SE(16)089A1

Spectrum Engineering Services

Wireless Power Transfer bus charging system

Final Report

Measurements at Bletchley Bus Station

Baldock Radio Station
Royston Road
Baldock
SG7 6SH

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# Report Number: SES (16)012	
WPT Bus Charging System at Bletchley Bus Station	
Assistance requested	8 January 2016
Tests carried out	5 & 12 June 2016
Final Report	24 June 2016

 # SES (16)012 replaces the Interim Report (SES (16)004) issued on 27 May 2016 which contained an error - fully described in Section 2.3 of this report

Work performed by	
James Loughlin	*Measurements & Report*
Dave Carter	*Measurements*

Report Author & authorisation		
James Loughlin	Author	
Mark Austin Measurements Manager	Authorisation	

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Contents

1 Introduction

This is a 5 year closely monitored demonstration programme run as a joint venture between Mitsui and ARUP to show the sustainability of using electric busses.

The system is operated by the Number 7 bus service being used in Milton Keynes (MK). The electric buses (8 in total) are charged from a standard cabled supply each night when in the bus depot. During their normal daily service running between Bletchley Bus Station (MK2 2AS) and Wolverton via the MK central railway station they park for between 10 and 15 minutes at each end of the route. During this time they lower a vehicle mounted induction loop over four induction pads set in the road. This procedure uses a Wireless Power Transfer (WPT) System to induce a charging current in the lowered induction loop plate.

Figure 1: Bay No1 with the induction loop plate lowered over the induction pad.

The bus can recharge the on-board batteries to 90% capacity in twenty minutes. Recharging in this manner allows the busses to remain operational throughout the day before returning to the depot in the evening.

1.1 Company

MASP Ltd. (MBK Arup Sustainable Projects – Mitsui-Arup joint venture)

Website:

http://www.masp-ltd.com/

Contact:

Murat Basarir, Business Development Manager, 13 Fitzroy Street, London W1T 4BQ
Tel: 01027 553521.

1.2 Equipment Under Test (EUT)

The frequency of operation is between 15 and 20 kHz and the charging is done at the rate of 120 kW using four 30 kW plates (set in the road surface).

Figure 2: Unoccupied Bay No1 with the 4 induction pads visible.
(Loop antenna 3 m from centre of pads – initial measurement for interim report)

There is a 2.4 GHz communications link between the WPT installation and the bus which monitors the charging process.

1.3 Classification

The UK Interface Requirements 2030 (Licence Exempt Short Range Devices); Interface number IR2030/15/1 identifies inductive applications in the band 9 – 59.75 kHz. The transmit power/power density limit is quoted as 72 dBμA/m measured at 10 metres. This is referenced from the European Standard EN 300 330.

ETSI EN 300 330-1 v1.8.1 (2015-03). Electromagnetic compatibility and Radio spectrum matters (ERM); Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the range 9 kHz to 30 MHz; Part 1: Technical characteristics and test methods.

The standard also covers the following parameters:

4.1.3 General performance criteria for WPT systems

> Table 3 identifies ETSI EN 300 330 to satisfy the essential requirements of the applicable R&TTE directive. According to Case 2 of this table, it covers WPT systems which consist of:
>
> “A power transmitter with additional communication capability to control the charge function in conjunction with the receiving part. The power transmitter could also be named as charger.”

6.6 Measuring receiver

Both resolution bandwidth (RBW) and detector type are given in Table 4 of the standard EN 300 330.

A CISPR bandwidth of 200 Hz for use between 9 and 150 kHz is quoted for the measurement receiver. *Both spectrum analysers used to complete the measurements have the ability to select this Resolution BandWidth (RBW).*

The detector type required for a compliance measurement is stated as Quasi-peak (Qp). *As neither analyser has a Qp detector all measurements were completed with a peak detector selected. This detector gives a value typically +4 dB above the level recorded using Qp detection.*

7.2.1.2 Methods of measurement

Measurements of the radiated H-field shall be made on an open field test site … any measured values shall be at least 6 dB above the ambient noise level.

Since the WPT system is installed in the bus station the measurements have been completed in-situ. Initial noise floor measurements confirmed that the measured levels where more than 6 dB above the ambient noise.

The H-field is measured with a shielded loop antenna connected to the measurement receiver.

7.2.1.3 Limits

Table 6: H-field limits at 10 m in the frequency range (MHz) 0.009 $\leq$ f < 0.090 Is 72 dBμA/m.

Two notes under the table refer to this limit:

- The Limit is 42 dBμA/m for the following spot frequencies:
  60 kHz ± 250 Hz, 66.6 kHz ± 750 Hz, 75 kHz ± 250 Hz, 77.5 kHz ± 250 Hz, and 129.1 kHz ± 500 Hz.

  As the third harmonic falls on 60 kHz measured levels related to this limit are included in the results section.

- The H-field strength limits (Hf) in dBμA/m at 10 m distance of a Wireless Power Transfer System in the declared working situations.

Published in the Official Journal of the European Union an amendment to Decision 2006/771/EC on harmonisation of the radio spectrum for use by SRDs identifies the same band and quotes the same limits for use by inductive devices.

Reference to the Standard EN 300 330-1 v1.8.1 in this report does not infer compliance with the whole of that standard but the magnetic field strength limit (H_f) measured at 10 metres - specifically stated in Table 6 Clause 7.2.1.3 has been used as a guide to the results published herein.

Since the measurements were completed in-situ using a peak detector the results must be treated as an indicative measurement of the H-field (H_f) radiated disturbance produced by the Wireless Power Transfer (WPT) installation.

2 Method

2.1 Antenna polarisation and orientation

Measurements were completed with the shielded loop antenna mounted on tripod 1 metre above ground level. A loop antenna has directional properties. Figure 3 shows the loop orientated for maximum pick-up from the induction pads set in the road surface of Bay 1.

Figure 3: Loop orientation for maximum received signal from the induction pads.

The *figure of eight* polar pattern produced by a loop antenna means that the response should change with its orientation to the signal source. Measurements were completed with two antenna orientations at each location. The results reflect the change in amplitude with respect to this orientation. By recording the amplitude of a known strong broadcast station (BBC Radio 4 on 198 KHz) a confidence check in the measurements was maintained throughout the site visits.

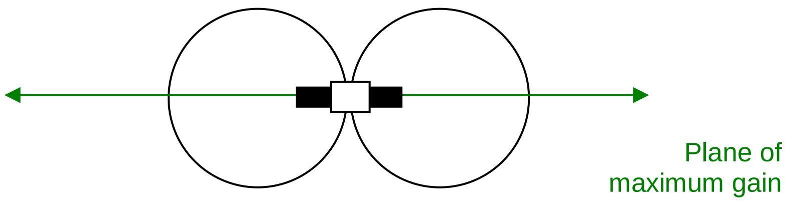


Figure 4: Polar diagram of loop antenna showing the plane of maximum gain.

2.2 Measurement Site

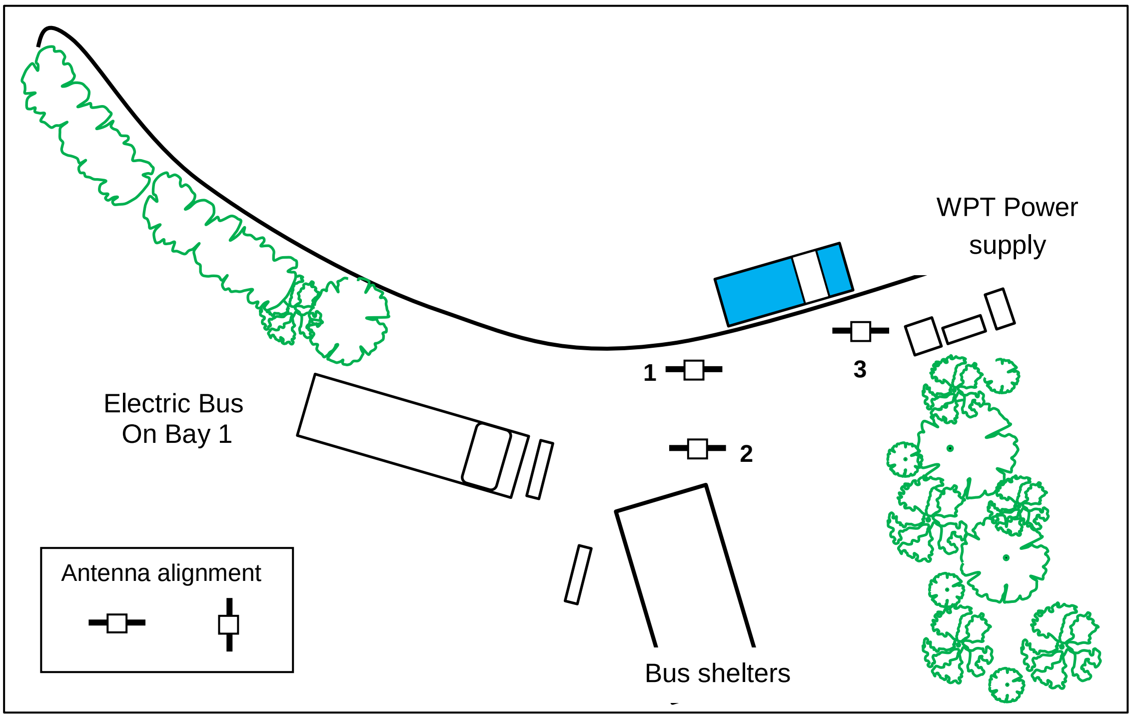


Figure 5: Bus station plan showing position of mobile laboratory and antenna locations.

Measurements were completed at the Bletchley Bus Station on three Sundays when parking restrictions were relaxed and the deployment of the antenna and cables did not restrict passenger and pedestrian movements.

Figure 5 identifies the three measurement locations used within the Bus Station. The initial measurements were carried out with the tripod mounted loop set 10 metres from the centre of the induction pads (location 1 in Figure 5 and photograph Figure 6) but without obstructing the free access to the bus passenger doors or pedestrian movements.

Figure 6: Initial 10m antenna location segregated from passenger movements.

