft equipment measurements use a distance of 1 m as in RTCA/DO-160 [4], EUROCAE ED-14 [5] and Def Stan 59-411 [6], while distances of 3 m or 10 m are used for commercial equipment testing as in EN 61000-6-1:2007 [7].

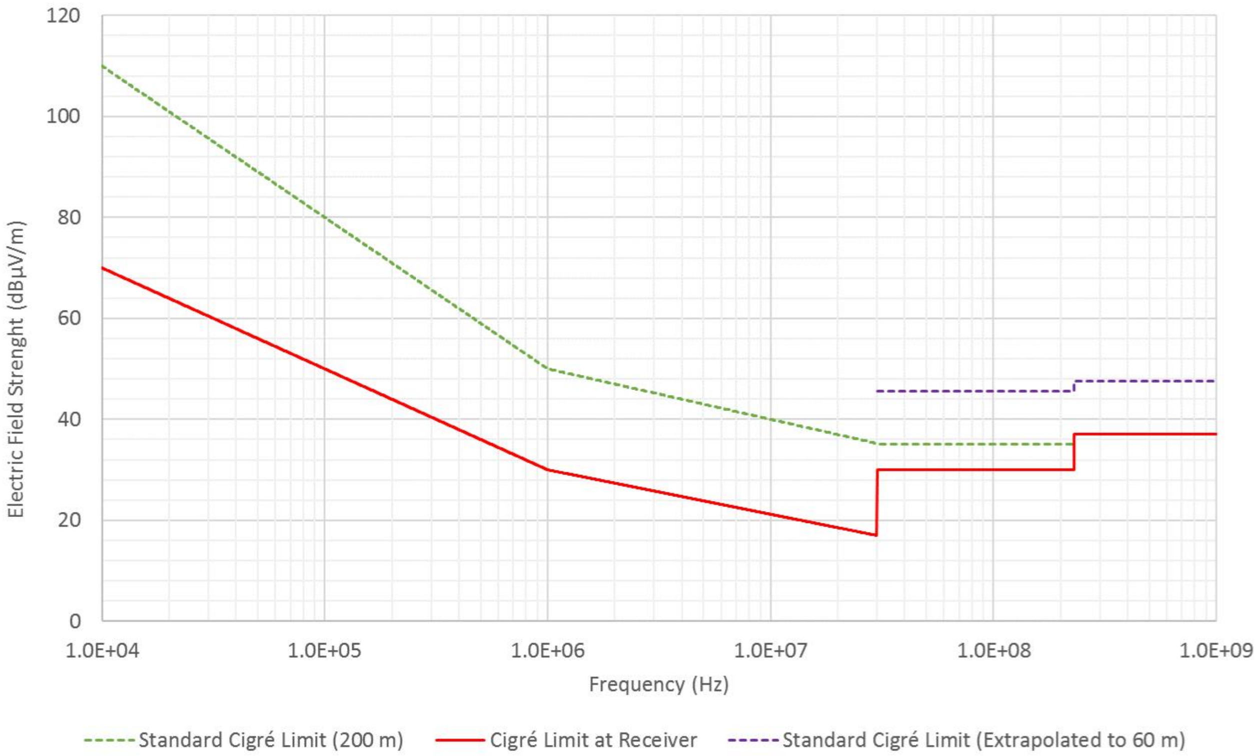


Figure 1: Cigré Reference Limits

3 Test Method

3.1 Test Equipment

The following table details the test equipment and its calibration details.

Equipment Description	Manufacturer	Part Number	Serial Number	Calibration Due
EMC Test Receiver, 9 kHz to 3 GHz	Rohde Schwarz		100403	22 March 2017
Magnetic Field Loop Antenna, 9 kHz to 30 MHz	Electro Metrics	EM-6879	690230	5 June 2018
Electric Field Biconical Antenna, 20 MHz to 300 MHz	EMCO	3104P	3213	30 June 2019
Electric Field Biconical Antenna, 30 MHz to 1 GHz	Schwarzbeck	VUBA9117-1	3471	1 November 2018
Coaxial Cable, 5 m	Radiall	R284C0351044	LSA/COAX/001	Calibrated prior to test.
Coaxial Cable, 5 m	Sucoflex	S106A	LSA/COAX/006	Calibrated prior to test.

Equipment Description	Manufacturer	Part Number	Serial Number	Calibration Due
Coaxial Cable, 2 m	Sucoflex	S106	LSA/COAX/007	Calibrated prior to test.
Attenuator, 10 dB, 100MHz '6GHz	Pasternack	PE7014-10	LSA/ATT/001	Calibrated prior to test.

3.2 Test Receiver Settings

The testing was performed spanning the frequency range from 10 kHz to 1 GHz to cover principal spectrum use, including:

- Medium Frequency (MF) and High Frequency (HF) radio and aircraft Non-Directional Beacons (NDB) that use the spectrum range where the highest level of emissions from the electrical conversion equipment could occur; and
- VHF-FM radio and Digital Audio Broadcast (DAB) radio, airfield VHF Air Traffic Control (ATC) radio, Terrestrial Trunked Radio (TETRA), Digital Television (DTV) and the lower mobile phone bands that are more frequently used, but where emissions from IFA2 are expected to be lower.

The testing was performed in four frequency bands within this overall range to allow for equipment configuration changes as shown in Table 3:

Table 3: Equipment Configurations

Frequency Band	10 kHz to 150 kHz	150 kHz to 30 MHz	30 MHz to 300 MHz	300 MHz to 1 GHz
Antenna	Electro Metrics EM-6879	Electro Metrics EM-6879	EMCO 3104P	Schwarzbeck VUBA9117-1
Receiver Bandwidth (CISPR bandwidths selected)	200 Hz	9 kHz	120 kHz	120 kHz
Frequency Step	100 Hz	4.5 kHz	60 kHz	60 kHz
Measurement Time	50 ms	50 ms	10 ms	10 ms

The test receiver was configured as follows for all frequency bands:

- Detector: Peak;
- Trace Mode: Maximum-Hold;
- Bandwidth Type: 6 dB;
- Pre-Amplifier Mode: On, Auto-Preamp;
- Attenuation: Auto-Ranging, 10 dB Minimum On for Control Tower (to prevent damage in the event of ATC VHF radio transmissions), Off for Innovation Centre and Warehouse; and
- Sweep Mode: Continuous

Each measurement was run using the maximum-hold function to improve the capture intermittent signals and the data was directly stored into Microsoft Excel for analysis. The measurement for each frequency band were repeated with the antenna set in three orthogonal orientations, one vertical and, nominally North-South and East-West horizontal orientations.

Finally, the noise floor of the test receiver was measured with the antenna and coaxial cable disconnected.

3.3 Measurement Locations

Measurements were performed at three locations as required by NGIL:

- Control Tower, indicated by the blue circle in Figure 2. The testing was performed on the roof outside the Control Room, as indicated by the red oval in Figure 3. The VHF ATC radio antennas can be seen above and to the left of the red oval;
- The Innovation Centre, indicated buy the green circle in Figure 2. The testing was performed at ground level, behind the building, as shown in Figure 4; and
- A new warehouse, indicated by the magenta circle in Figure 2. The testing was performed at ground level at the north-west corner of the building, as shown in Figure 5.

Figure 2: Measurement Locations

Figure 3: Antenna Location on Control Tower Roof

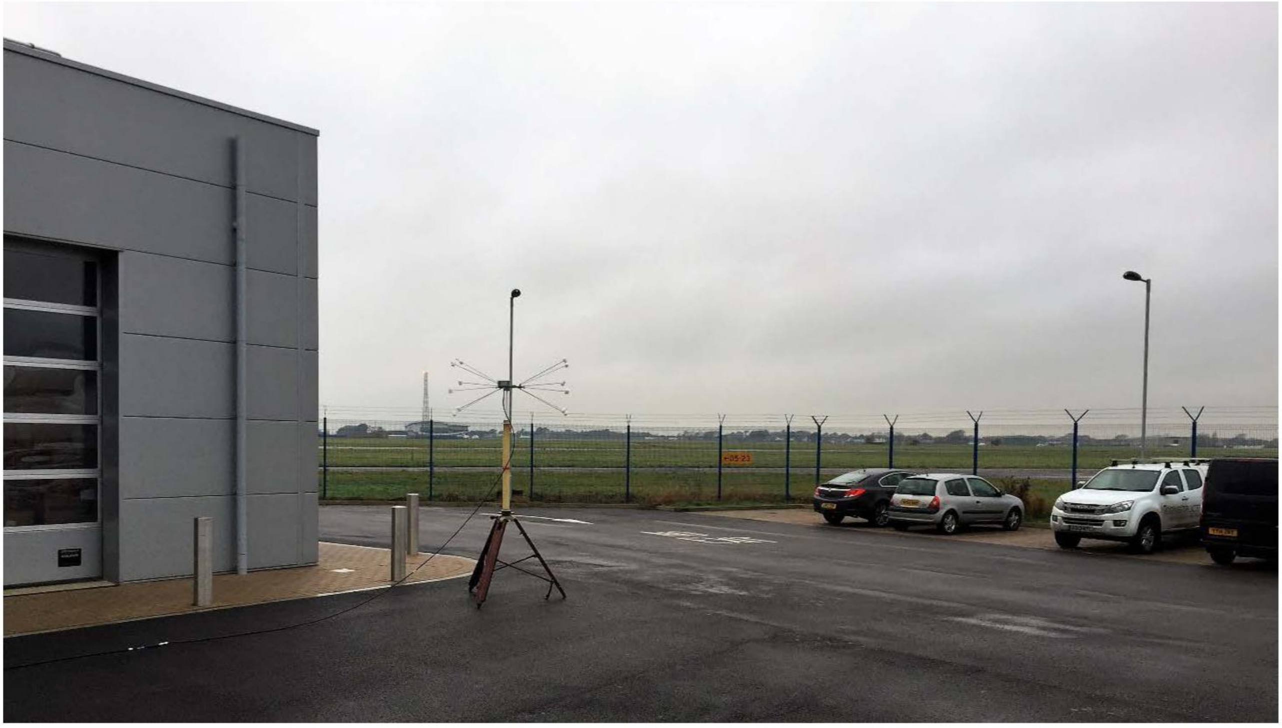


Figure 4: Antenna Location at Innovation Centre

Figure 5: Antenna Location at New Warehouse

3.4 Data Processing

The measured data, recorded as a voltage in dBμV, was corrected for the cable losses between the antenna and the test receiver and for the antenna factor to calculate the electrical field strength in dBμV/m.

The field strengths for each data set were plotted graphically against the Cigré limit at the receiver position (see Appendix B of Report 391 [3]) and against the standard Cigré proposed limit for HV converter stations, as shown in Figure 1.

In addition, the electric field strength for the three orthogonal orientations was vector summed to determine the overall field strength using the following expression:

$$E = \sqrt{E_{Vert}^2 + E_{N-S}^2 + E_{E-W}^2}$$

4 Results

The measurement results are shown in the following Appendices:

- The overall electric field strength results for all three measurement locations are shown in Appendix A with both Cigré limits from Figure 1 being shown;
- The results for the individual Control Tower, Innovation Centre and Warehouse locations are shown in Appendix B, Appendix C and Appendix D respectively.

5 Discussion

5.1 Test Receiver Attenuation Setting Impact

Firstly, it should be noted that the 10 dB minimum attenuation setting used for the Control Tower location (used to prevent equipment damage by ATC radio transmissions as the ATC antennas were close to the test antennas) results in a higher measured background level. The minimum attenuation used for the Innovation Centre and Warehouse locations was set to 0 dB to reduce the measurement noise floor. This effect can clearly be seen in the receiver noise floor measurements shown in Appendix E.

