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UNIONE RADIOAMATORI DI ONDE CORTE SVIZZERI
UNION OF SWISS SHORT WAVE AMATEURS



Field Test of RFI by Inductive Charging of a WPT-EV and Amateur Radio on the HF Bands

Report about Field Tests in August and September 2020

Performed and written by

Ad hoc USKA EMC Test Group

HB9AZO and HB9BKT

1 Executive Summary

This report describes a series of practical RFI interference tests by WPT (wireless power transfer) at a real amateur radio station in a *residential environment* with moderate background noise. The disturbance source used was an electric vehicle (EV) charging by WPT at defined distances.

During these tests, in the test situation available (e.g. environmental noise, distance, antennas, transferred power by WPT), virtually no interference on the receiver of the amateur radio station could be registered between 1.8 MHz and 30 MHz.

This result was obtained under the specific local conditions during the tests and **may not be generalised.** It is valid only for the particular case (only one WPT-EV) in the test situation available with the specific WPT-EV system provided for the tests by the manufacturer, when it was operating with a transferred power of 2.6 kW or 3.7 kW. The tests were carried out in August and September 2020.

Note:

As there were three different organisations (BRUSA (manufacturer), OFCOM (CH) and USKA (UNION OF SWISS SHORT WAVE AMATEURS), who were not interested in exactly the same results, it was decided to write three somewhat different test reports. These reports consist of a general part in the beginning and the end (e.g. description of the situation and some main results), which were written in co-operation and are partly nearly identical. The reports are different in other parts, where they focus on the main interests of the institution concerned [5], [6]. An independent measurement of transfer power was performed by a team from Electrosuisse.

The investigation has been carried out by field trials in August and September 2020 in Ersigen, Switzerland, at the QTH of HB9AZO with the participation of representatives from the following organizations and companies present:

- Alfred Furrer (Electrosuisse)
- Carlo Compare (Electrosuisse)
- Emmanuel de Raemy (BAKOM/OFCOM)
- Hansrudolf Spring (BAKOM/OFCOM)
- Dr. Heinrich Häberlin (USKA, Project Lead, HB9AZO)
- Lukas Böhler (BRUSA Elektronik AG)
- Dr. Urs Lott (USKA, HB9BKT)

Authors and responsible for the content of this report are Heinrich Häberlin (HB9AZO) and Urs Lott (HB9BKT), both PhD in Electrical engineering and member of the EMC group of USKA.

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3 Introduction

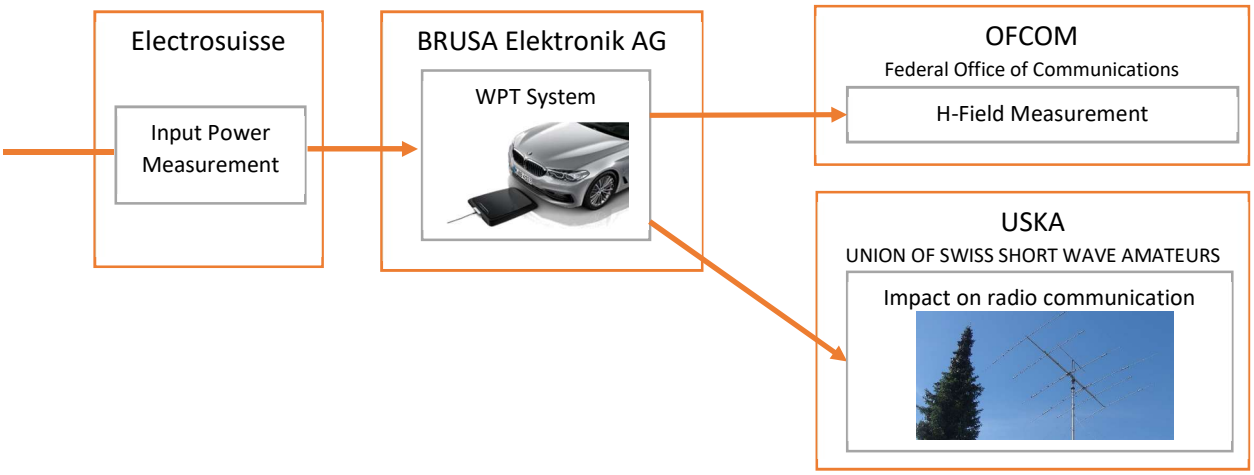
The EMC limits for wireless power transfer (WPT), e.g. for inductive charging of electric vehicles, have been discussed intensely for years. However, there is only a limited number of publicly accessible EMC measurements available to help the different stakeholders estimate the EMC risks of WPT systems.