2.3 Measurement method

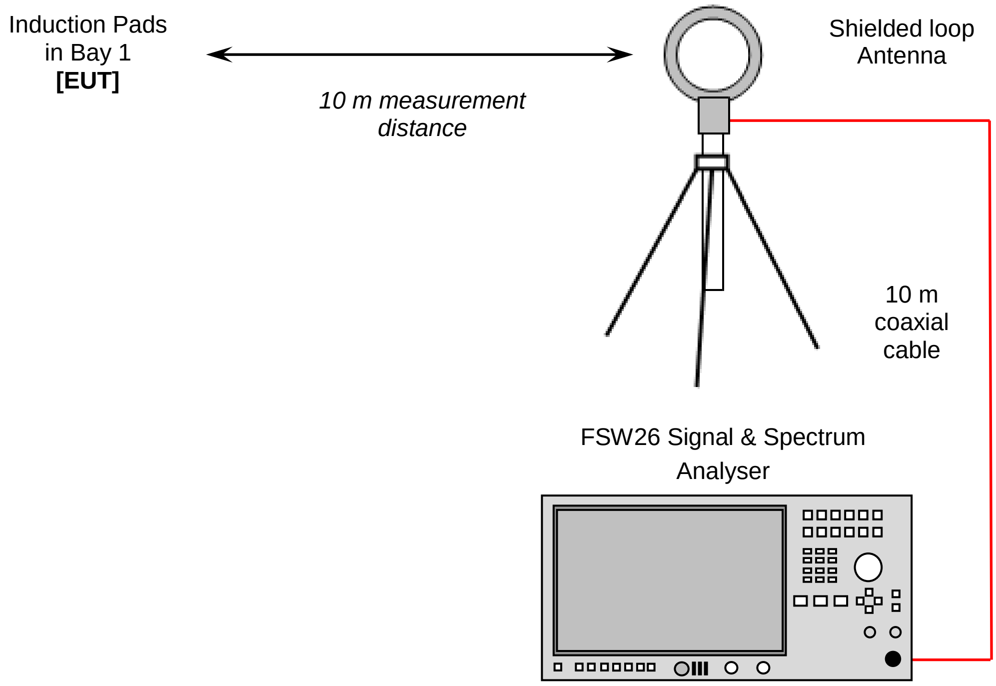


Figure 7: Equipment configuration.

The Interim report (SES (16)004) indicated that both the Agilent PSA and the Rohde Schwarz FSW analysers had the capability to capture the required spectrum plots and store them in an industrial standard file format. The individual screen plots are recorded in the results section together with expanded plots derived from the c.s.v. files.

However, the screen plots captured by the PSA analyser carried the caption '*AC coupled: unspecified below 20 MHz*'. This recognised the effect of the analyser input d.c. blocking capacitor had on the recorded signal amplitude below 20 MHz. The capacitor could not be switched out of circuit. After the 5 June site visit, when the files from both analysers were compared, it became apparent that the capacitor degraded the accuracy of the PSA results to the point that they were unusable.

Spectrum Technology (Technical Regulation) Team, who was the recipient of the interim report, was informed both of this discrepancy and the intention to repeat the measurements on a return visit.

The FSW analyser signal input included a dc blocking capacitor which could be switched out of circuit. Using an external isolating adapter, whose loss had been characterised across the frequencies of interest, the amplitude inaccuracy was removed from all further measurement plots.

Hence only the FSW analyser was used in the final visit and the results are recorded in this report as an accurate representation of the signal levels associated with the WPT system. The adapter characteristics are included in the Annex and a correction factor at 20 kHz added to the calculations in the results Table 4.

A number of background measurements were completed during the time between the two scheduled bus arrivals. These initial sweeps were used to identify any strong out-of-band signals which could have affected the accuracy of the subsequent measurements. Section 3.5 shows the background plots.

A section of out-of-band spectrum with a raised noise floor was observed between 4.2 and 7.7 MHz. This broadband signal did not appear to affect the portion of the spectrum under investigation. Further measurements to confirm whether it was associated with the charging system were carried out by changing the antenna location and orientation. Subsequent plots indicated that the source of this signal was not related to the WPT System. This was confirmed when the bus arrived and began the charging process without any noticeable variation in either the broadband signal or the raised noise floor associated with it. For this reason the source of this signal was not investigated further.

Figure 8: Antenna in location 1 measuring emissions during the bus charging cycle.

3 Results

The results detailed in this section apply only to the tests made at that time, using the test equipment detailed. They do not indicate that on another date an identical set of results may be achieved, due to changes in local environmental conditions or other factors which may or may not have an effect on the measurement results obtained at that future time.

Measurements and Locations			
Plot Number	†Location	RBW kHz	Plot title
Antenna orientated towards Bay 1 (CISPR BW = 200 Hz)			
1	1	0.2	KP63 TDZ Charging in Bay 1
2	1	0.2	KP63 TDX Charging in Bay 1
3	1	0.2	KP63 TDX Charging in Bay 1
4	1	0.2	KP63 TDZ Charging in Bay 1
5	1	0.2	KP63 TDZ Charging complete
6	1	0.2	Bus reversed out of Bay 1
Antenna orientated at right angles to Bay 1 (CISPR BW = 200 Hz)			
7	1	0.2	KP63 TDZ Charging in Bay 1
8	1	0.2	KP63 TDX Charging in Bay 1
Antenna orientated towards Bay 1 (Audio BW)			
9	1	10	KP63 TDZ Charging in Bay 1
10	2	10	KP63 TDX Charging in Bay 1
11	1	10	KP63 TDZ Charging in Bay 1
Antenna orientated at right angles to Bay 1 (Audio BW = 10 kHz)			
12	1	10	KP63 TDZ Charging in Bay 1
13	2	10	KP63 TDX Charging in Bay 1
Background Plots – No bus in Bay 1 (CISPR BW = 200 Hz)			
14	2	0.2	10m with antenna orientated towards Bay 1
15	2	0.2	10m with antenna orientated at right angles to Bay 1
16	3	0.2	4m from transformer antenna orientated towards it
17	3	0.2	4m from transformer orientated at right angles
18	2	0.2	Span 3.2 – 7.8 MHz NOT attributed to WPT system
19	2	0.2	KP63 TDX commenced Charging in Bay 1

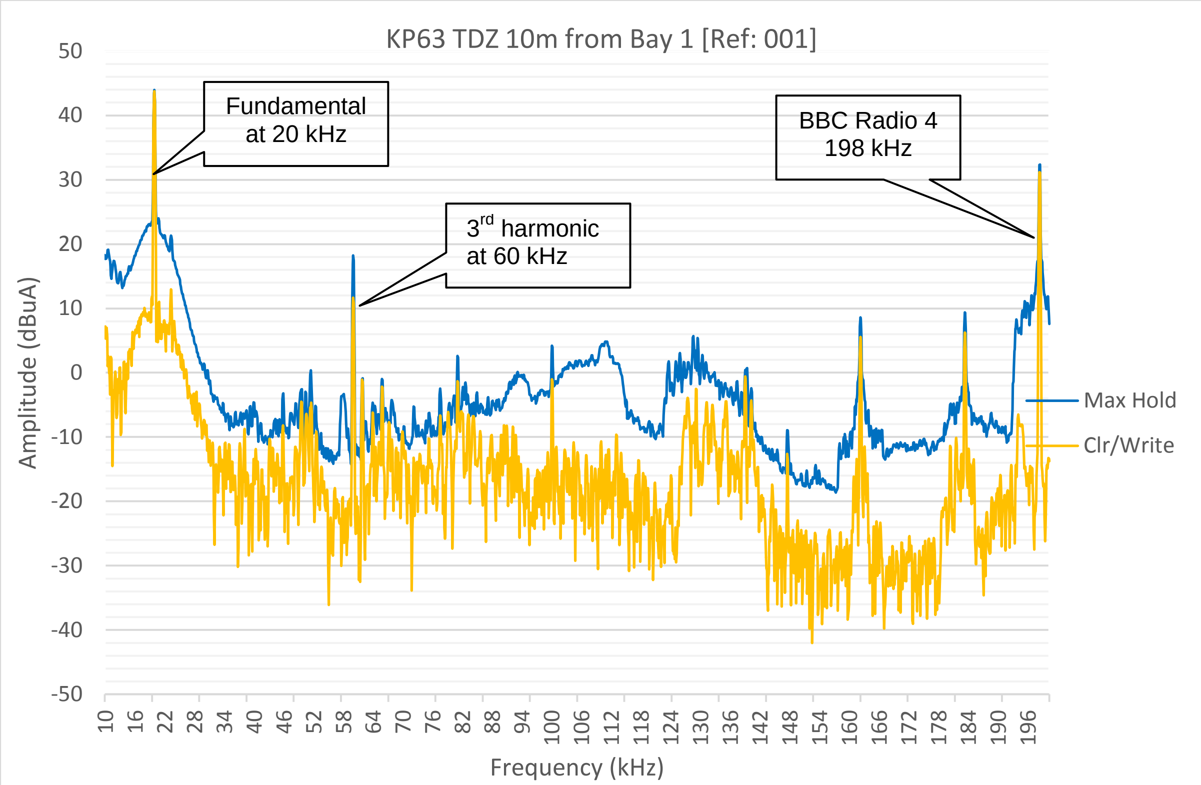
†**Note**: Locations 1 and 2 were both 10m from the centre of the charging pads. They were spaced 1.5 metres apart (Figure 5) to help identify the possible origin of local out of band signals.

Table 1: Locations and measurement plots

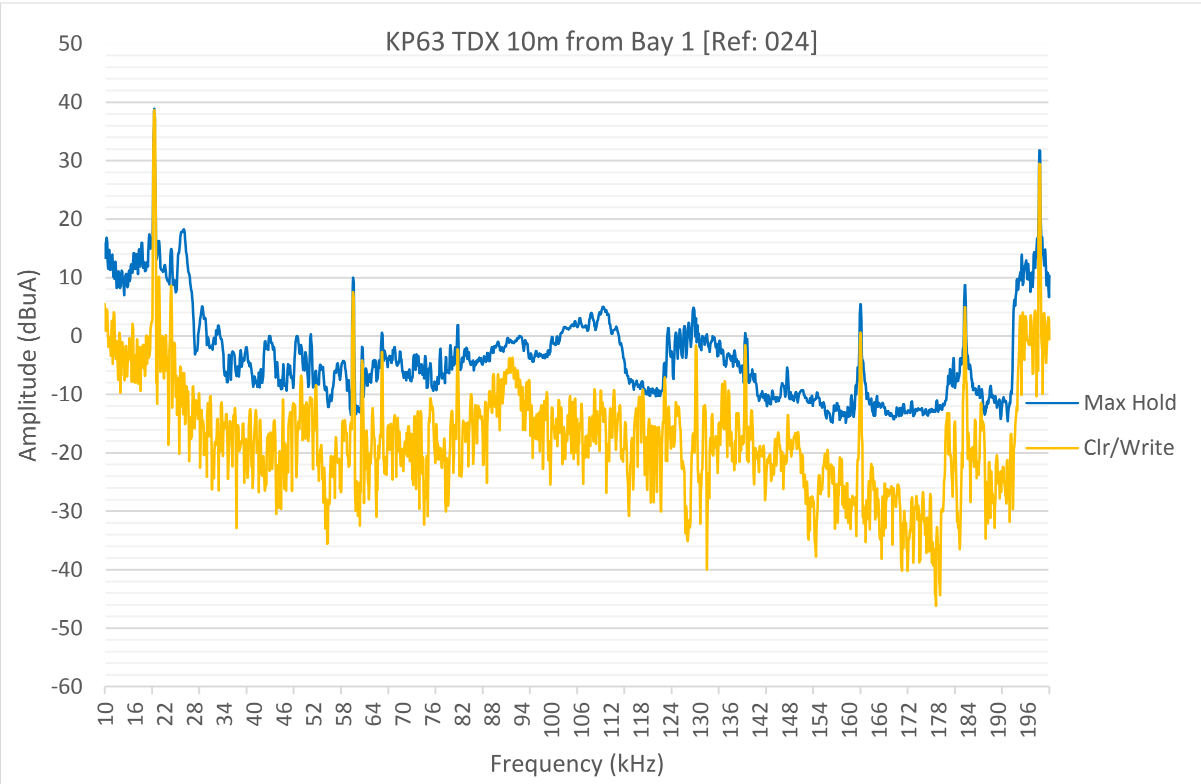
The Plots associated with each location have been produced from the captured c.s.v. files referred to in the previous section. Both the 'Max Hold (blue) and Clr/Write (yellow) traces are shown in the following sections. A Resolution Bandwidth (RBW) of 200 Hz has been used to satisfy the Standard requirement (Section 1.3).