5.2 10 kHz to 150 kHz Frequency Range

The results for the 10 kHz to 150 kHz frequency range on page 17 show that the RF environment is significantly lower than the standard proposed Cigré limit at 200 m. The background RF environment is also generally lower than the Cigré at-receiver limit for the Innovation Centre and Warehouse locations, but exceeds the limit at the Control Tower due to the use of the higher attenuation; the results at the Control Tower measured with a lower attenuation would also be expected to be below the Cigré at-receiver limit. There is clear spectrum use that generates signals that exceed the at-receiver limit, including the 60 kHz time signal (circled in blue). The standard Cigré limit would not provide protection of this signal.

5.3 150 kHz to 30 MHz Frequency Range

The results for the 150 kHz to 30 MHz frequency range on page 18 show ambient levels at all locations that exceed the Cigré at-receiver limit, but it should be noted that these measurements were limited by the noise floor of the test receiver which was already set to its maximum sensitivity. The RF environment for the Control Tower away from intentional signals shows the result of the increased minimum attenuation and would be expected to follow the trend shown for the Innovation Centre and Warehouse.

There are significant intentional narrow-band signals, some of which are lower than the standard proposed Cigré limit:

- Low Frequency (LF) AM radio broadcast between 150 kHz and 290 kHz;
- Medium Frequency (MF) AM radio broadcast between 530 kHz and 1710 kHz; and
- High Frequency (HF) transmissions between 3 MHz and 30 MHz.

A wide-band increase in emissions is apparent in the environment at Warehouse just below 10 MHz (the source could not be identified but, based on the results in Appendix D, it may be caused by the electrical installation in the building).

5.4 30 MHz to 300 MHz Frequency Range

The results for the 30 MHz to 300 MHz frequency range on page 19 indicate that the background environment at the Innovation Centre and Warehouse is generally lower than the Cigré at-receiver limit. The results for the Control Tower indicate a background level of EMI that exceeds the at-receiver limit and not all of this can be attributed the use of an increased attenuation on the test receiver (e.g. the increased emissions below 80 MHz).

The background environment for the Innovation Centre and Warehouse locations is close to, but still generally less than, the Cigré at-receiver limit and is 10 dB lower than the standard Cigré 200 m limit. Intentional signals are clearly apparent, including VHF FM radio between 98 VHF-FM radio between 88 MHz and 108 MHz

- DAB radio between 216 MHz and 226 MHz and

The results over the complete range indicate that, except for high level transmitted signals, the extrapolated Cigré limit at 60 m from the converter station exceeds the ambient RF environment over almost the entire frequency range.

The measurement results for the VHF ATC frequency range from 118 MHz to 137 MHz are shown in a separate graph on page 20. These results show that the standard 200 m Cigré limit is insufficient to ensure that the IFA2 emissions would be below the ambient RF environment in this frequency range.

5.5 300 MHz to 1 GHz Frequency Range

The results for the 300 MHz to 1 GHz frequency range on page 21 show that the background emissions are close to the Cigré at-receiver and 200 m limits, allowing for the test receiver attenuation setting impact. However, the results are lower than the standard Cigré limit extrapolated to 60 m, again indicating that this limit is insufficient to provide protection against the risk of EMI when receiving low level signals.

A number of intentional transmissions are clearly shown:

- TETRA mast transmissions between 390 MHz and 395 MHz'
- DTV between around 475 MHz and 602 MHz, that correspond to the frequencies used by Rowridge Transmitter on the Isle of Wight; and
- Mobile phone transmissions around to 800 MHz and between 900 MHz and 1 GHz.

6 Conclusions

The RF survey has measured the ambient RF environment at three locations on the Solent Airport, covering the Air Traffic Control Tower and two locations that would be close to the IFA2 converter station, one at the Innovation Centre and the second at a Warehouse.

The measurement results have characterised the RF environment present at the time of the measurement, with higher level transmissions being clearly identifiable above the background levels.

The results were compared with the standard proposed Cigré limit to be applied at 200 m from converter stations and the Cigré limit that would be applicable at the location of any RF receivers. This comparison indicates that the use of the Cigré 200 m limit would only provide protection against EMI for high level signals, especially where receivers are located closer to the converter station (e.g. at a distance of 60 m); reception of lower level signals that are still above the background level could suffer from EMI. The comparison indicates that the use of the Cigré at-receiver limit would provide an appropriate level of protection against EMI to the reception of lower level signals.

7 Abbreviations

AC	Alternating Current
ATC	Air Traffic Control
DAB	Digital Audio Broadcasting
DC	Direct Current
DTV	Digital Television
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
HF	High Frequency
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
LF	Low Frequency
LSAEM	LSA Electromagnetics
MF	Medium Frequency
NG	National Grid
NGIL	National Grid IFA2 Ltd
RF	Radio Frequency
TETRA	Terrestrial Trunked Radio
UK	United Kingdom
VLF	Very Low Frequency
VSC	Voltage Source Converter

8 References

[1] *IFA2 and Daedalus Airfield EMF Compatibility Report*
National Grid, IFA2-ENG-REP-0001, Draft 0.5, 13 January 2016

[2] *Directive 2014/30/EU of the European Parliament and of the Council*
2014/30/EU, 26 February 2014

[3] *Guide for Measurement of Radio Frequency Interference from HV and MV Substations*
CIGRE, Report 391, August 2009

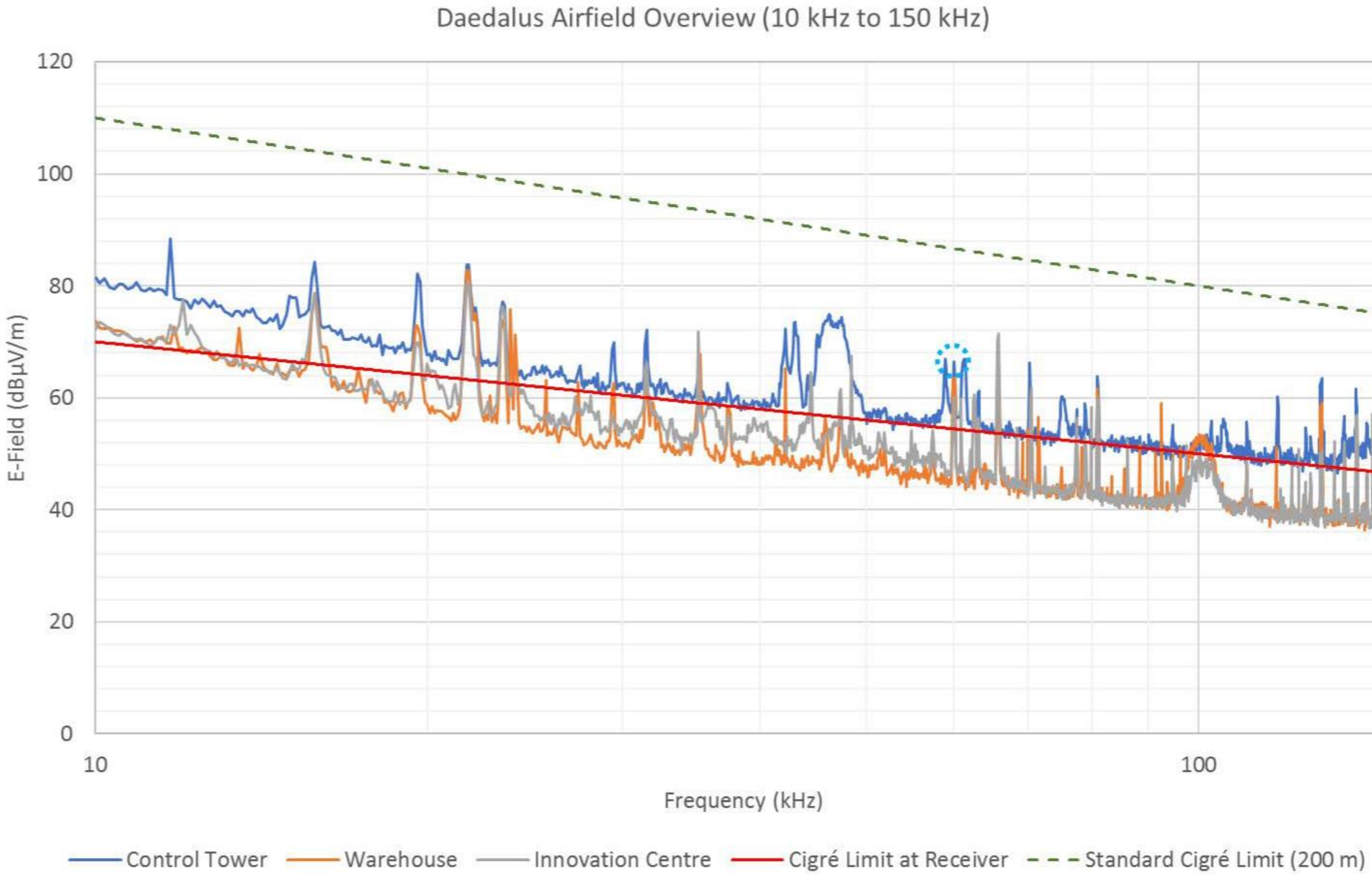
[4] *Environmental Conditions and Test Procedures for Airborne Equipment*
RTCA, RTCA/DO-160G, 8 December 2010.

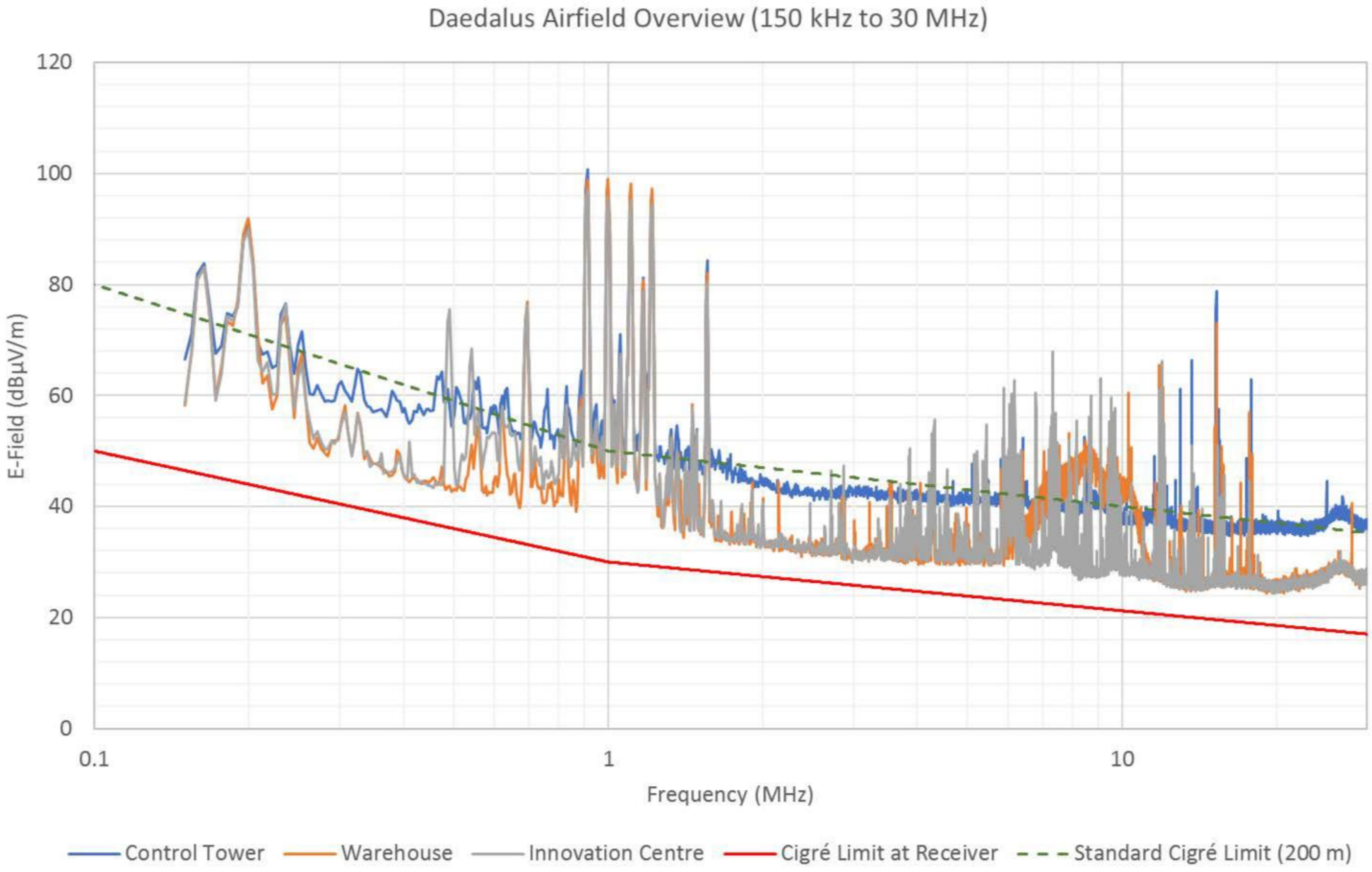
[5] *Environmental Conditions and Test Procedures for Airborne Equipment*
EUROCAE, ED-14G, May 2011.