Based on mainly **theoretical** studies, the Amateur Radio (AR) Service Community is concerned of being disturbed by WPT [1] and, because of a lack of available operational systems, is unable to assess the impact on radio communication. The goal of this report is to fill this gap by extended **practical interference measurements** at a typical amateur radio station, which has been used successfully for worldwide long distance traffic (DX) for many years.

The CISPR Swiss national committee has as members in his group a manufacturer of WPT systems, representatives of USKA (Swiss Union of short wave radio amateurs), the Swiss office of communication (OFCOM) with competences in EMC measurements and Electrosuisse with the "Comité Électrotechnique Suisse" (CES) to start this on-site measurement project. Quickly, many other stakeholders showed interest to this project, even outside of Switzerland. Due to the Covid-pandemic, the project members decided not to accept more participants and observers during the measurements.

The manufacturer of the WPT system is the Swiss company BRUSA Elektronik AG with a subsidiary in Munich. This product is currently the only one certified WPT product on the market. It is the ICS1 system integrated in the BMW 530e. ICS1 stands for **I**nductive **C**harging **S**ystem Generation **1**. The vehicle is properly homologated and was sold with the BRUSA Elektronik AG ICS1 WPT system. Since it is a publicly sold product, the system is, on the contrary to other analysed systems, optimized regarding EMC in the frequency range above 1 MHz.

For this measurement project BRUSA Elektronik AG provided a vehicle including an inductive charging system. Electrosuisse measured and protocolled the input power of the WPT system. The Swiss Federal Office of Communications (OFCOM) measured the magnetic field at 10 m distance from the WPT and USKA (Project Leader Heinrich Häberlin, HB9AZO) analyzed the impact of WPT on the Amateur Radio System he has been using for the last 37 years.



4 Measurement Setup (Location, available Equipment)

The measurements took place on 25.08.2020 and 23.09.2020 at Lindenmattweg 15, Ersigen, Switzerland. The location can be categorized as residential. It is about a model of a typical amateur radio station.