Independently, the chairman of the European standards body for audio apparatus (ETSI TG17) accompanied the team during these measurements. Separate plots using a resolution bandwidth of 10 kHz were completed (see Sections 3.3 and 3.4) to help him assess the effects of these transmissions on assistive listening devices.

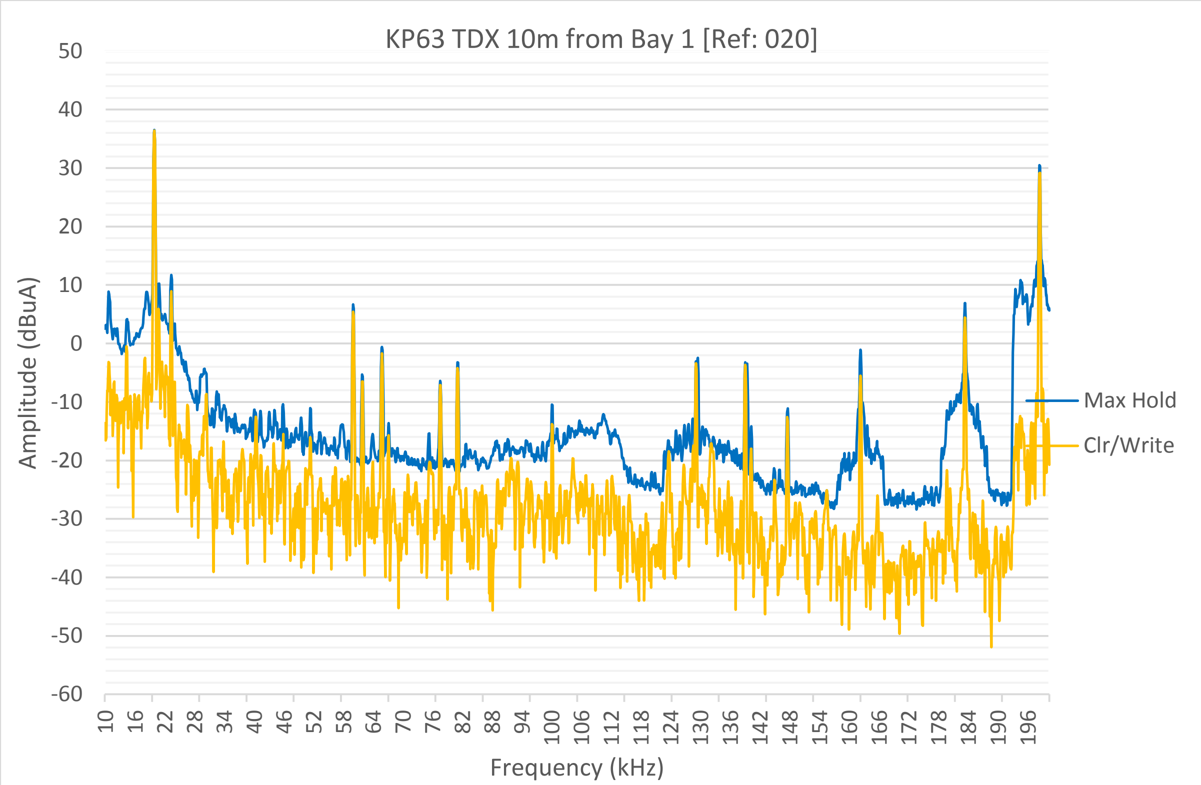
3.1 (RBW = 200 Hz) Antenna orientated towards Bay 1
[Antenna plane set for maximum signal reception]



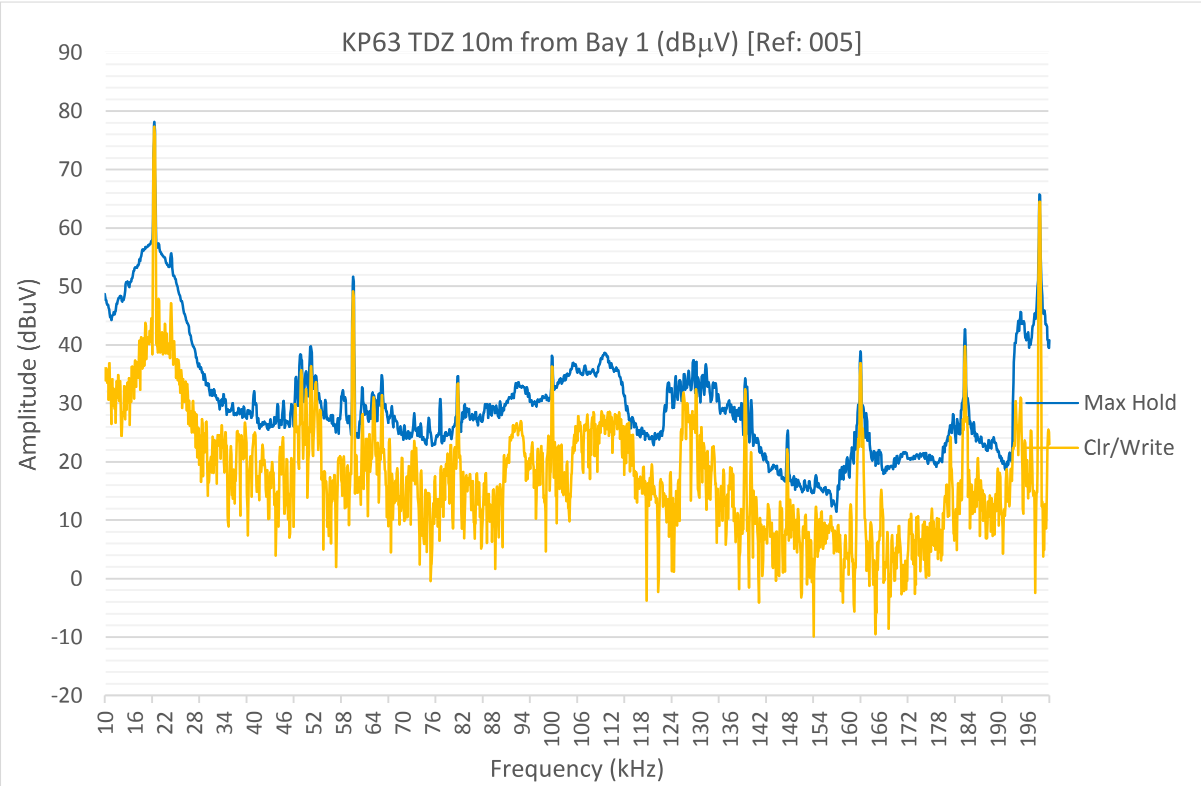
Plot 1



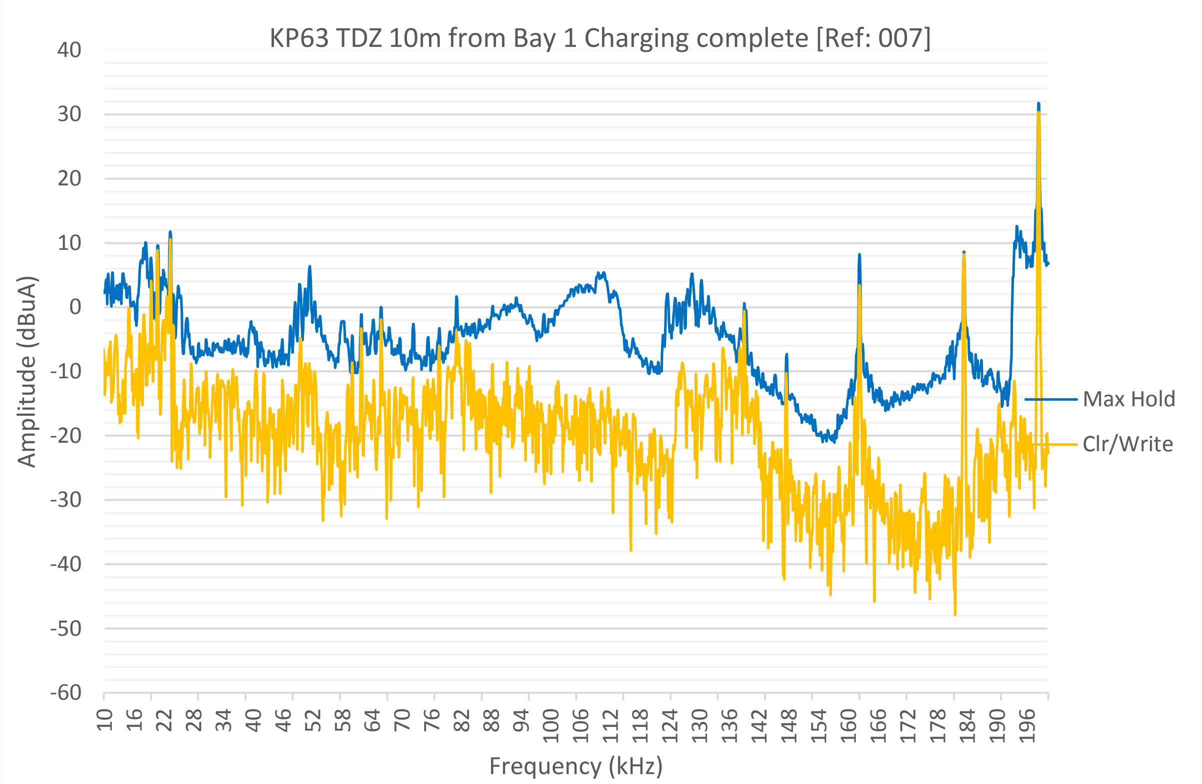
Plot 2


KP63 TDX 10m from Bay 1 [Ref: 020]
Amplitude (dBuA)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154 160 166 172 178 184 190 196
Frequency (kHz)
Max Hold
Clr/Write