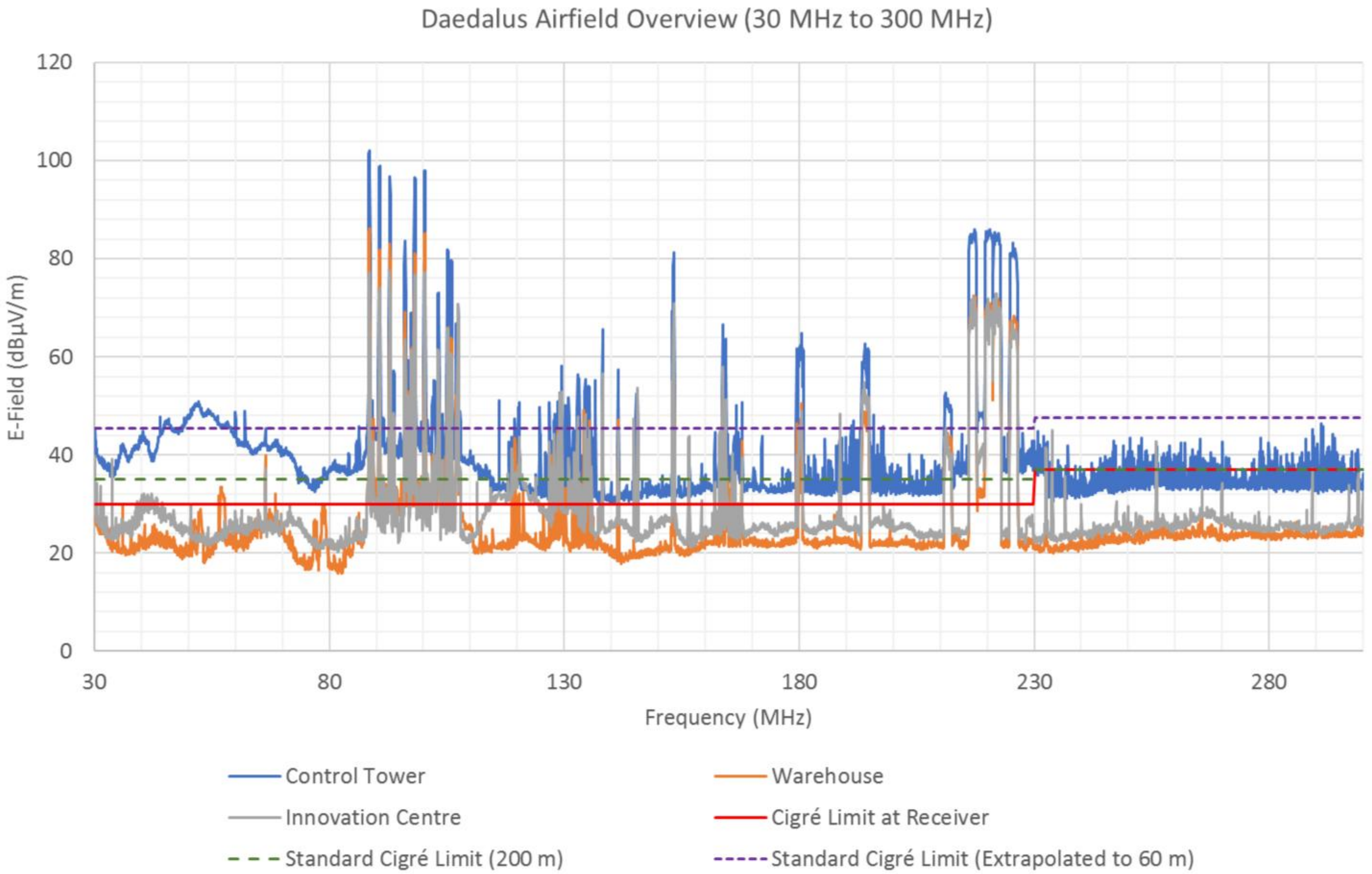
[6] *Electromagnetic Compatibility*
Ministry of Defence, Def Stan 59-411, Issue 2, 31 March 2014.

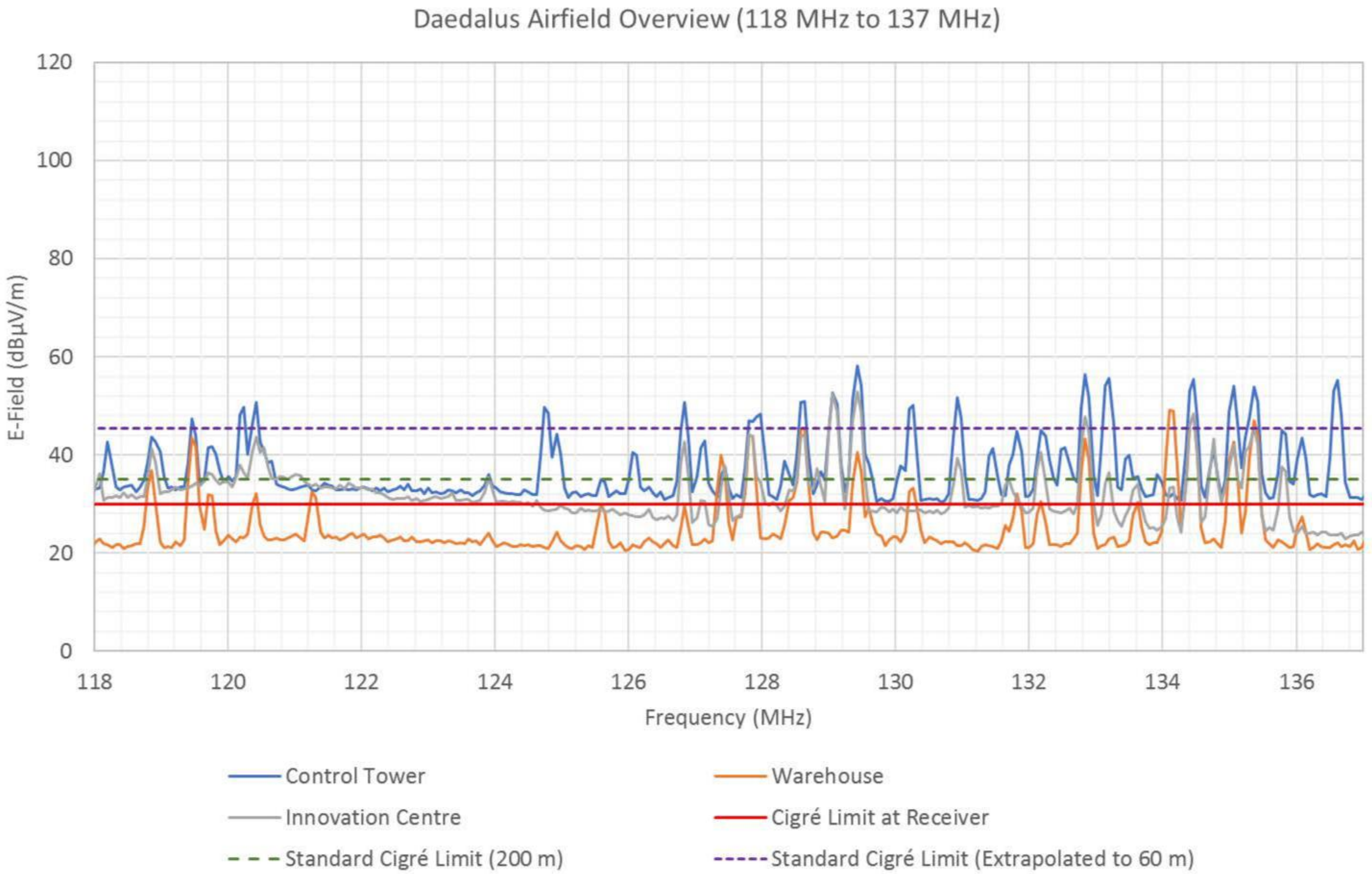
[7] *Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments*
EN 61000-6-1:2007+A1:2011

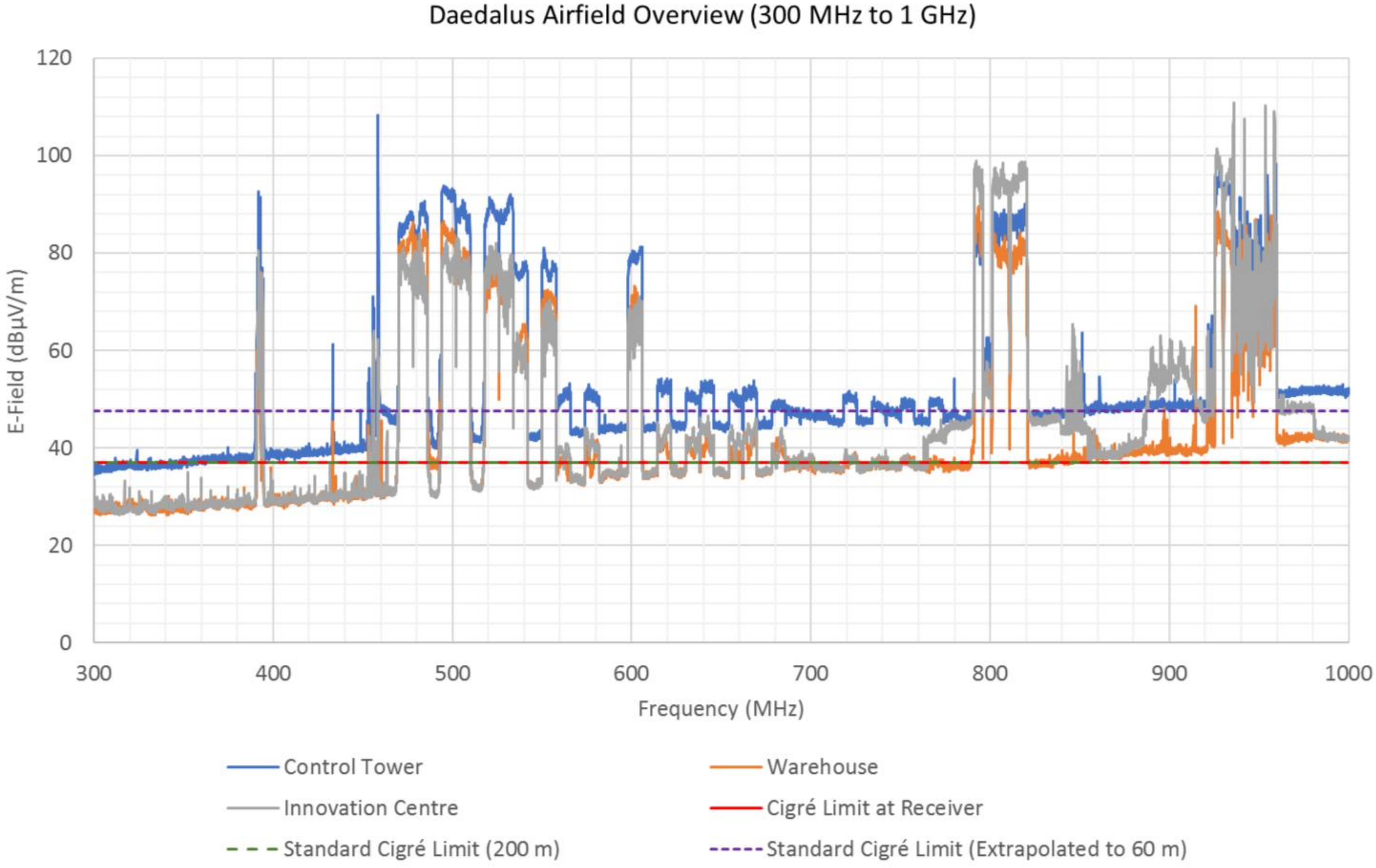
APPENDIX A
OVERALL TEST RESULTS FOR ALL POSITIONS


Daedalus Airfield Overview (10 kHz to 150 kHz)
E-Field (dBµV/m)
120
100
80
60
40
20
0
10
100
Frequency (kHz)
Control Tower
Warehouse
Innovation Centre
Cigré Limit at Receiver
Standard Cigré Limit (200 m)