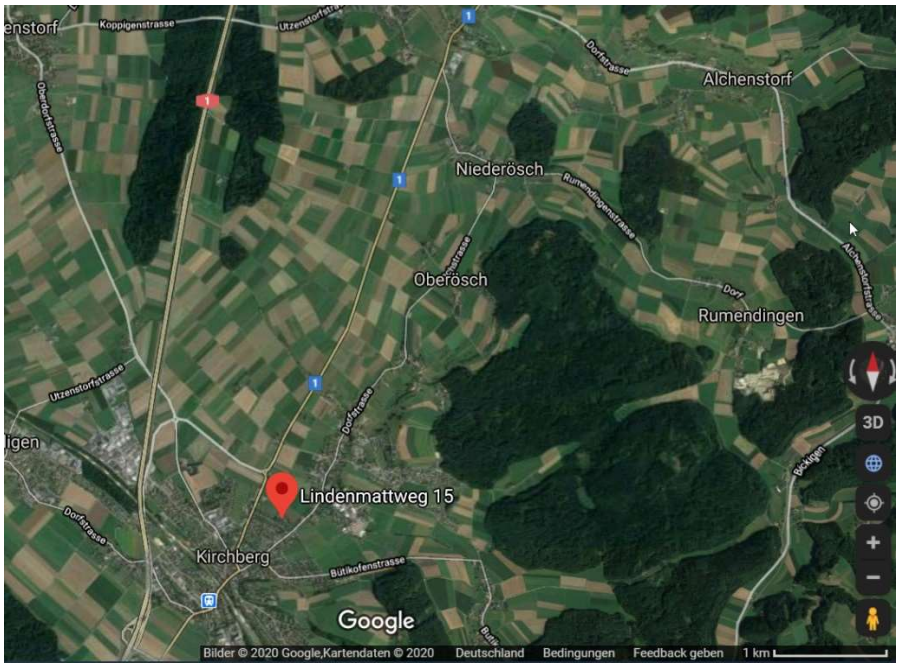


Figure 1: *The Measurement Location is located in a Residential Area*

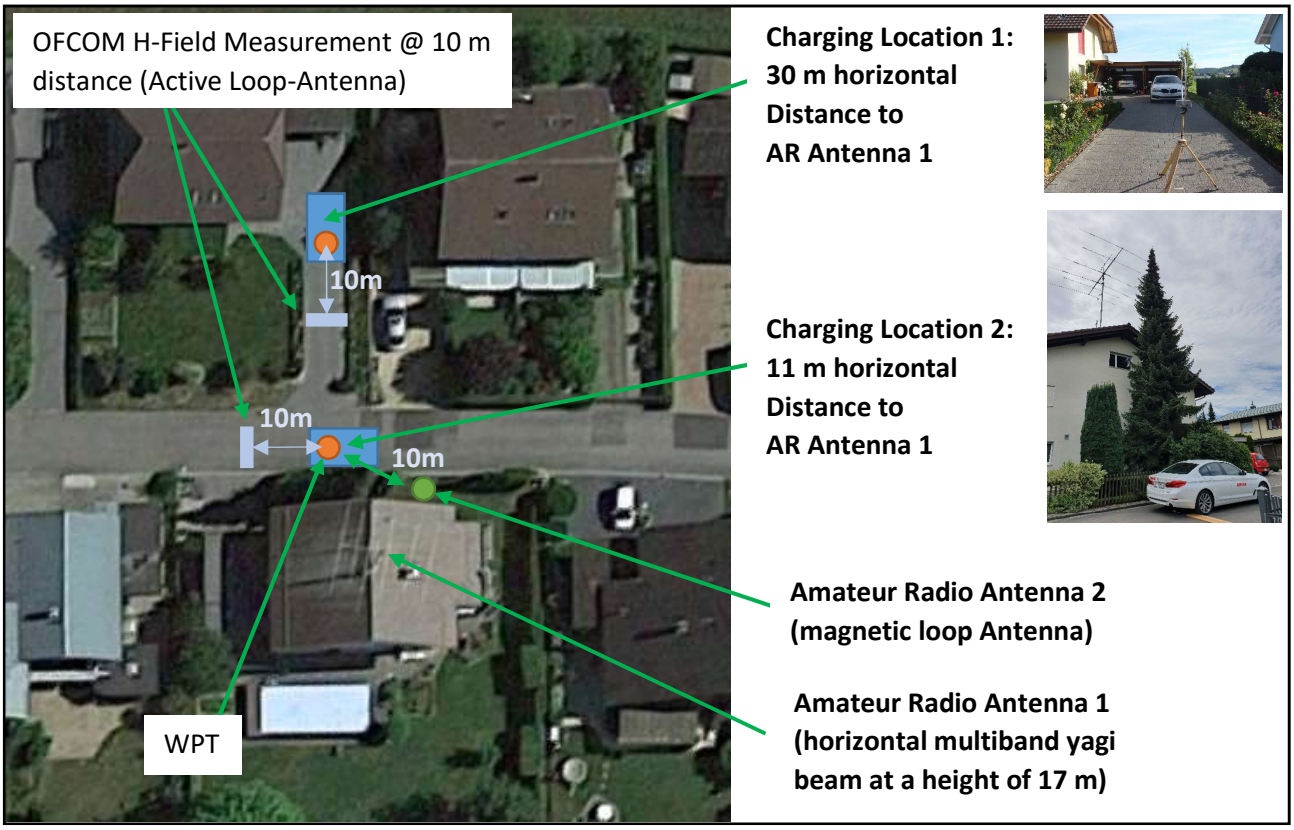


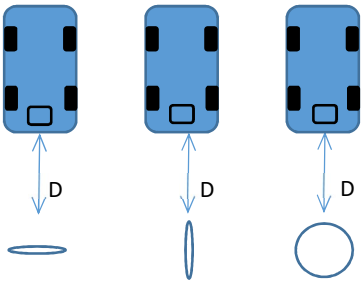
Figure 2: *Details of Measurement Situation close to WPT and receiver antennas*

4.1 Magnetic Field Strength Measurement by OFCOM(CH)

OFCOM was responsible for the magnetic field measurement equipment. Antenna factor, cable attenuation and filter characteristics were considered for the measurement results. The measurement receiver was put into Realtime-Modus (Scan) to enable continuous and fast measurement of QP-Values over the full frequency range. Measuring equipment and parameters are according to CISPR requirements for magnetic field measurements in the frequency range 9 kHz to 30 MHz. This setup is similar to the one used by OFCOM for investigating reported interference to radio services.