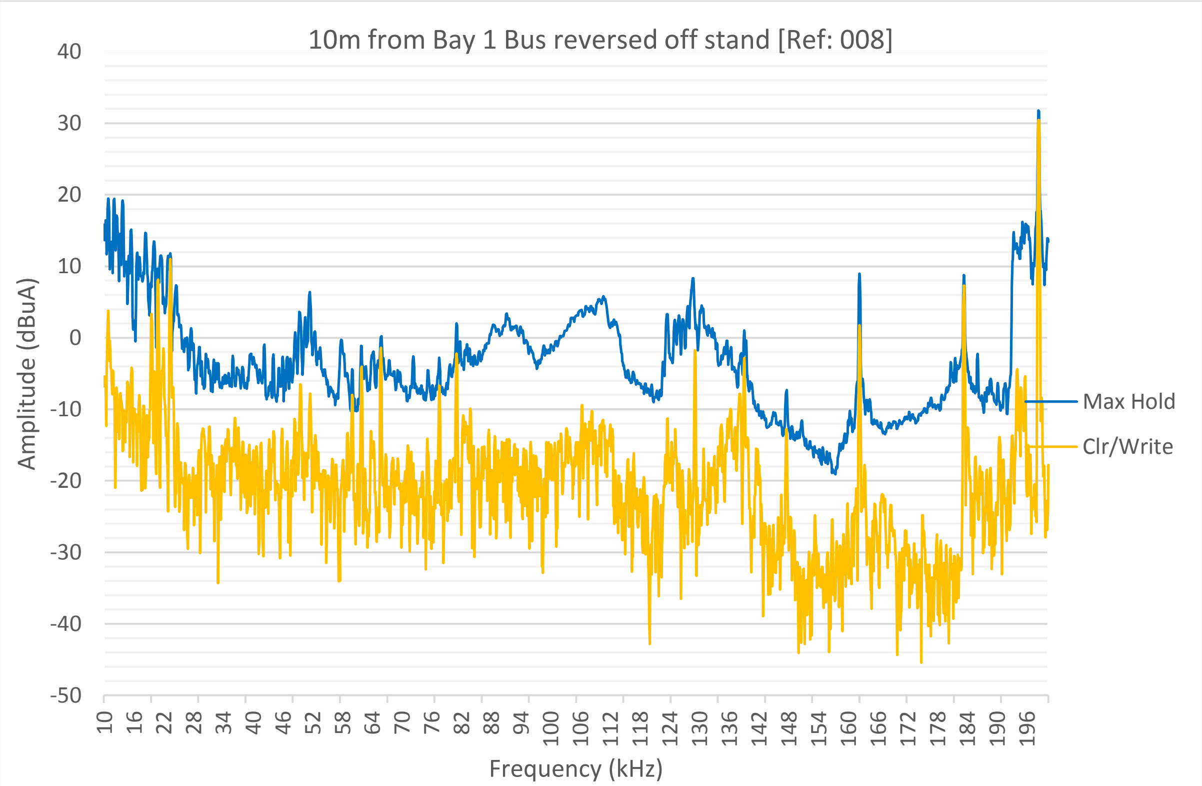
Plot 3


KP63 TDZ 10m from Bay 1 (dBµV) [Ref: 005]
Amplitude (dBuV)
90
80
70
60
50
40
30
20
10
0
-10
-20
10 16 22 28 34 40 46 52 58 64 70 76 82 88 94 100 106 112 118 124 130 136 142 148 154 160 166 172 178 184 190 196
Frequency (kHz)
Max Hold
Clr/Write

Plot 4


KP63 TDZ 10m from Bay 1 Charging complete [Ref: 007]
Amplitude (dBuA)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
10
16
22
28
34
40
46
52
58
64
70
76
82
88
94
100
106
112
118
124
130
136
142
148
154
160
166
172
178
184
190
196
Frequency (kHz)
Max Hold
Clr/Write

Plot 5


10m from Bay 1 Bus reversed off stand [Ref: 008]
Amplitude (dBuA)
40
30
20
10
0
-10
-20
-30
-40
-50
10
16
22
28
34
40
46
52
58
64
70
76
82
88
94
100
106
112
118
124
130
136
142
148
154
160
166
172
178
184
190
196
Frequency (kHz)
Max Hold
Clr/Write

Plot 6

Calculation of Magnetic Field Strength (dBμA/m) at 10 m. Antenna orientated towards bus in Bay 1 with RBW = 200 Hz.							
Plot	**Frequency kHz**	**dBμA**	***[1]A/C I/P correct**	**dBμV (Z = 50Ω)**	**K dB(S/m) Cal doc**	**Magnetic Field Strength dBμA/m**	**Comments**
1	20	43.75	44.17	78.15	-22.4	55.75	KP63 TDZ
	60	17.46	17.46	51.44	-22.8	28.64	
	100	4.19	4.19	38.17	-22.9	15.27	
	198	32.37	-	-	-	-	confidence check
2	20	38.68	39.10	73.08	-22.4	50.68	KP63 TDX
	60	9.98	9.98	43.96	-22.8	21.16	
	198	31.78	31.78	-	-	-	confidence check
3	20	36.53	36.95	70.93	-22.4	48.53	KP63 TDX
	60	6.70	6.70	40.68	-22.8	17.88	
	198	30.48	-	-	-	-	confidence check
4	20	-	0.42	78.60	-22.4	56.20	KP63 TDZ
	60	-		51.65	-22.8	28.85	
	100	-		38.13	-22.9	15.23	
*[2]**5**	20	4.09	0.42	38.49	-22.4	16.09	Charging OFF
	60	-5.59	-5.59	28.39	-22.8	5.59	
	198	31.79	-	-	-	-	confidence check

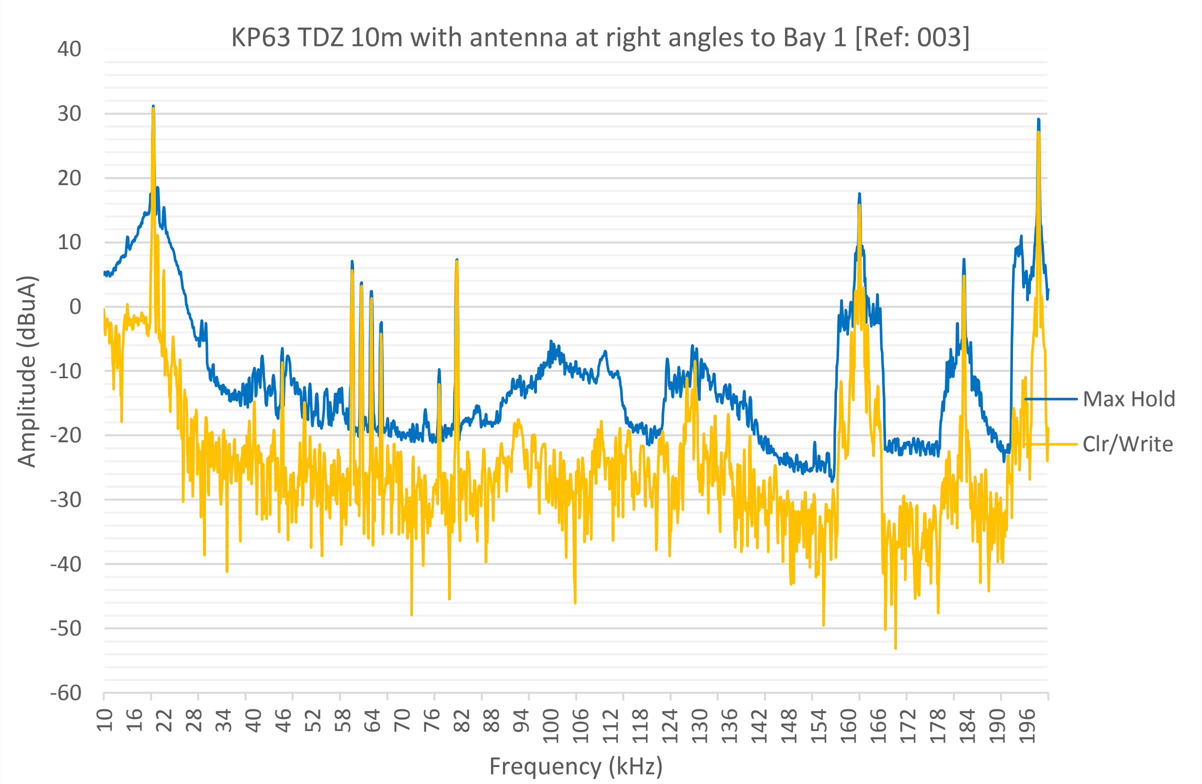
***Notes**:

1. *Input level corrected for the 0.42 dB insertion loss due to the dc block adapter (applied only to the 20 kHz frequency). The adapter does not influence the input above 55 kHz.*
2. *Plot 5 identifies the noise floor levels once the charging sequence has been completed.*

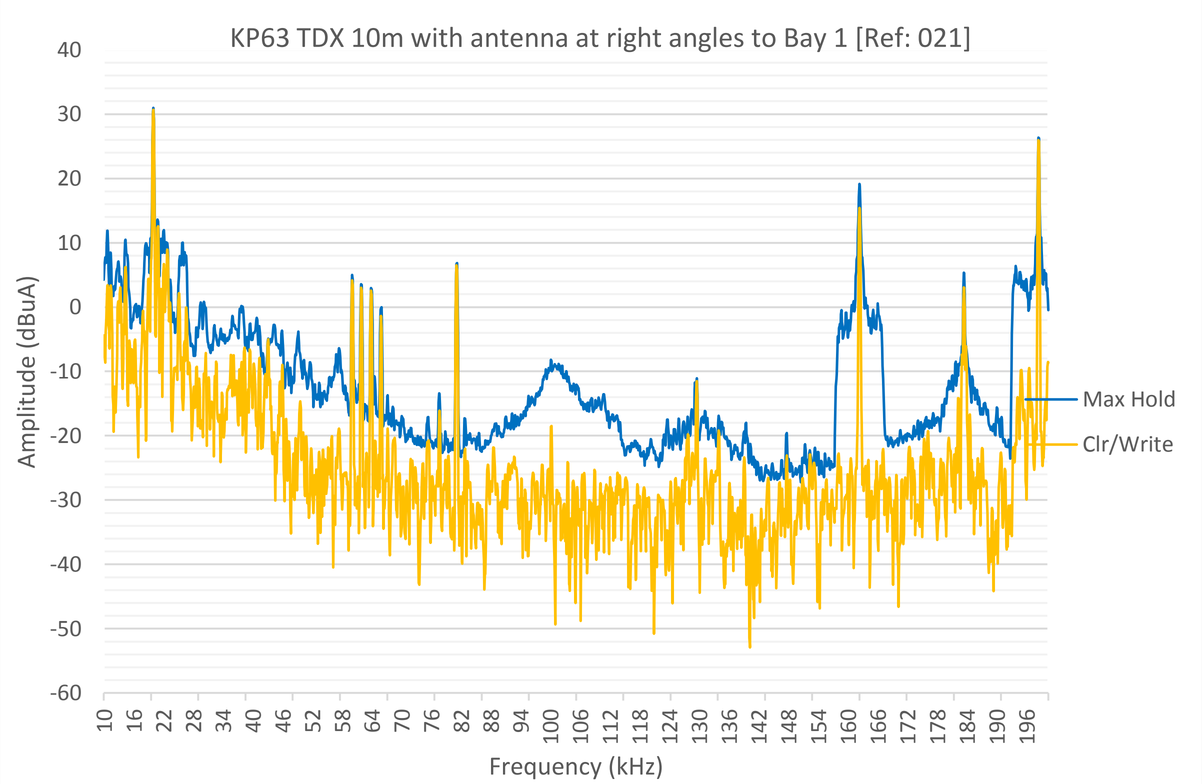
Table 2: Table of Measured signals and calculated Magnetic Field Strengths

3.2 (RBW = 200 Hz) Antenna orientated at right angles to Bay 1

[Antenna plane set for minimum signal reception from Bay 1]