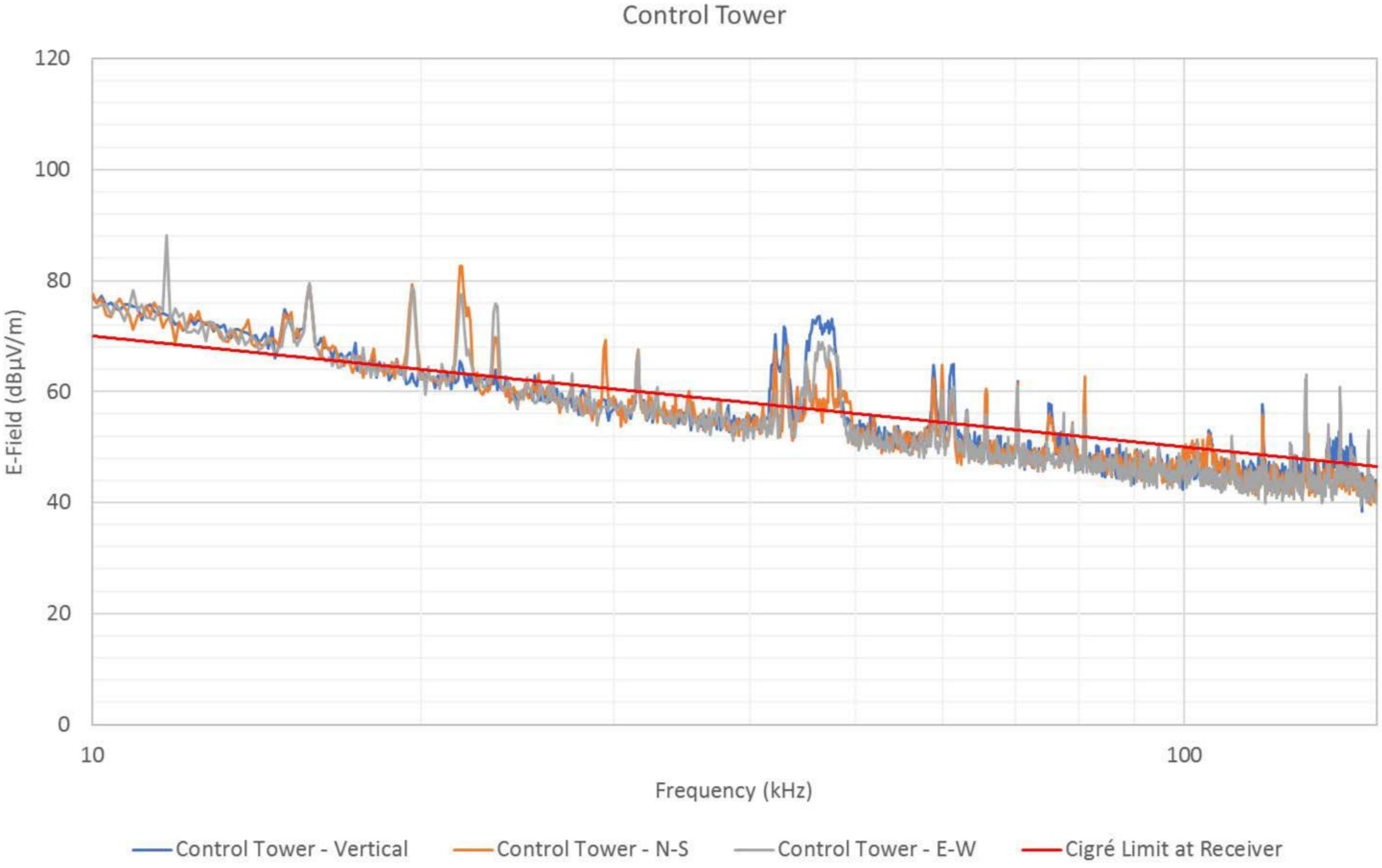

Daedalus Airfield Overview (150 kHz to 30 MHz)
120
100
80
60
40
20
0
E-Field (dBµV/m)
0.1
1
10
Frequency (MHz)
Control Tower
Warehouse
Innovation Centre
Cigré Limit at Receiver
Standard Cigré Limit (200 m)

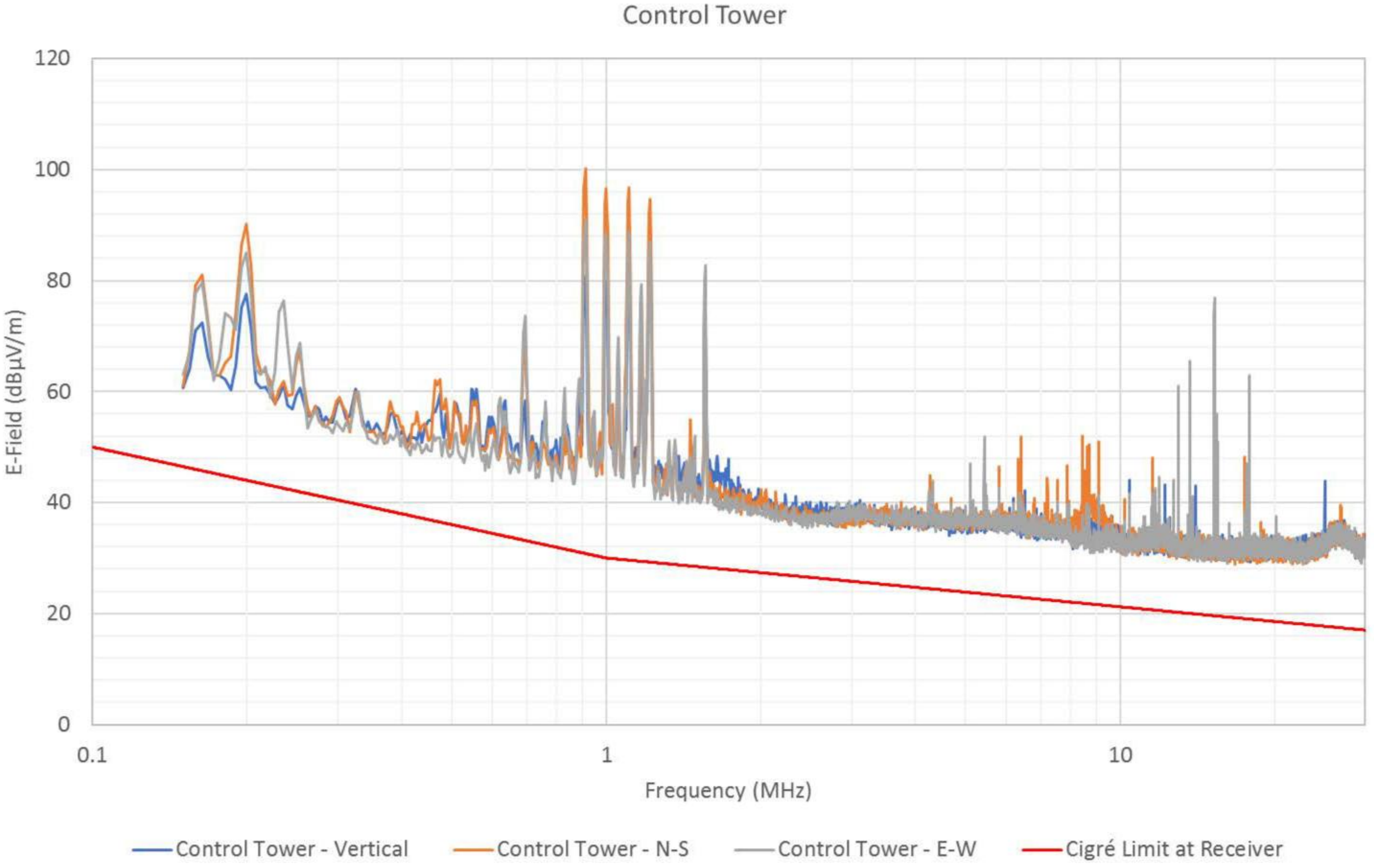

Daedalus Airfield Overview (30 MHz to 300 MHz)
E-Field (dBµV/m)
120
100
80
60
40
20
0
30
80
130
180
230
280
Frequency (MHz)
Control Tower
Warehouse
Innovation Centre
Cigré Limit at Receiver
Standard Cigré Limit (200 m)
Standard Cigré Limit (Extrapolated to 60 m)

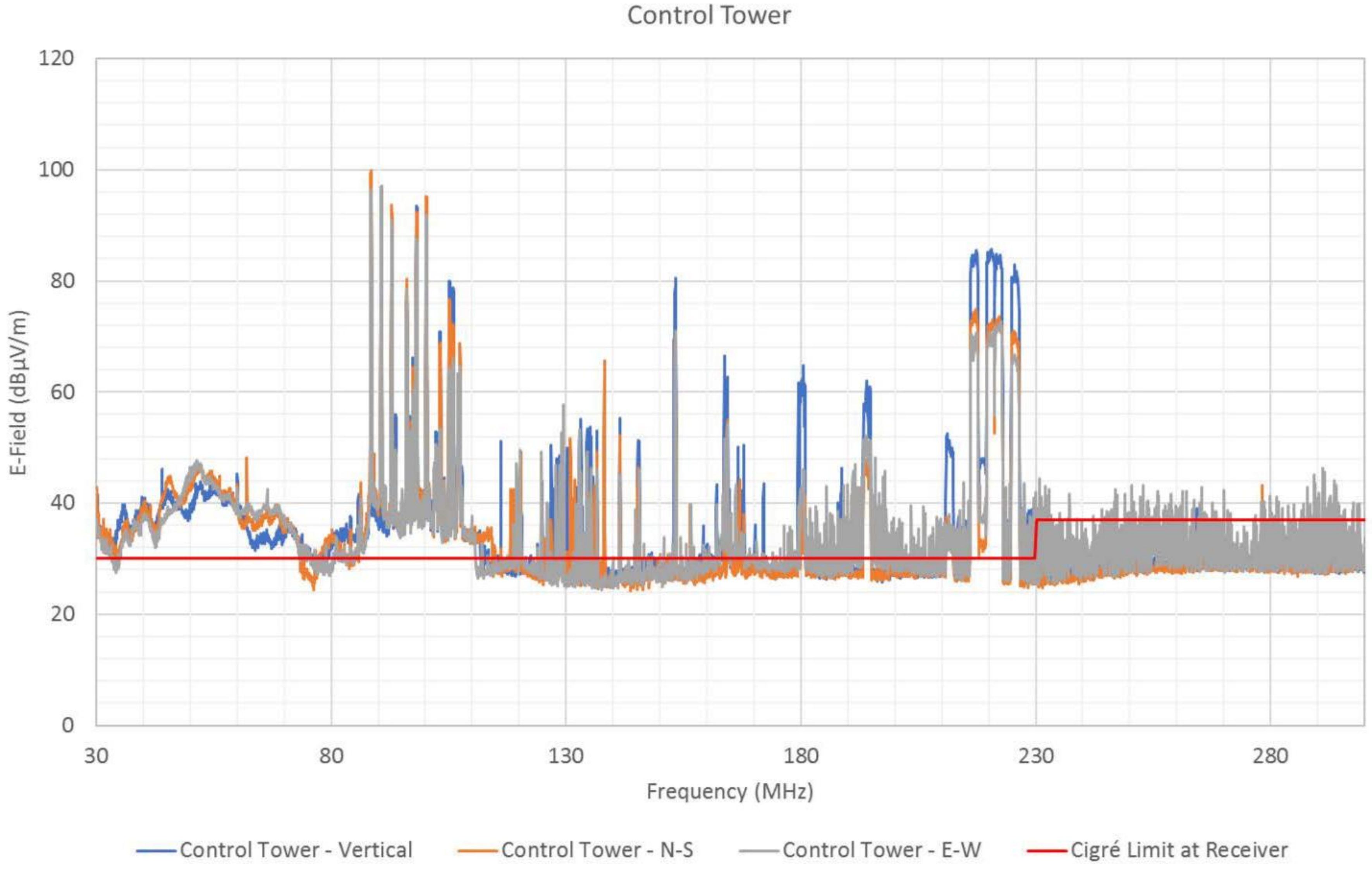

Daedalus Airfield Overview (118 MHz to 137 MHz)
E-Field (dBµV/m)
120
100
80
60
40
20
0
118
120
122
124
126
128
130
132
134
136
Frequency (MHz)
Control Tower
Warehouse
Innovation Centre
Cigré Limit at Receiver
Standard Cigré Limit (200 m)
Standard Cigré Limit (Extrapolated to 60 m)