Antenna orientations X, Y and Z:

X, parallel Y, vertical Z, horizontal to front of vehicle; D = Distance 10 m



The Antenna was a standard 60 cm Loop antenna (H-Field). The Antenna centre was placed 1.3 m above ground.

Equipment



Figure 3: Active Loop Antenna



Figure 4: Receiver

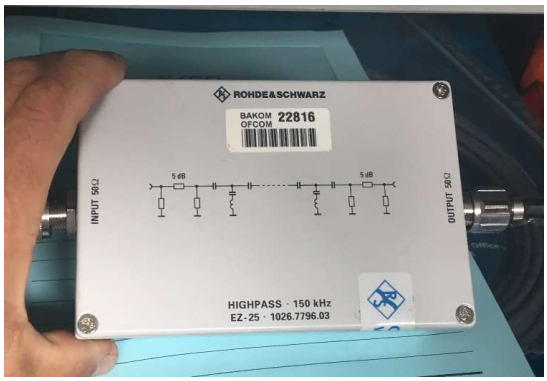


Figure 5: Filter for Measurement above 150 kHz



Figure 6: Measurement Vehicle

For further Details: see [5]

4.1 Available Equipment at the Amateur Station

4.2.1 Amateur Radio Antenna 1

The impact on radio communication was measured with a typical amateur radio system used since 1983. The amateur radio station preferably uses HF-Frequency bands of 21 MHz, 28 MHz and 14 MHz. In these frequency ranges the antenna has a beam characteristic. The horizontal yagi beam antenna is at a height of 17 m above ground and was rotated to have the main beam directing NE towards the WPT system under test.

To investigate the impact of the WPT system, an **IC7600 Transceiver** and a FPC1000 Spectrum analyser were **used to measure the HF signals from Amateur Radio antenna 1.**



Figure 7: *Amateur Radio Antenna 1 used for the tests (multiband yagi and inverted V).*

Available Antennas at antenna position 1 with main data:

- **Fritzel Yagi Beam FB DX660, Height 17m**
- **Inverted V for 40m and 80m, Height 15m**
- **Further Details:** HBradio 4/2017, p. 11 ff. (in German)

Frequency	Active Elements	Height	Antenna factor AF_e (inkl. Losses to RX input)
28.4 MHz	5	17 m	AF_E = -9 dB/m
21.2 MHz	5	17 m	AF_E = -11.5dB/m
14.2 MHz	3	17 m	AF_E = -13.5 dB/m
7.1 MHz	1	15 m	AF_E = -13 dB/m
3.7 MHz	1	15 m	AF_E = -18.5 dB/m