Plot 7



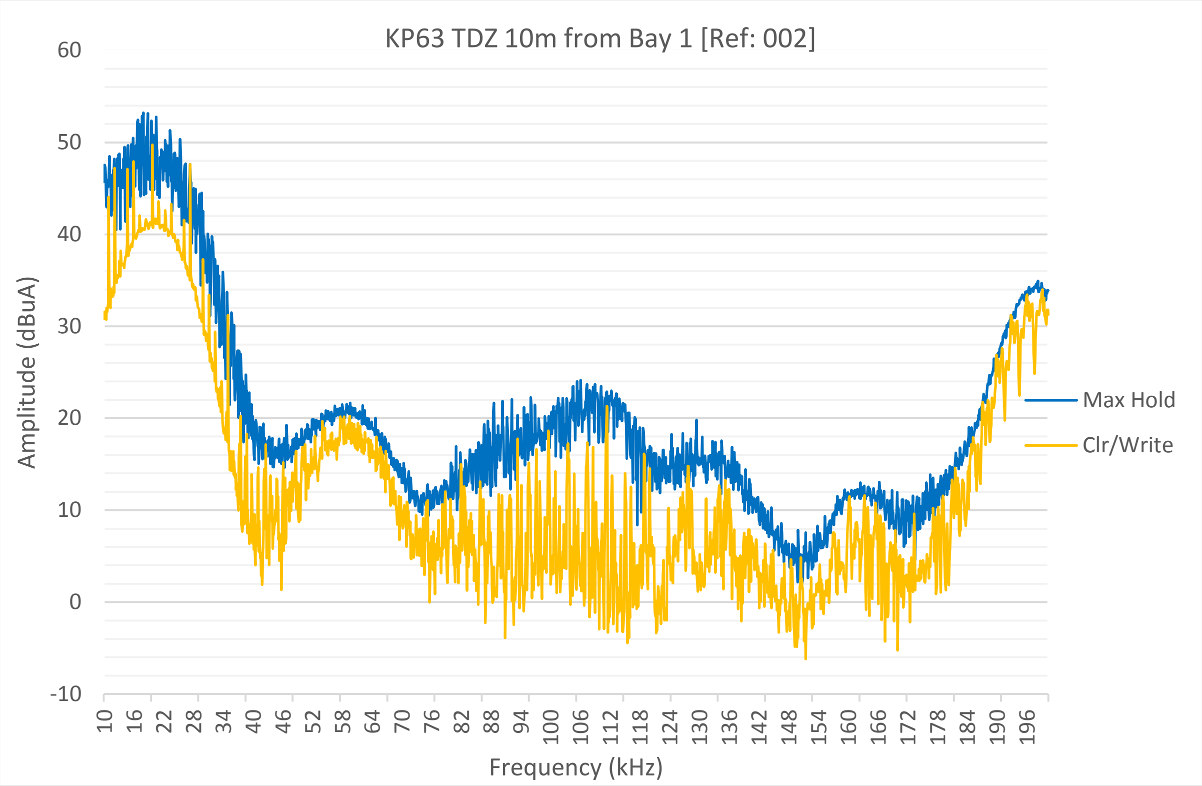
Plot 8

(RBW = 200 Hz) Magnetic Field Strength (dBμA/m) at 10 m. Antenna orientated at right angles to bus in Bay 1.							
Plot	**Frequency kHz**	**dBμA**	***A/C I/P correct**	**dBμV (Z = 50Ω)**	**K dB(S/m) Cal doc**	**Magnetic Field Strength dBμA/m**	**Comments**
7	20	31.25	31.67	65.65	-22.4	43.25	KP63 TDZ
	60	7.12	7.12	41.10	-22.8	18.30	
8	20	30.98	31.40	65.38	-22.4	42.98	KP63 TDX
	60	4.15	4.15	38.13	-22.8	15.33	

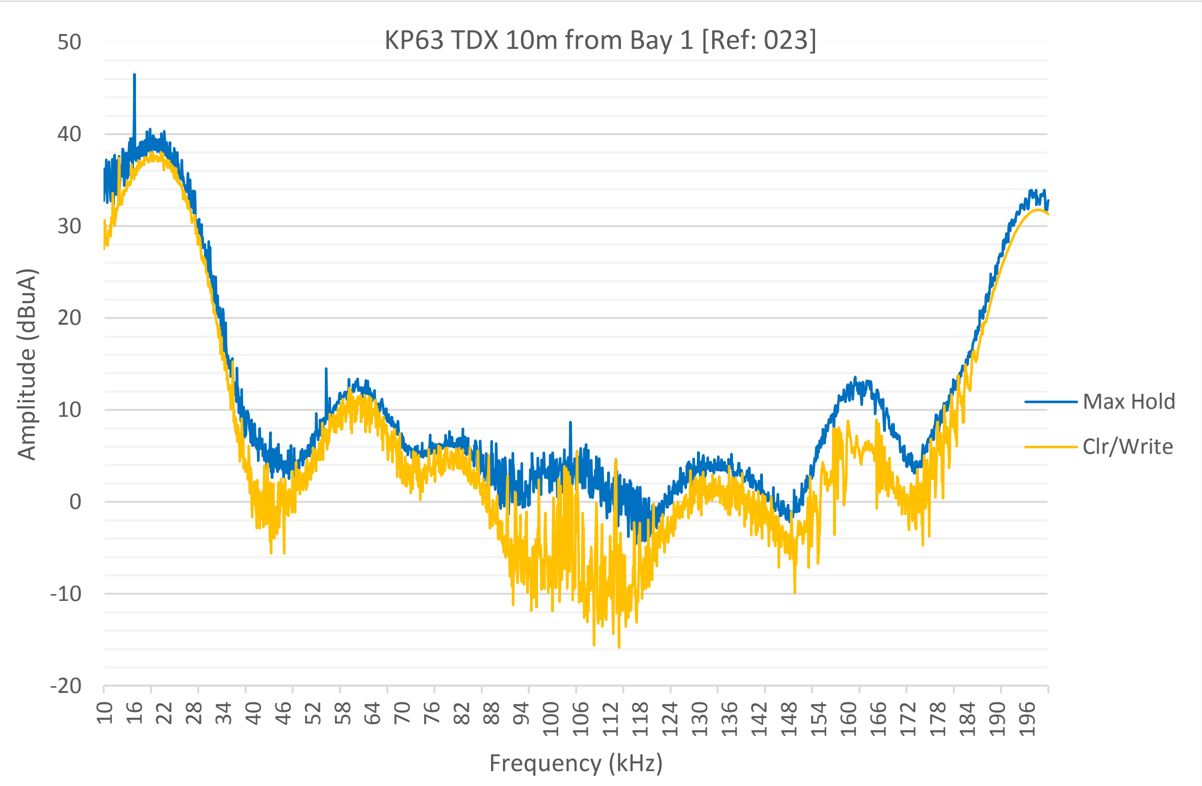
***Note**: *Input level corrected for the 0.42 dB insertion loss due to the dc block adapter (applied only to the 20 kHz frequency). The adapter does not influence the input above 55 kHz.*

Table 3: Table of Measured signals and calculated Magnetic Field Strengths

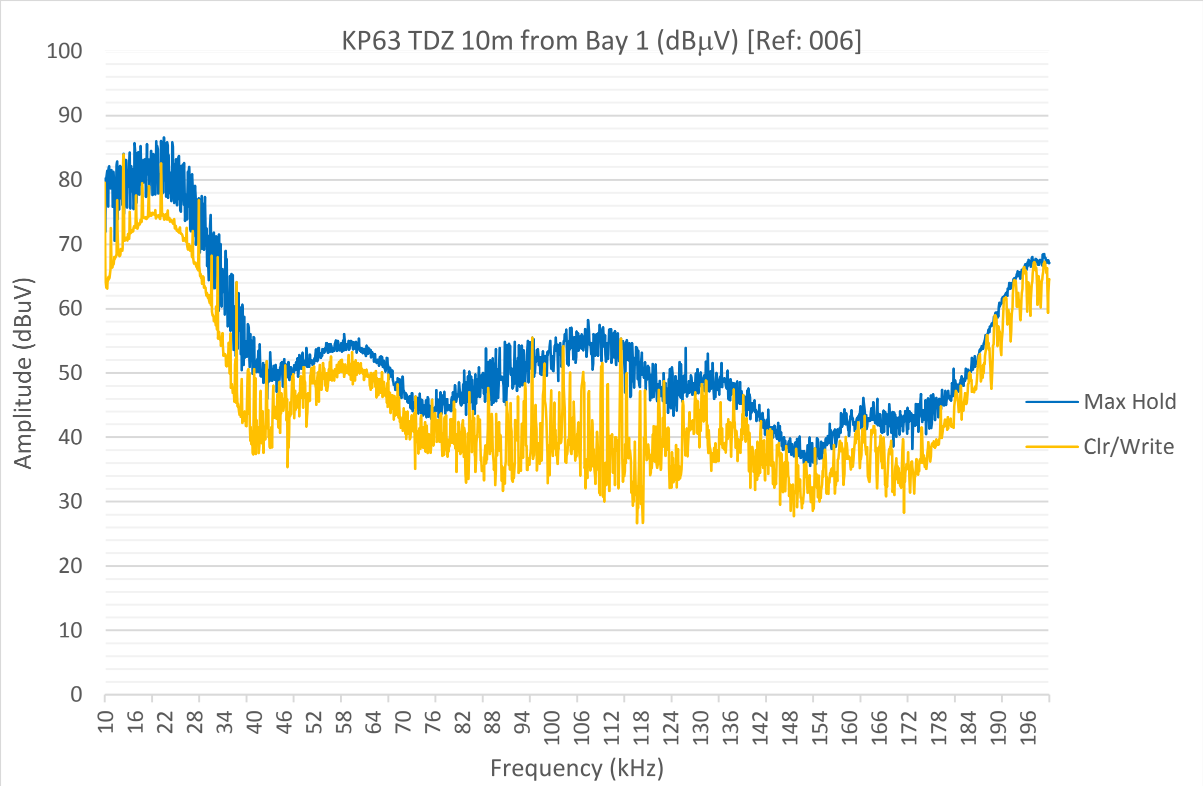
3.3 (RBW = 10 kHz) Antenna orientated towards Bay 1