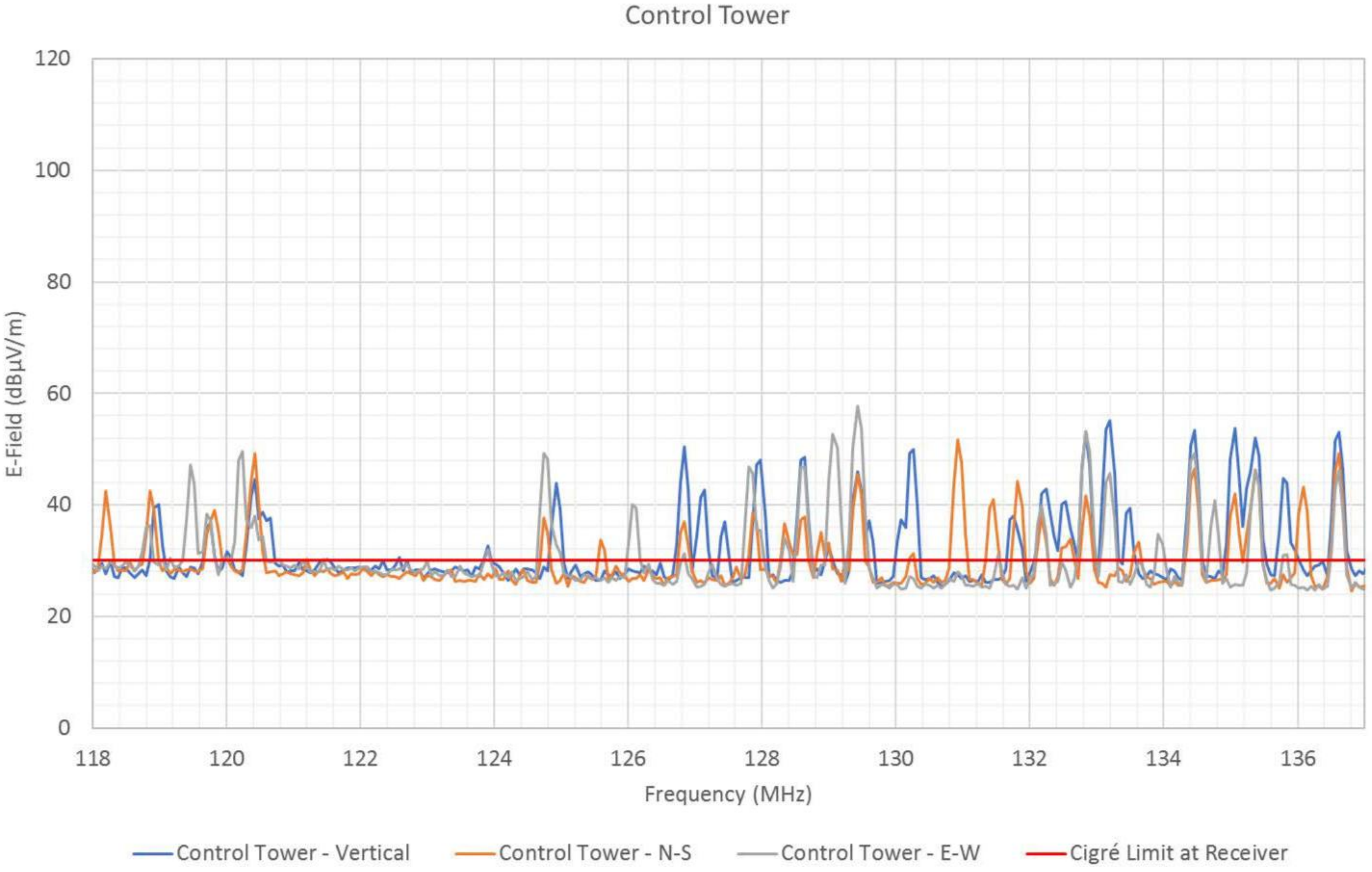

Daedalus Airfield Overview (300 MHz to 1 GHz)
E-Field (dBµV/m)
0
20
40
60
80
100
120
Frequency (MHz)
300
400
500
600
700
800
900
1000
Control Tower
Warehouse
Innovation Centre
Cigré Limit at Receiver
Standard Cigré Limit (200 m)
Standard Cigré Limit (Extrapolated to 60 m)

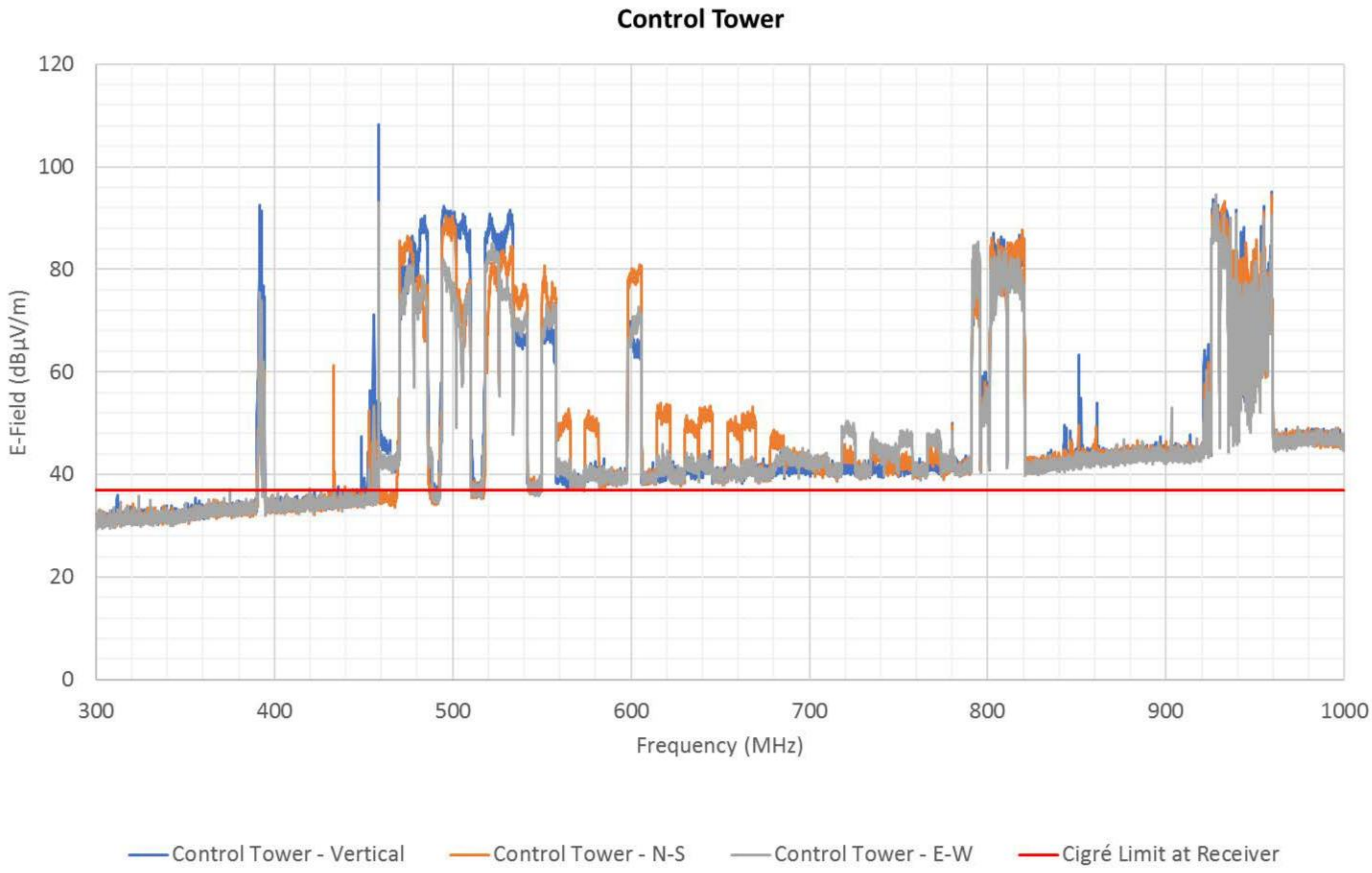
APPENDIX B
CONTROL TOWER


Control Tower
120
100
80
60
40
20
0
E-Field (dBµV/m)
10
100
Frequency (kHz)
Control Tower - Vertical
Control Tower - N-S
Control Tower - E-W
Cigré Limit at Receiver