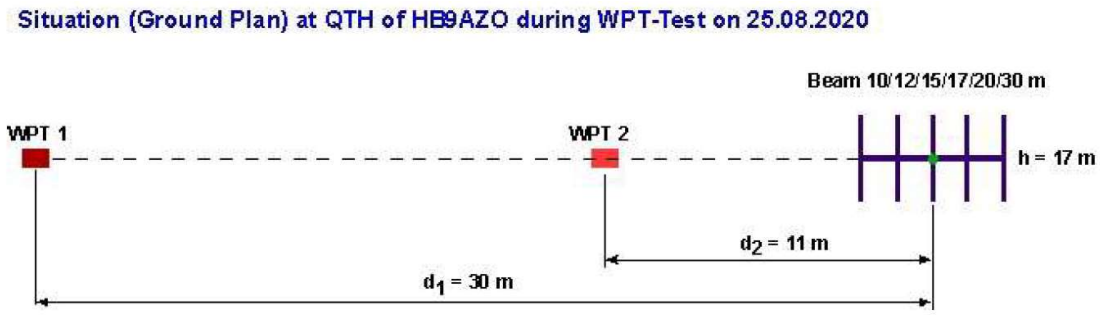


Figure 8: *Ground Plan of Test Situation at QTH of HB9AZO*

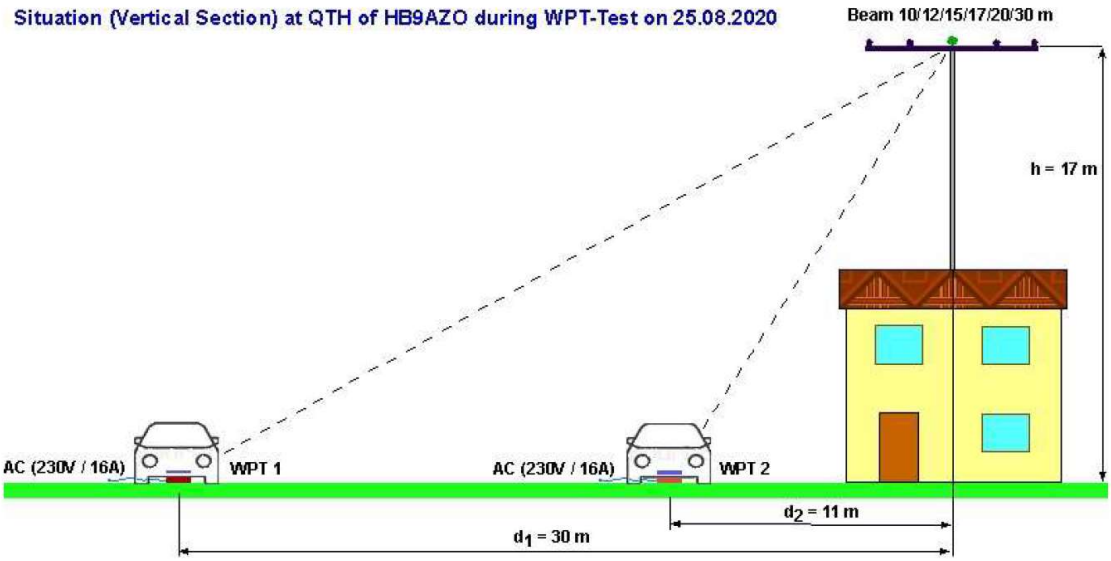


Figure 9: *Vertical Section of Test Situation at QTH of HB9AZO*

4.2.2 Amateur Radio Antenna 2

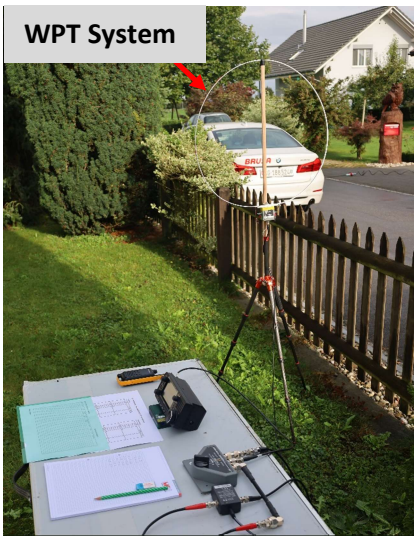


***Figure 10**: Situation Measurement Radio Antenna 2*



***Figure 11:** Radio Antenna 2 (MegaLoop FX)*



***Figure 12:** Situation Measurement Radio Antenna 2*



***Figure 13:** Receiver for Antenna 2 (ICOM IC-705)*

With antenna 1 (the beam) at 17 m above ground, the WPT-EV system charging the car is in an undefined side lobe of the antenna. Therefore, in a second setup, an active magnetic loop Antenna was used to receive mainly magnetic fields, with radio equipment, on the same height as the vehicle. The Antenna loop wire has a circumference of 2 m ($\phi \sim 60$ cm). Preamp 2 of IC-705 was switched on for all shortwave bands from 1.8 MHz to 28 MHz, and the gain setting for the waterfall display was at +15 dB. The MegaLoop FX internal amplifier gain was set to medium position (20 dB gain). The noise blanker in the IC-705 was set to on, to remove interference from the nearby farmer's electric fence. This had no impact on the signal to be analysed, as the WPT-EV charging is continuous. All equipment for antenna setup 2 was powered by batteries.

The antenna factor of this Antenna 2 is unknown. On Sept. 23, 2020 it was possible to receive e.g. stations in Indonesia (YB) on 21 MHz with a signal-to-noise ratio that was only slightly lower than on antenna 1 (the beam). While this antenna is not suitable for transmitting, it is certainly an adequate solution for receiving.

4.3 WPT Input Power Measurement

The input power was measured with a Camille Bauer Metrawatt AG AM1000. The input current, voltage and power were logged with a laptop every 10 s. Electrosuisse was responsible for the equipment and execution and correctness of the measurement.