Plot 9

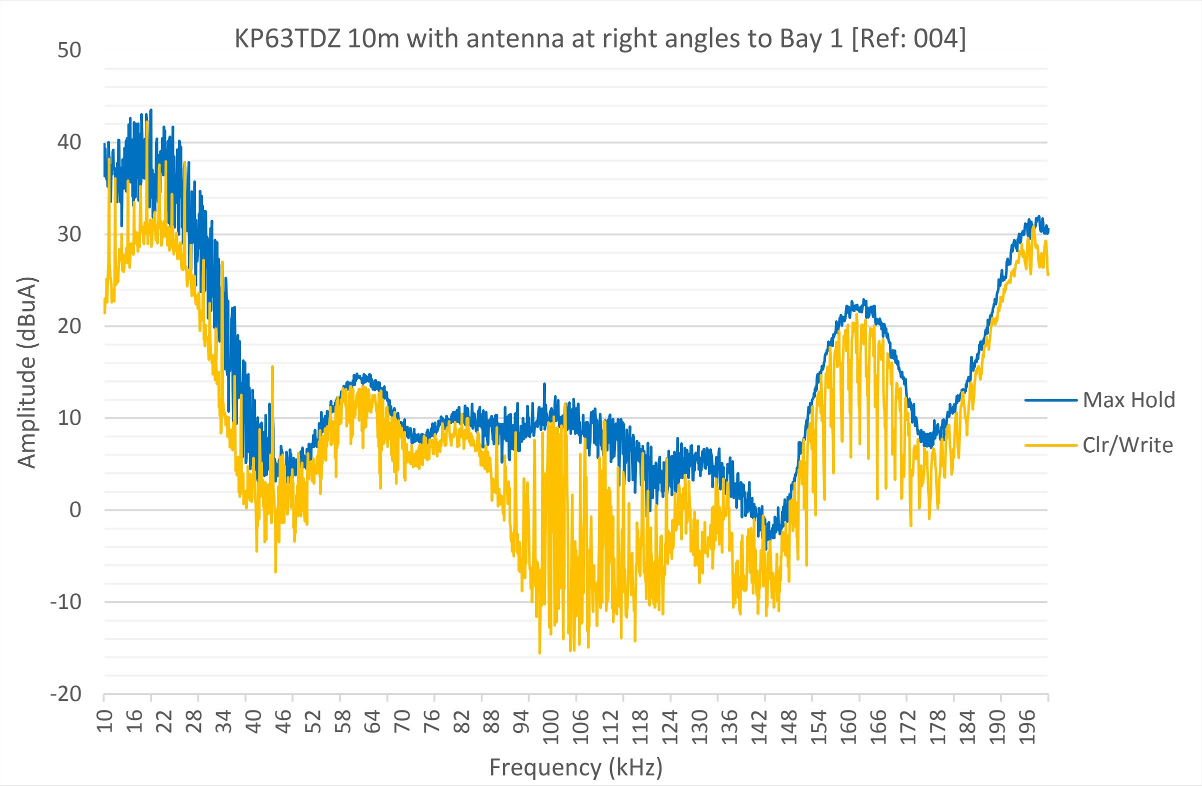


Plot 10

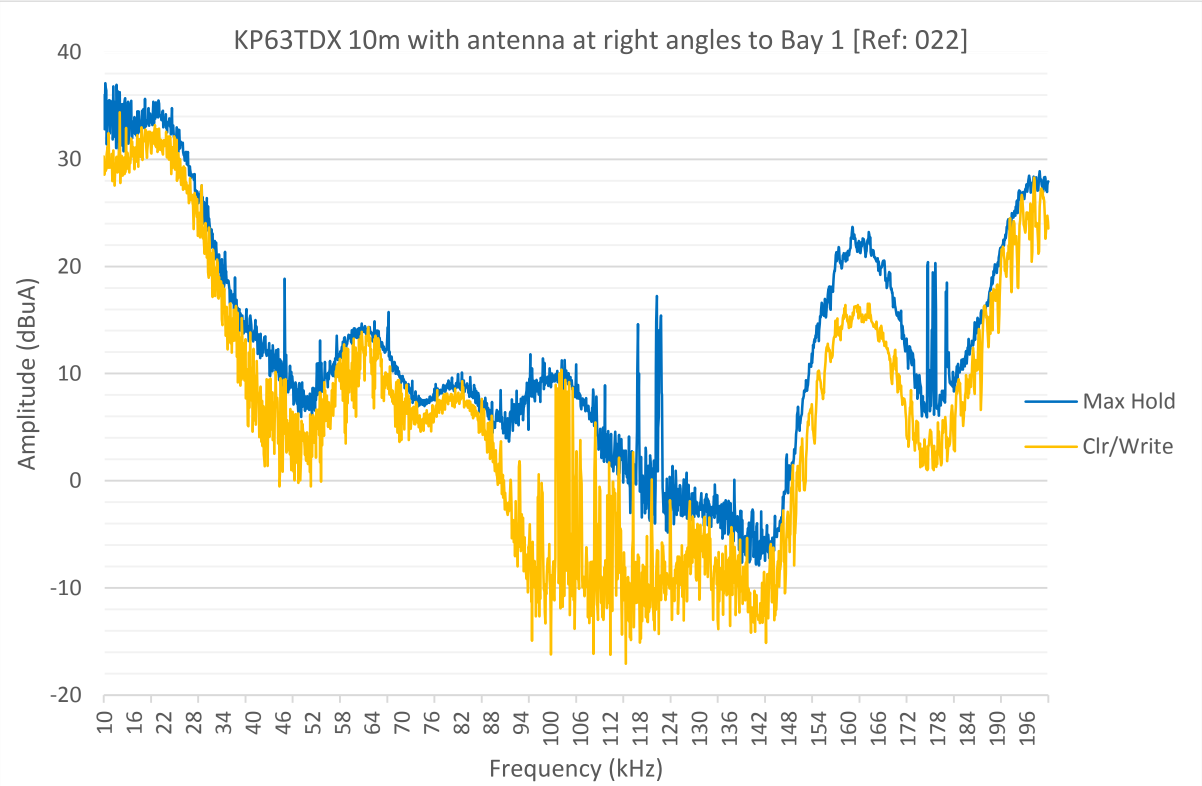

KP63 TDZ 10m from Bay 1 (dBµV) [Ref: 006]
Amplitude (dBuV)
100
90
80
70
60
50
40
30
20
10
0
10
16
22
28
34
40
46
52
58
64
70
76
82
88
94
100
106
112
118
124
130
136
142
148
154
160
166
172
178
184
190
196
Frequency (kHz)
Max Hold
Clr/Write