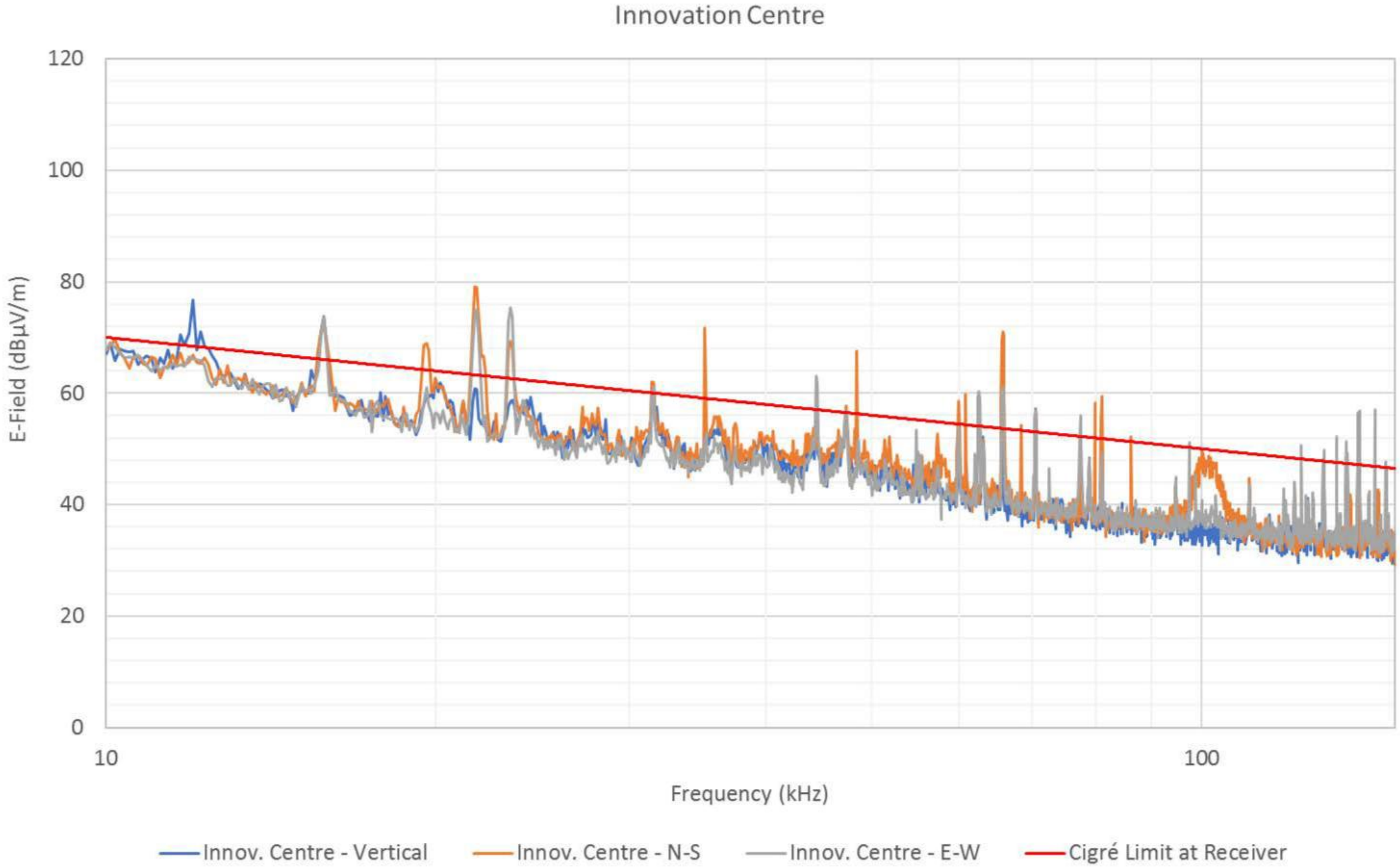

Control Tower
120
100
80
60
40
20
0
E-Field (dBµV/m)
0.1
1
10
Frequency (MHz)
Control Tower - Vertical
Control Tower - N-S
Control Tower - E-W
Cigré Limit at Receiver

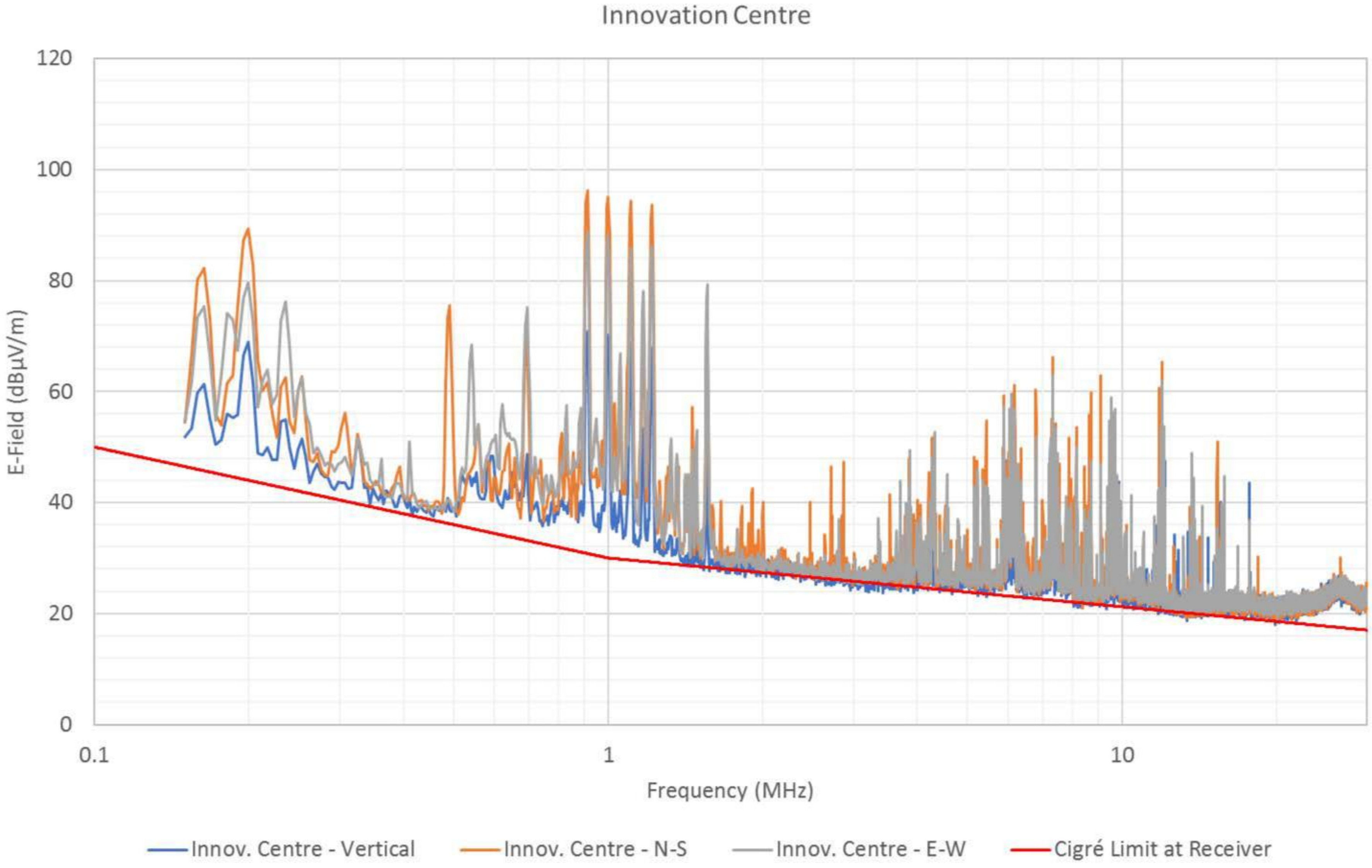

Control Tower
120
100
80
60
40
20
0
E-Field (dBµV/m)
30
80
130
180
230
280
Frequency (MHz)
Control Tower - Vertical
Control Tower - N-S
Control Tower - E-W
Cigré Limit at Receiver

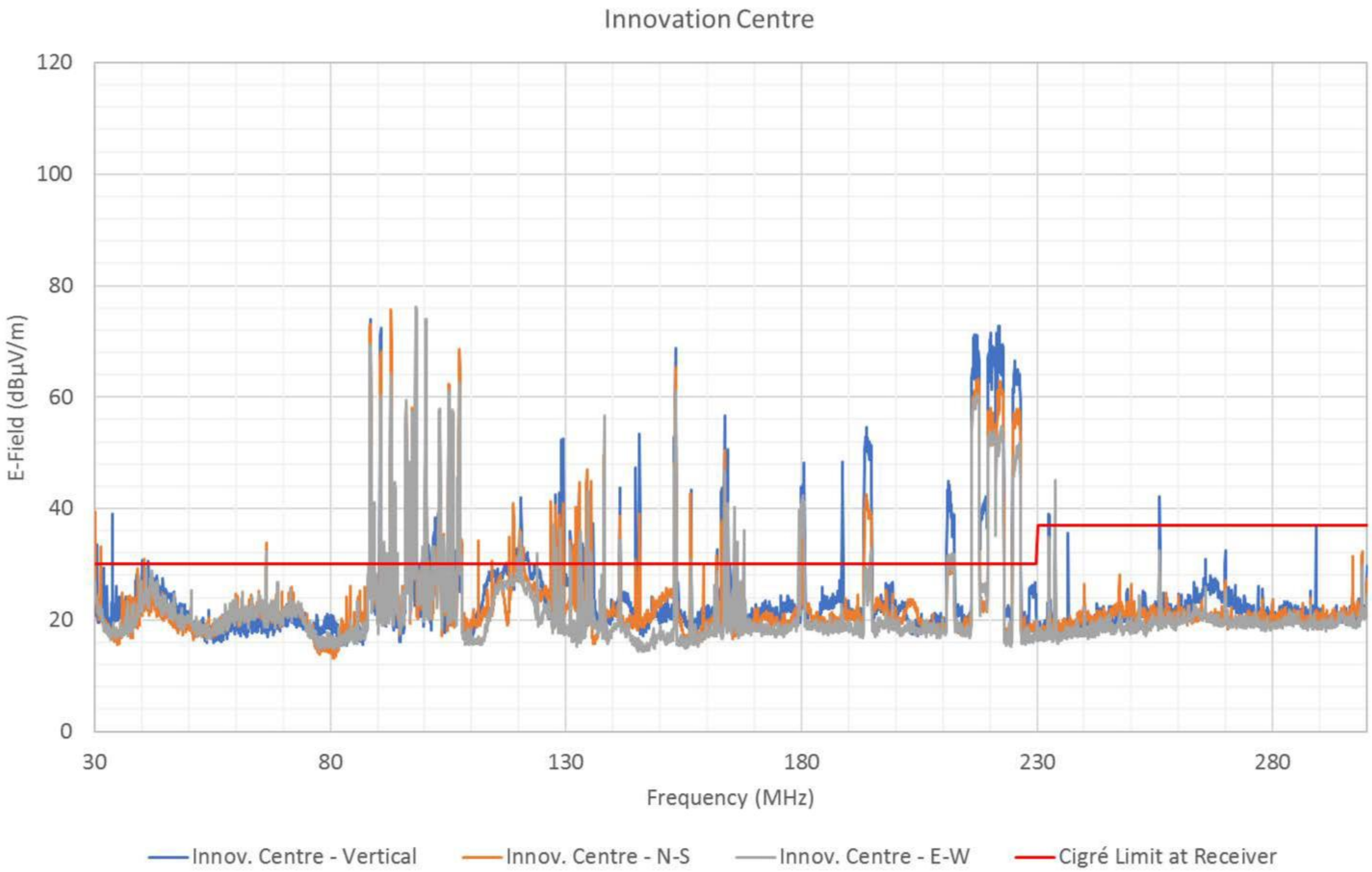

Control Tower
E-Field (dBµV/m)
120
100
80
60
40
20
0
118
120
122
124
126
128
130
132
134
136
Frequency (MHz)
Control Tower - Vertical
Control Tower - N-S
Control Tower - E-W
Cigré Limit at Receiver