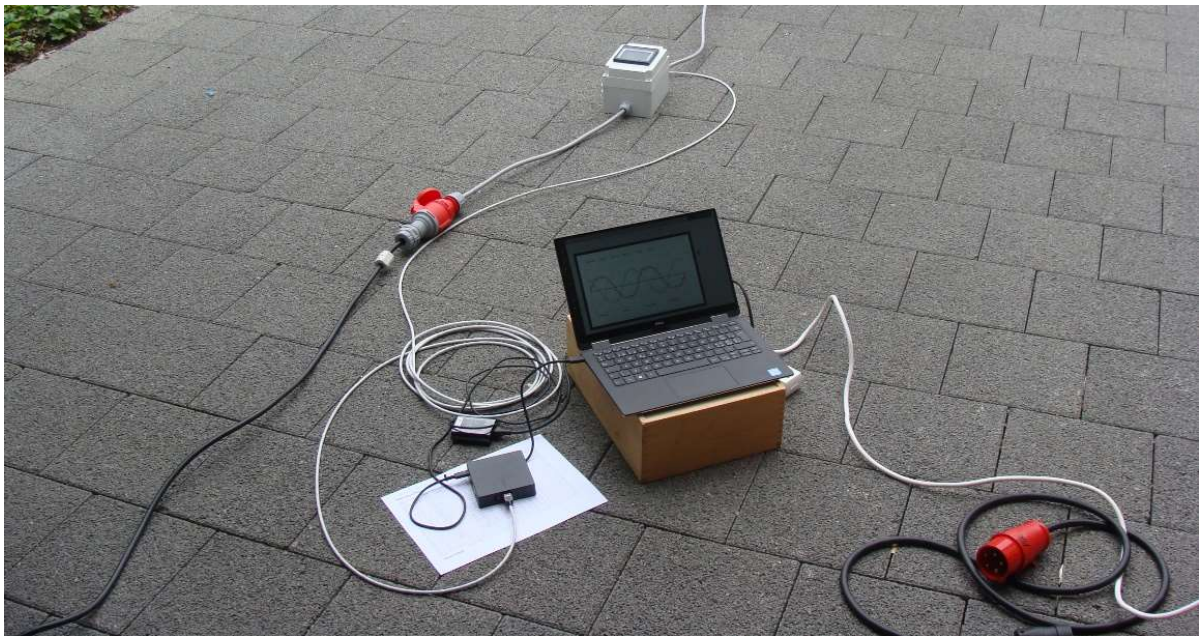


Figure 14: *Input Power Measurement*

In order to eliminate a possible influence of conducted and/or radiated disturbances from the power supply cable of the WPT, the cable was connected to a power outlet of 230 V / 16 A on the other side of the street. In addition, the cable was placed in a CMAD (common mode absorbing device) close to the WPT.

Before starting the measurements it was made sure that the accumulator battery in the vehicle was sufficiently discharged in order to allow charging during the test time.

The measurements in this test series were performed with an AC input power of 2.6 kW or 3.7 kW.

In the description of each test a test ID number is indicated. With this ID number the test power level actually applied during this test can be found in figure 16 in chapter 5.1.

4.4 WPT System

The WPT system is an ICS1 3.7 kW system of BRUSA Elektronik AG integrated in a BMW 530e [6]. The vehicle was bought by BRUSA from an official BMW dealership and no modifications were made subsequently. The ground assembly is from a series production line. The system (vehicle, ground assembly, vehicle assembly) were randomly chosen without selecting a specifically optimal sample. The system was produced in 2018.



Figure 15: *BRUSA ICS1 WPT System*

The ICS1 is a fully integrated system which contains all functionalities in one ground assembly and one vehicle assembly device. During the test all functions were running on standard production Software (SW) without derating. The functionalities were:

- Power Transfer
- WiFi Communication
- Metal detection (FOD)
- Living Object Detection (LOD)
- Positioning System
- Safety Functionalities

The system has certification from TÜV Rheinland for Japan, China, Europe, North America and was developed and is based on the BRUSA Elektronik AG owned FRAME technology.

Model / Type: ICSP11W-U0-01D-K01 (GPM); ICSS115-U0-01D-L01 (CPM)

The measurements in this test series were performed with an AC input power of 2.6 kW or 3.7 kW.