Plot 11

3.4 (RBW = 10 kHz) Antenna orientated at right angles to Bay 1

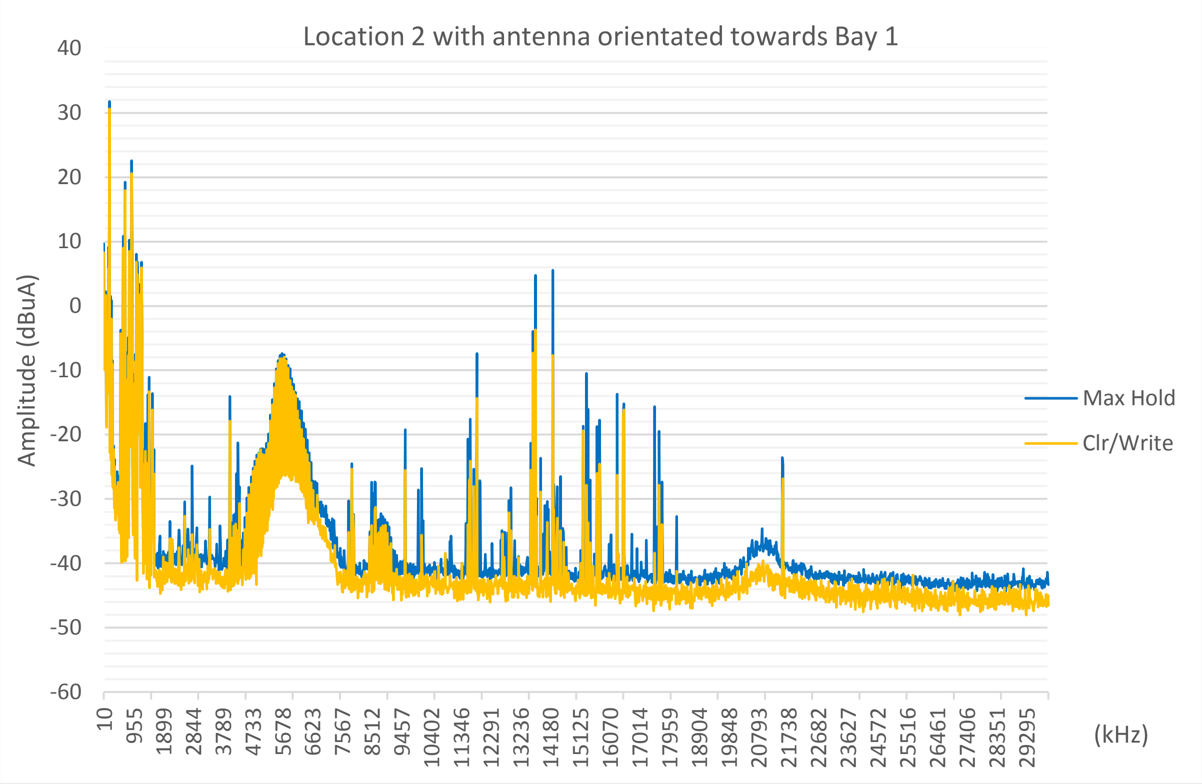


Plot 12

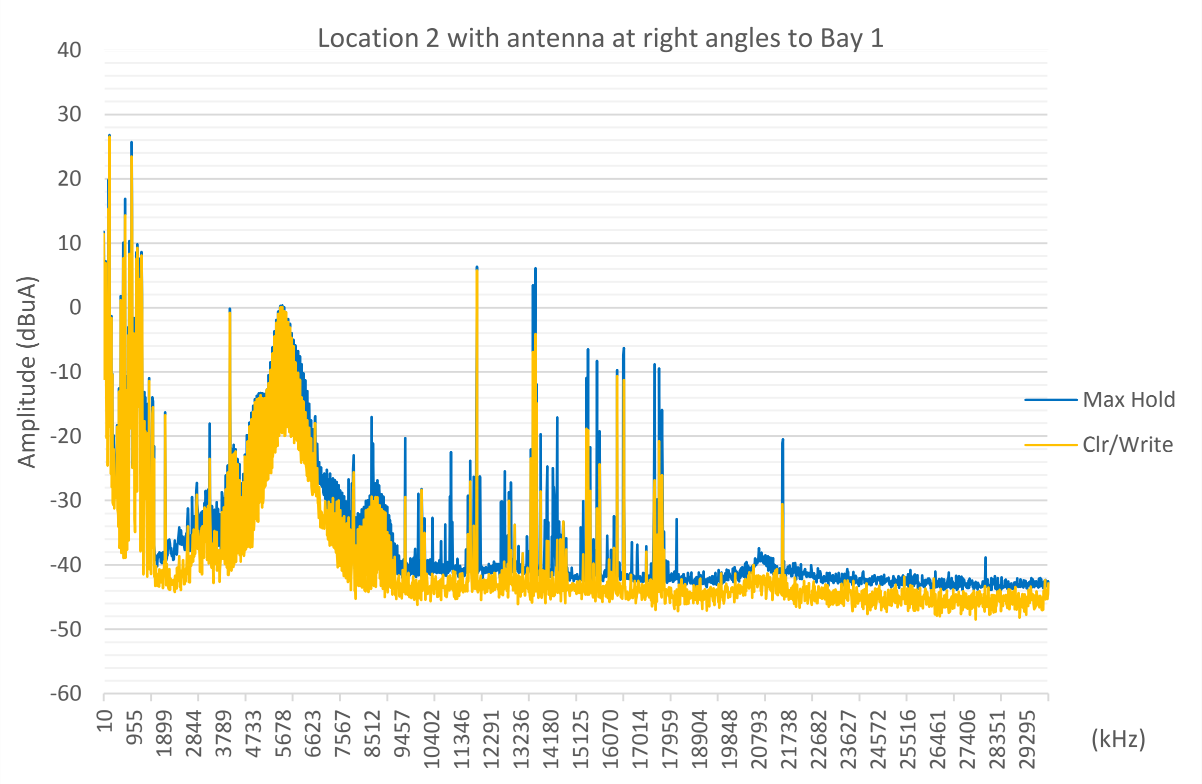


Plot 13

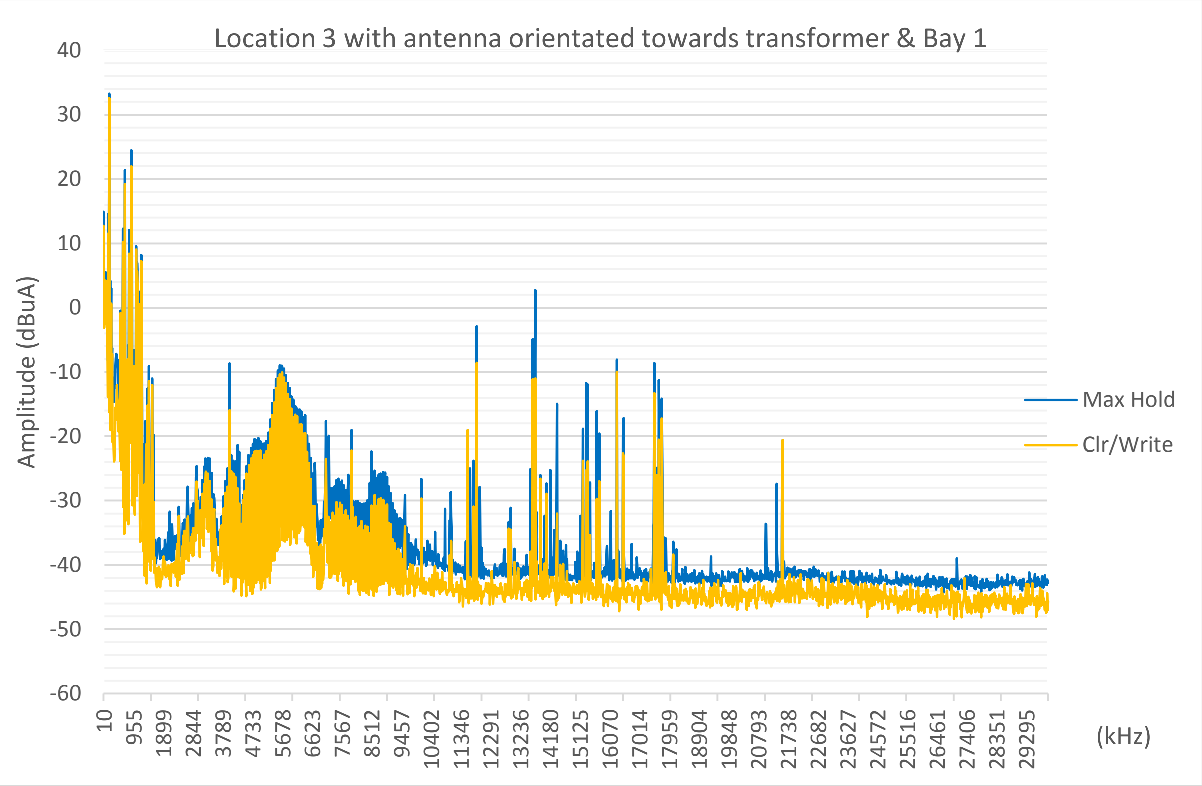
3.5 (RBW = 200 Hz) Background Plots (10 kHz to 30 MHz)



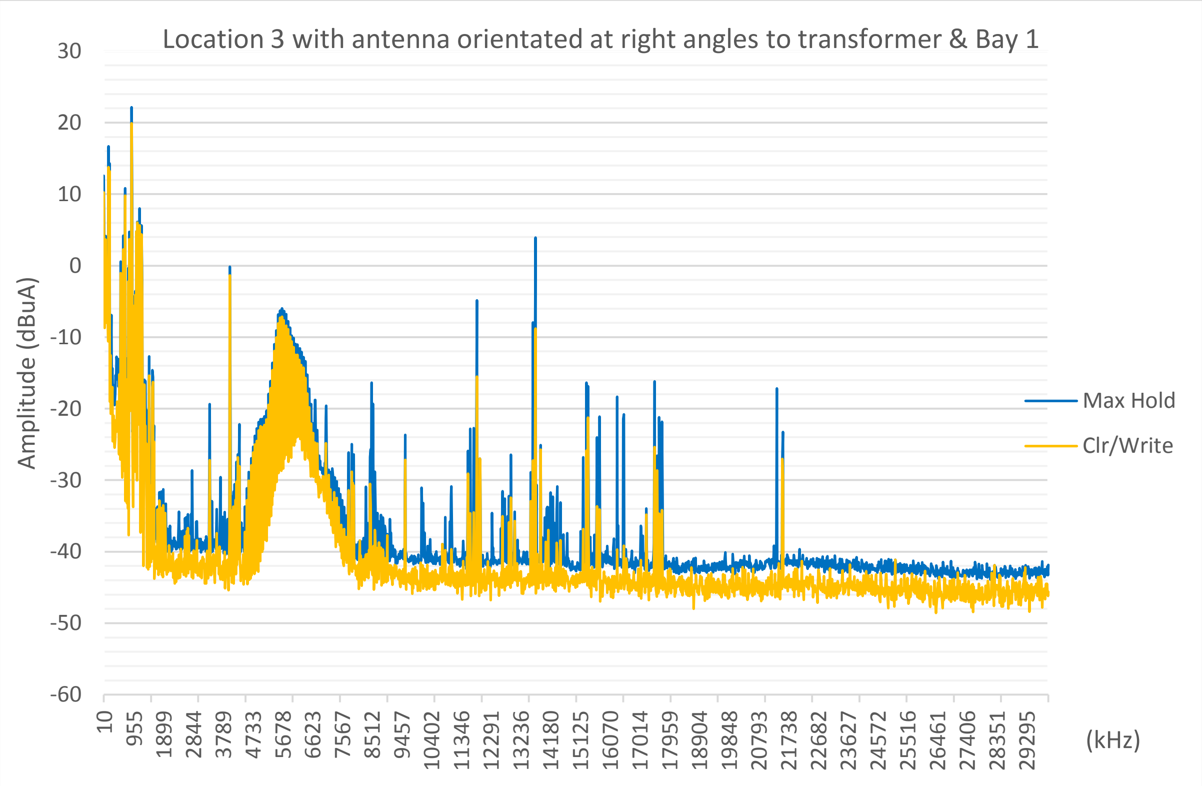
Plot 14: Raised noise floor at –8 dBµA



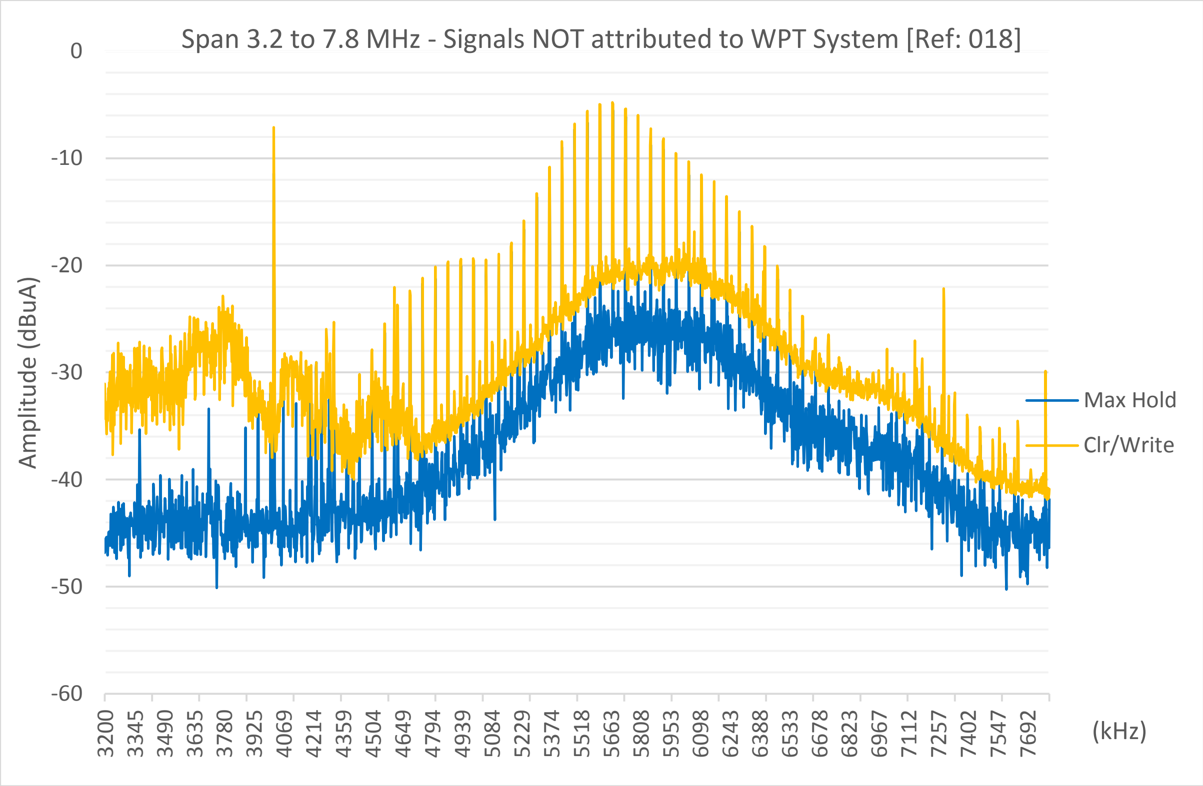
Plot 15: Raised noise floor increases with antenna at right angles to Bay 1 (0 dBµA)