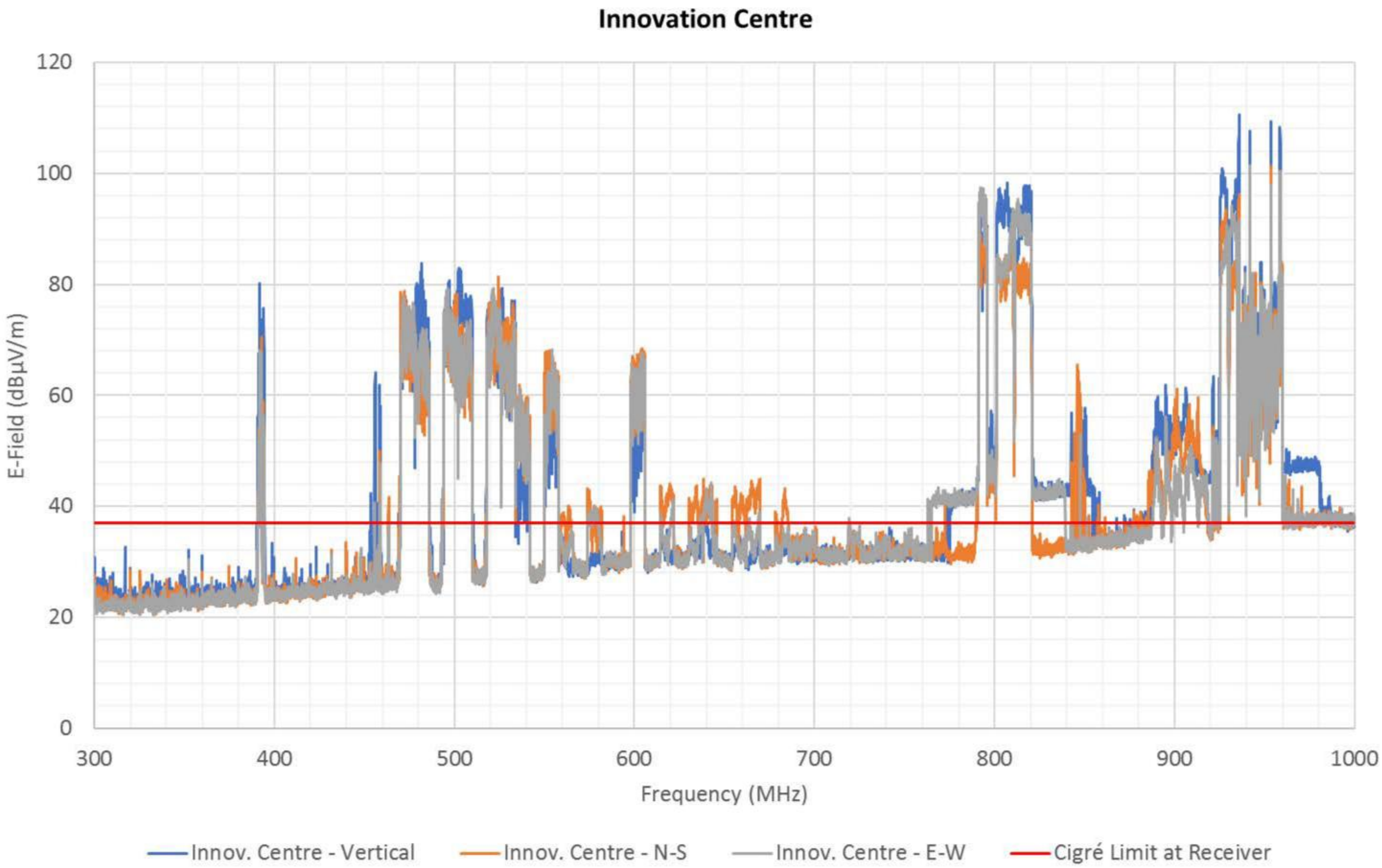

Control Tower
120
100
80
60
40
20
0
E-Field (dBµV/m)
300
400
500
600
700
800
900
1000
Frequency (MHz)
Control Tower - Vertical
Control Tower - N-S
Control Tower - E-W
Cigré Limit at Receiver

APPENDIX C
INNOVATION CENTRE

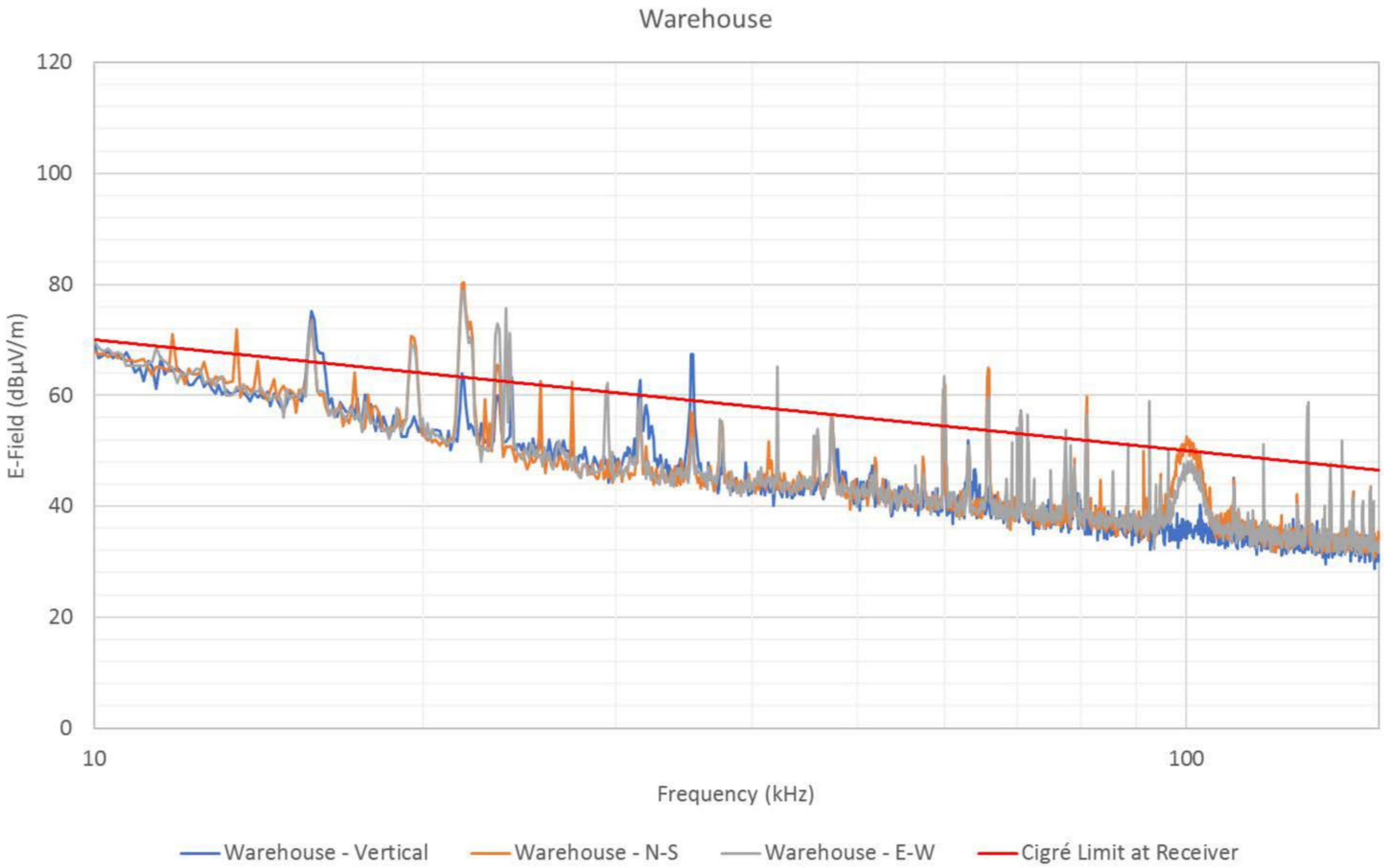

Innovation Centre
120
100
80
60
40
20
0
E-Field (dBµV/m)
10
100
Frequency (kHz)
Innov. Centre - Vertical
Innov. Centre - N-S
Innov. Centre - E-W
Cigré Limit at Receiver

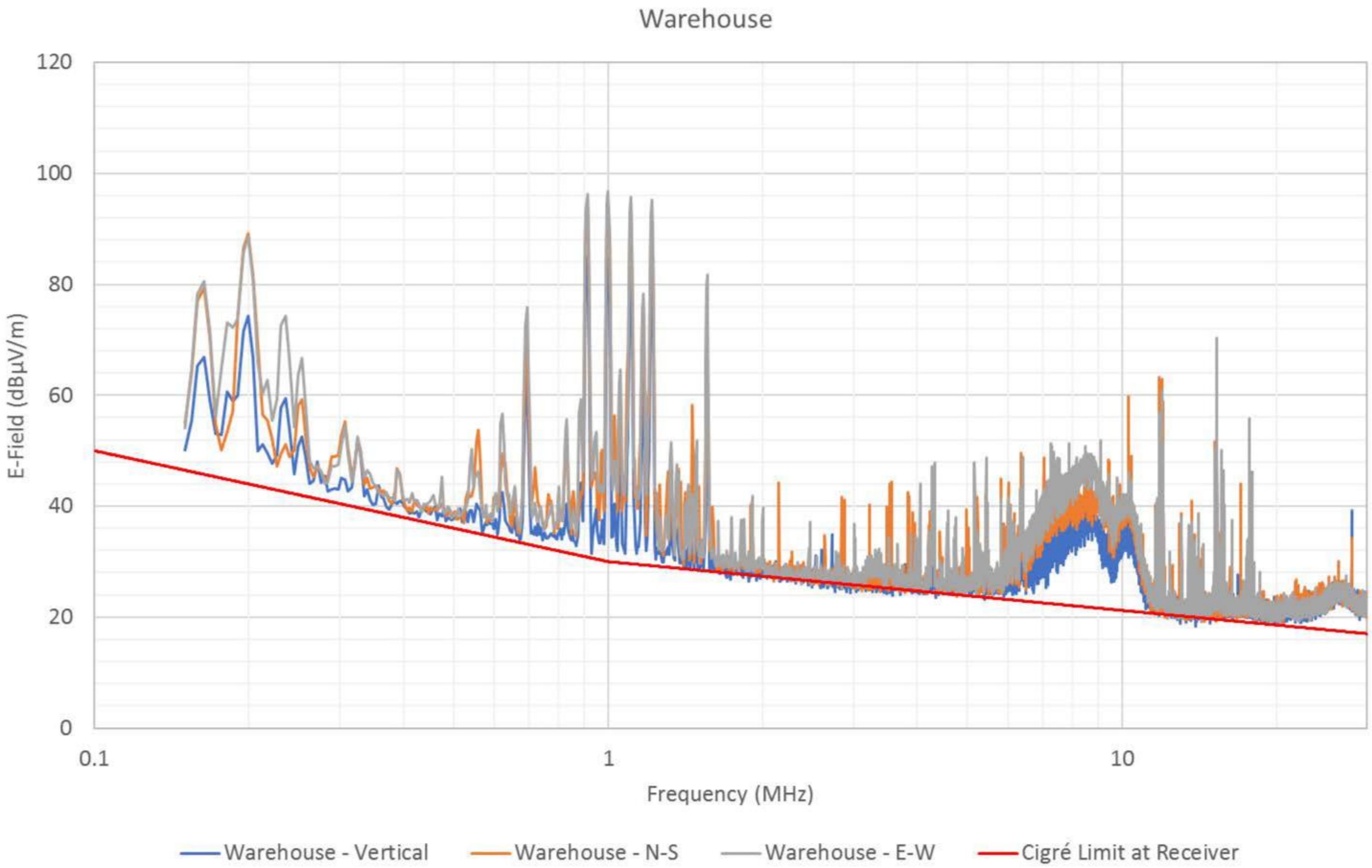

Innovation Centre
120
100
80
60
40
20
0
E-Field (dBµV/m)
0.1
1
10
Frequency (MHz)
Innov. Centre - Vertical
Innov. Centre - N-S
Innov. Centre - E-W
Cigré Limit at Receiver