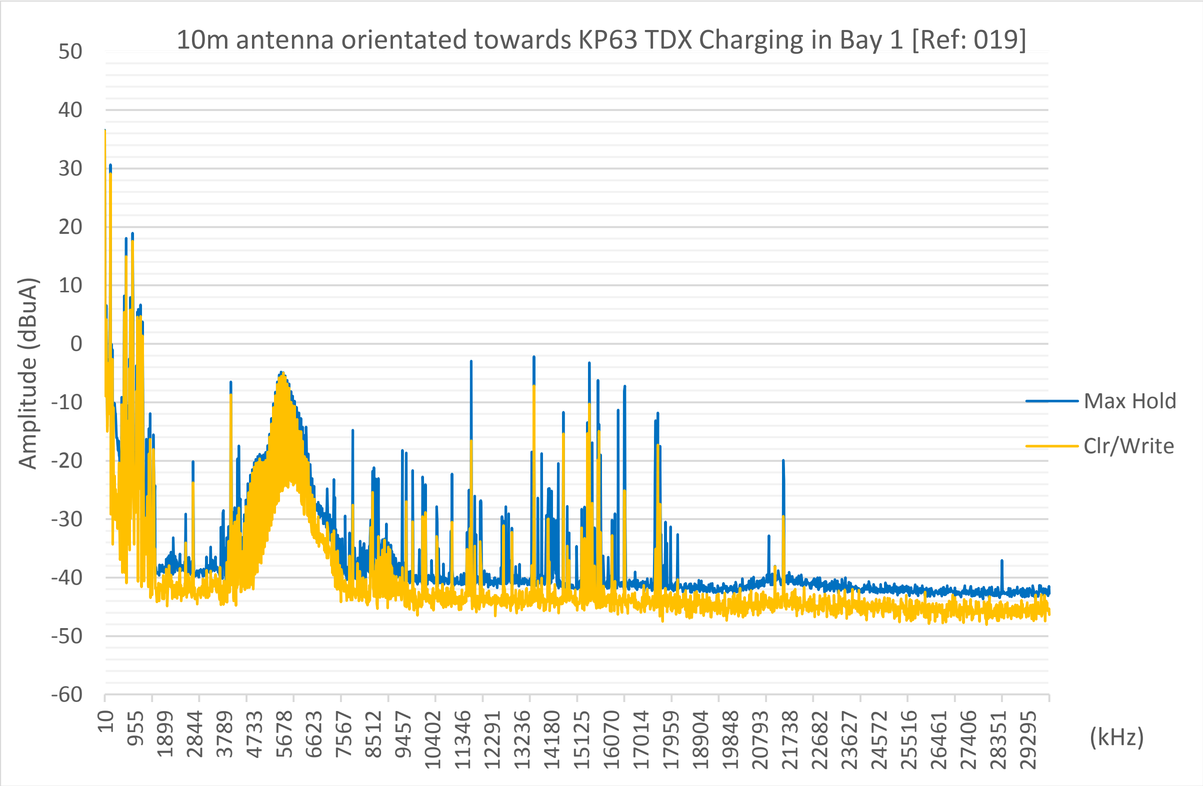
Plot 16: Raised noise floor at –10 dBµA



Plot 17: Raised noise floor increases with antenna at right angles to Bay 1 (-6 dBµA)



Plot 18: Antenna at Location 2 and Signals NOT attributed to the WPT System



Plot 19: Antenna at Location 2 and KP63 TDX in Bay 1 with the charging cycle started.

4 Conclusions

The results detailed in this section apply only to the tests made at that time, using the test equipment detailed. They do not indicate that on another date an identical set of results may be achieved, due to changes in local environmental conditions or other factors which may or may not have an effect on the measurement results obtained at that future time.

Table 4 has been extracted from the Results shown in Section 3. Using the peak values measured at the fundamental frequency (20 kHz) and the third harmonic (60 kHz) the Magnetic Field Strength has been calculated for both buses. Using a CISPR bandwidth and correct measurement distance these results have then been related to the stated limits in the ETSI Standard EN 300 330 referred to in Section 1.3.

Magnetic Field Strength (dBµA/m) at 10 m in a CISPR 200 Hz RBW. Related to Limits in ETSI EN 300 330-1 v1.8.1 (2015-03)						
Bus	**Plot**	**Frequency kHz**	**Calculated Magnetic Field Strength dBµA/m**	**Limit in dBµA/m**	**Measured MFS related to Limit in dB**	**Comments**
KP63 TDZ	1	20	55.75	72.0	-16.25	PASS
		60	28.64	42.0	-13.36	PASS
KP63 TDZ	4	20	56.20	72.0	-15.8	PASS
		60	28.85	42.0	-13.15	PASS
KP63 TDX	2	20	50.68	72.0	-21.32	PASS
		60	21.16	42.0	-20.84	PASS
KP63 TDX	3	20	48.53	72.0	-23.47	PASS
		60	17.88	42.0	-24.12	PASS

Table 4: Results in relation to the EN Standard Limits

With the measurements being completed in-situ, using a peak detector, the results must be treated as an indicative measurement of the H-field (H_f) radiated disturbance produced during the charging process of each bus. However considering the results are between 16 and 23.5 dB below the limit for the fundamental frequency both buses appear compliant with the Standard. At the third harmonic identified in the original plots at 60 kHz, the vehicles also appear to pass the more stringent limit of 42 dBµA/m.

5 Measurement Equipment

Equipment	Model	Serial No.	Cal due	Certificate No.
Spectrum Analyser	Agilent PSA	44302576	12/05/17	1-6826496866-1A
Signal Analyser	R&S FSW	101574	01/02/17	1400-54075
30cm loop Antenna	HLA 6120	1172	16/05/17	2016050007-1
I/P signal isolator	ADB-18NMF-1	987517	-	-
10m cable	Chase	-	-	-

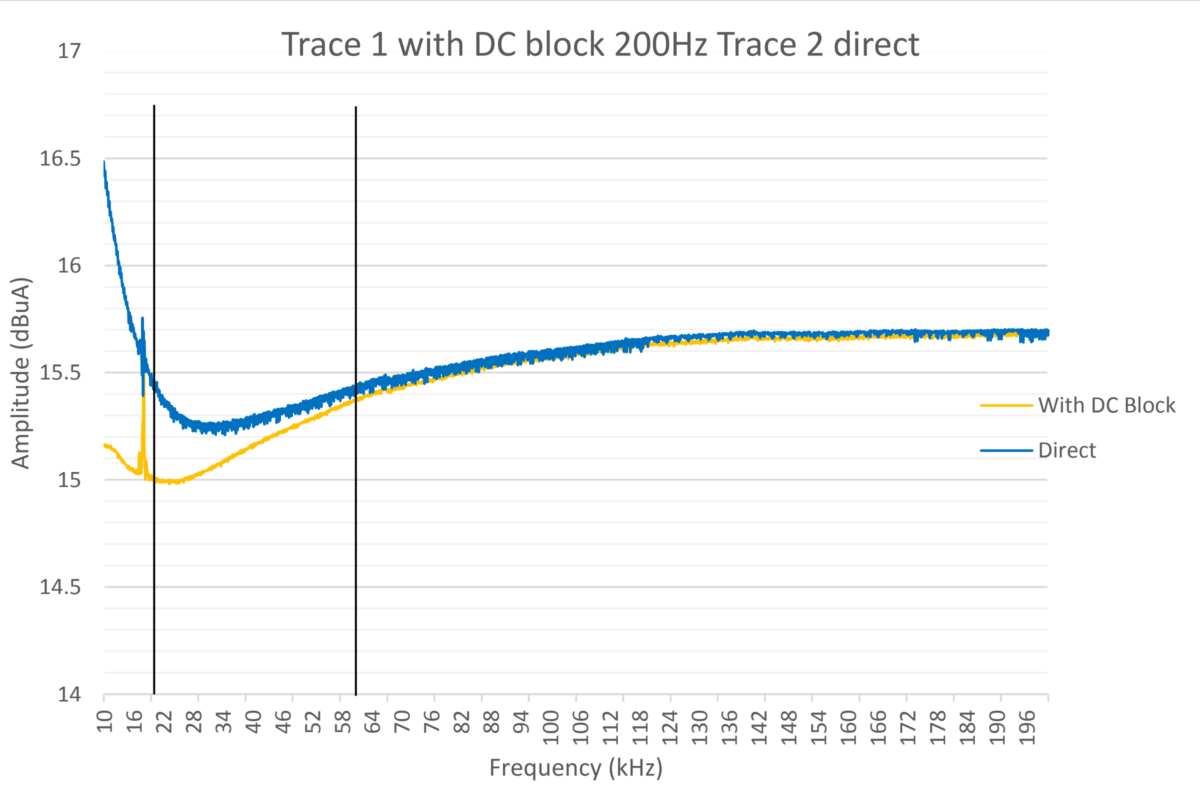
Table 5: Equipment details (including calibration status)

6 Glossary

a.g.l.	above ground level
ALD	assistive listening device
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
CISPR	International Special Committee on Radio Interference (*English*)
EMC *or* emc	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETSI	European Telecommunications Standards Institute
EUT	Equipment Under Test
FS	Field Strength measured in dBμV/m
MFS	Magnetic Field Strength measured in dBμA/m
NGA	Next Generation Access
Ofcom	Office of Communications
RBW	Resolution Bandwidth
RF	Radio Frequency
VDSL	Very high bit rate DSL
WPT	Wireless Power Transfer
λ	Wavelength
kHz	kilohertz
MHz	Megahertz
GHz	Gigahertz
μV	microvolt
mV	millivolt
mV/m	millivolts per metre
dB	decibel
dBμA/m	decibels above one microampere per metre
dBμV/m	decibels above 1 microvolt per metre (see FS above)
dBm	decibels relative to 1 milliwatt
dBW	decibels relative to 1 Watt
m	metres
s	seconds

Table 6

7 Annex



Plot 20: Characterisation of ADB-18NMF-1 input isolator

Correction at 20 kHz = 0.42 dB
Correction at 60 kHz ~ 0 dB

Convert dBuA to dBµV:

dBµV = dBµA + 20 log (Z) *Where Z = 50Ω*

dBµV = dBµA + 20 log (50)

dBµV = dBµA + 33.98 dBµV

Convert dBµV to dBuA/m (H):

H = dBµV + *K (dB(s/m)) dBµA/m

*Where: *K = Magnetic Antenna Factor (MAF) from NPL calibration document (see Table 7 overleaf)*

Magnetic Antenna Factor Corrections (K) measured in dB S/m

Loop Antenna Type: HLA6120 s/n: 1172			
Frequency [MHz]	Magnetic Antenna Factor [dB (S/m)]	Frequency [MHz]	Magnetic Antenna Factor [dB (S/m)]
0.009	-21.9	0.548	-23.2
0.010	-22.0	0.606	-23.2
0.011	-22.1	0.675	-23.3
0.012	-22.2	0.752	-23.3
0.014	-22.2	0.845	-23.2
0.015	-22.3	0.933	-23.3
0.017	-22.4	1.040	-23.3
0.019	-22.4	1.159	-23.3
0.021	-22.4	1.303	-23.3
0.024	-22.4	1.439	-23.4
0.026	-22.5	1.618	-23.3
0.030	-22.6	1.802	-23.4
0.033	-22.6	2.008	-23.4
0.036	-22.6	2.218	-23.5
0.041	-22.7	2.493	-23.4
0.046	-22.7	2.778	-23.4
0.051	-22.7	3.095	-23.4
0.057	-22.8	3.449	-23.5
0.063	-22.8	3.843	-23.4
0.070	-22.8	4.244	-23.5
0.078	-22.8	4.728	-23.5
0.086	-22.9	5.316	-23.4
0.097	-22.9	5.923	-23.4
0.108	-22.9	6.600	-23.4
0.121	-22.9	7.353	-23.3
0.133	-22.9	8.193	-23.3
0.150	-23.0	9.047	-23.4
0.165	-23.0	10.081	-23.4
0.186	-23.0	11.232	-23.4
0.205	-23.0	12.628	-23.3
0.231	-23.0	13.944	-23.1
0.257	-23.0	15.678	-23.2
0.284	-23.0	17.313	-23.0
0.319	-23.2	19.289	-22.8
0.356	-23.1	21.493	-22.7
0.393	-23.1	24.165	-22.6
0.442	-23.1	26.683	-22.4
0.492	-23.2	30.000	-22.5

Table 7: Extract from NPL calibration document.

End of Report