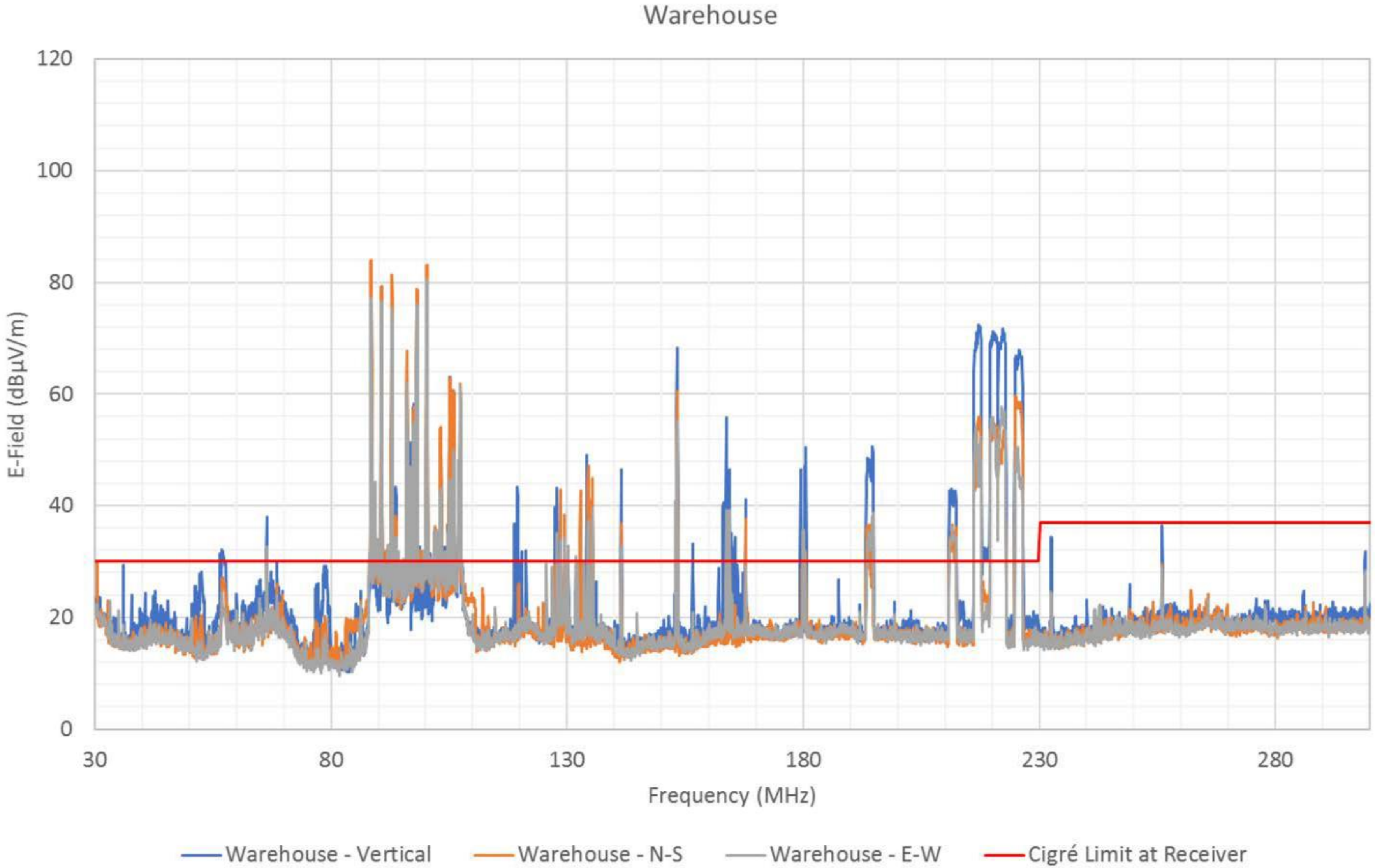

Innovation Centre
120
100
80
60
40
20
0
E-Field (dBµV/m)
30
80
130
180
230
280
Frequency (MHz)
Innov. Centre - Vertical
Innov. Centre - N-S
Innov. Centre - E-W
Cigré Limit at Receiver

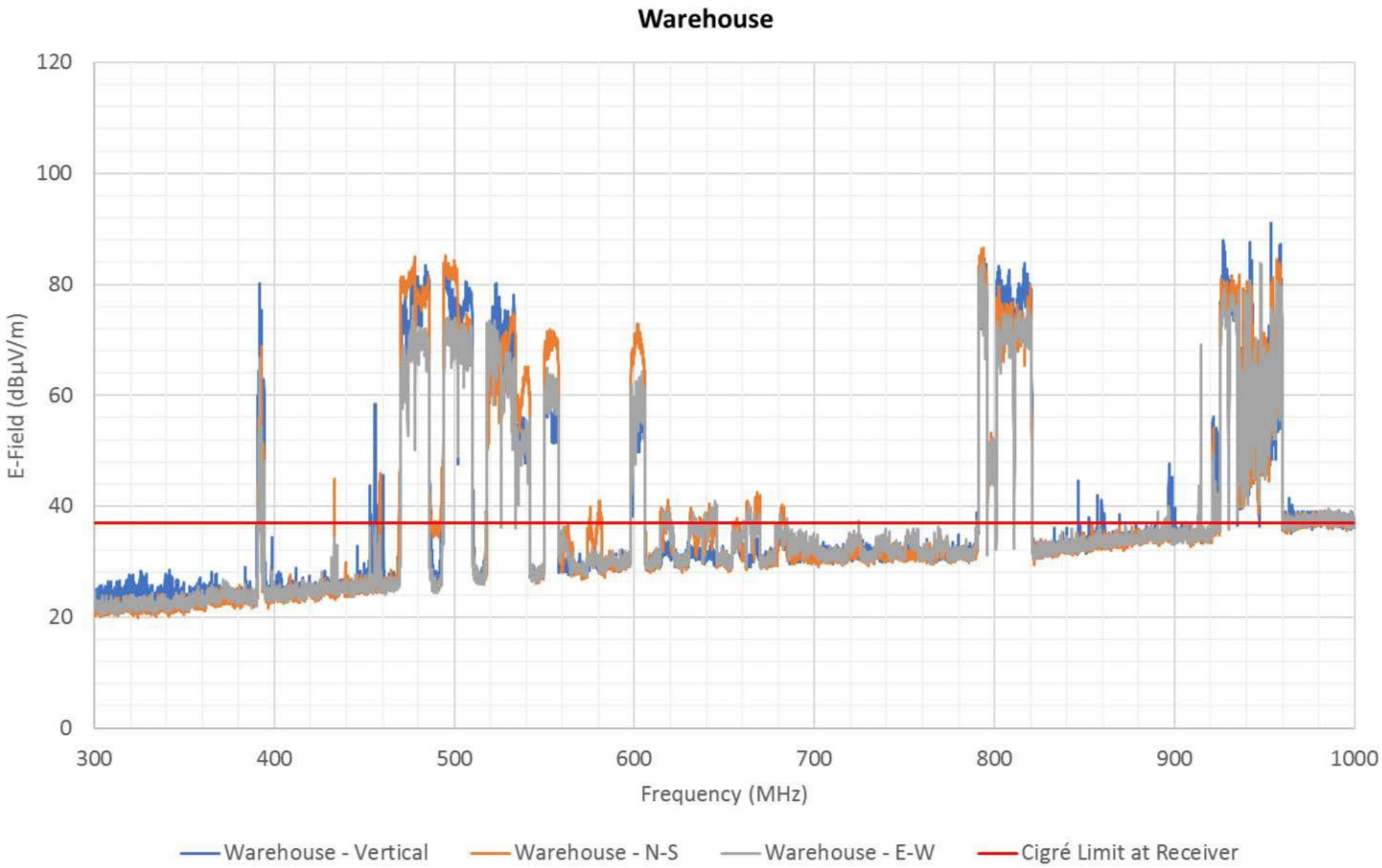

Innovation Centre
120
100
80
60
40
20
0
E-Field (dBµV/m)
300
400
500
600
700
800
900
1000
Frequency (MHz)
Innov. Centre - Vertical
Innov. Centre - N-S
Innov. Centre - E-W
Cigré Limit at Receiver

APPENDIX D
WAREHOUSE

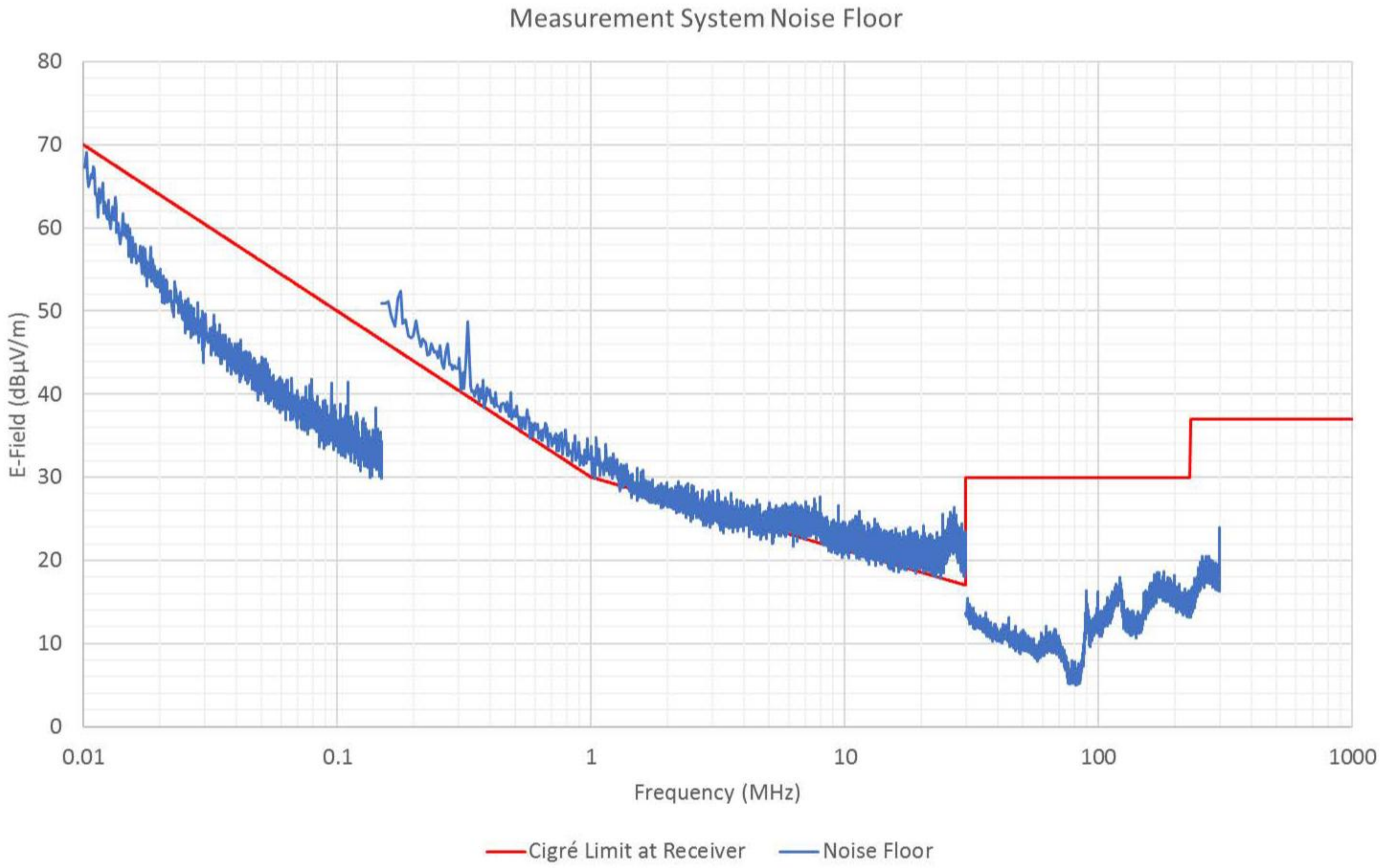

Warehouse
120
100
80
60
40
20
0
E-Field (dBµV/m)
10
100
Frequency (kHz)
Warehouse - Vertical
Warehouse - N-S
Warehouse - E-W
Cigré Limit at Receiver


Warehouse
120
100
80
60
40
20
0
E-Field (dBµV/m)
0.1
1
10
Frequency (MHz)
Warehouse - Vertical
Warehouse - N-S
Warehouse - E-W
Cigré Limit at Receiver


Warehouse
120
100
80
60
40
20
0
E-Field (dBµV/m)
30
80
130
180
230
280
Frequency (MHz)
Warehouse - Vertical
Warehouse - N-S
Warehouse - E-W
Cigré Limit at Receiver


Warehouse
120
100
80
60
40
20
0
E-Field (dBµV/m)
300
400
500
600
700
800
900
1000
Frequency (MHz)
Warehouse - Vertical
Warehouse - N-S
Warehouse - E-W
Cigré Limit at Receiver

APPENDIX E
MEASUREMENT SYSTEM NOISE FLOOR


Measurement System Noise Floor
80
70
60
50
40
30
20
10
0
E-Field (dBµV/m)
0.01
0.1
1
10
100
1000
Frequency (MHz)
Cigré Limit at Receiver
Noise Floor