The WPT input power actually applied during a certain test can be determined with the ID number indicated at each test by means of Figure 16. It can be assumed that the power factor was close to 1.

Before starting the measurements it was always made sure that the accumulator battery in the vehicle was sufficiently discharged in order to allow charging during the test time.

5 Measurement Results

5.1 Input Power

Time was split in different timeslots with a specific ID in order to synchronize the different measurements.

Timeslot ID	I1 [Aeff]	Start Time	Stop Time	Date	WPT state	Distance Vehicle – Antenna 1 center
ID0	0	00:00:00	09:00:00	25.08.2020	WPT OFF	30 m
ID1	0	08:54:30	09:25:30	25.08.2020	WPT OFF	30 m
ID2	11.3	08:59:00	09:03:20	25.08.2020	Charging	30 m
ID3	0	09:03:30	09:10:10	25.08.2020	WPT OFF	30 m
ID4	11.3	09:10:30	09:26:40	25.08.2020	Charging	30 m
ID5	0	09:26:50	09:39:20	25.08.2020	WPT OFF	30 m
ID6	11.3	09:39:40	09:41:30	25.08.2020	Charging	30 m
ID7	0	09:41:40	09:42:40	25.08.2020	WPT OFF	30 m
ID8	11.3	09:43:00	09:51:30	25.08.2020	WPT ON	30 m
ID9	0	09:51:40	10:42:00	25.08.2020	WPT OFF	30 m
ID10	11.3	10:42:30	11:07:20	25.08.2020	WPT ON	30 m
ID11	0	11:07:30	11:33:10	25.08.2020	WPT OFF	30 m
ID12	11.3	11:33:30	11:51:50	25.08.2020	WPT ON	30 m
ID13	0	11:52:00	11:53:30	25.08.2020	WPT OFF	30 m
ID14	0	13:32:30	13:33:00	25.08.2020	WPT OFF	30 m
ID15	11.3	13:33:20	13:39:20	25.08.2020	WPT ON	11 m
ID16	16.1	13:39:40	13:51:00	25.08.2020	WPT ON MAX	11 m
ID17	0	13:51:20	14:05:50	25.08.2020	WPT OFF	11 m
ID18	16.1	14:06:20	14:19:30	25.08.2020	WPT ON MAX	11 m
ID19	0	14:19:50	14:22:10	25.08.2020	WPT OFF	11 m
ID20	16.1	14:22:40	14:52:50	25.08.2020	WPT ON MAX	11 m
ID21	0	14:53:10	15:04:10	25.08.2020	WPT OFF	11 m
ID22	16.1	15:04:40	15:05:10	25.08.2020	WPT ON MAX	11 m
ID23	0	15:05:30	15:06:00	25.08.2020	WPT OFF	11 m
ID24	16.1	15:06:40	15:06:40	25.08.2020	WPT ON MAX	11 m
ID25	0	15:07:00	24:00:00	25.08.2020	WPT OFF	11 m
ID26	0	0:00	9:37	23.09.2020	WPT OFF	11 m
ID27	16.1	9:37	9:39	23.09.2020	WPT ON MAX	11 m
ID28	0	9:39	9:45	23.09.2020	WPT OFF	11 m
ID29	16.1	9:45	9:55	23.09.2020	WPT ON MAX	11 m
ID30	0	9:55	10:00	23.09.2020	WPT OFF	11 m
ID31	16.1	10:00	10:10	23.09.2020	WPT ON MAX	11 m
ID32	0	10:10	10:15	23.09.2020	WPT OFF	11 m
ID33	16.1	10:15	10:25	23.09.2020	WPT ON MAX	11 m
ID34	0	10:25	11:15	23.09.2020	WPT OFF	11 m
ID35	16.1	11:15	11:25	23.09.2020	WPT ON MAX	11 m
ID36	0	11:25	11:30	23.09.2020	WPT OFF	11 m
ID37	16.1	11:30	11:40	23.09.2020	WPT ON MAX	11 m
ID38	0	11:40	11:45	23.09.2020	WPT OFF	11 m
ID39	16.1	11:45	11:55	23.09.2020	WPT ON MAX	11 m
ID40	0	11:55	12:00	23.09.2020	WPT OFF	11 m
ID41	16.1	12:00	13:00	23.09.2020	WPT ON MAX	11 m

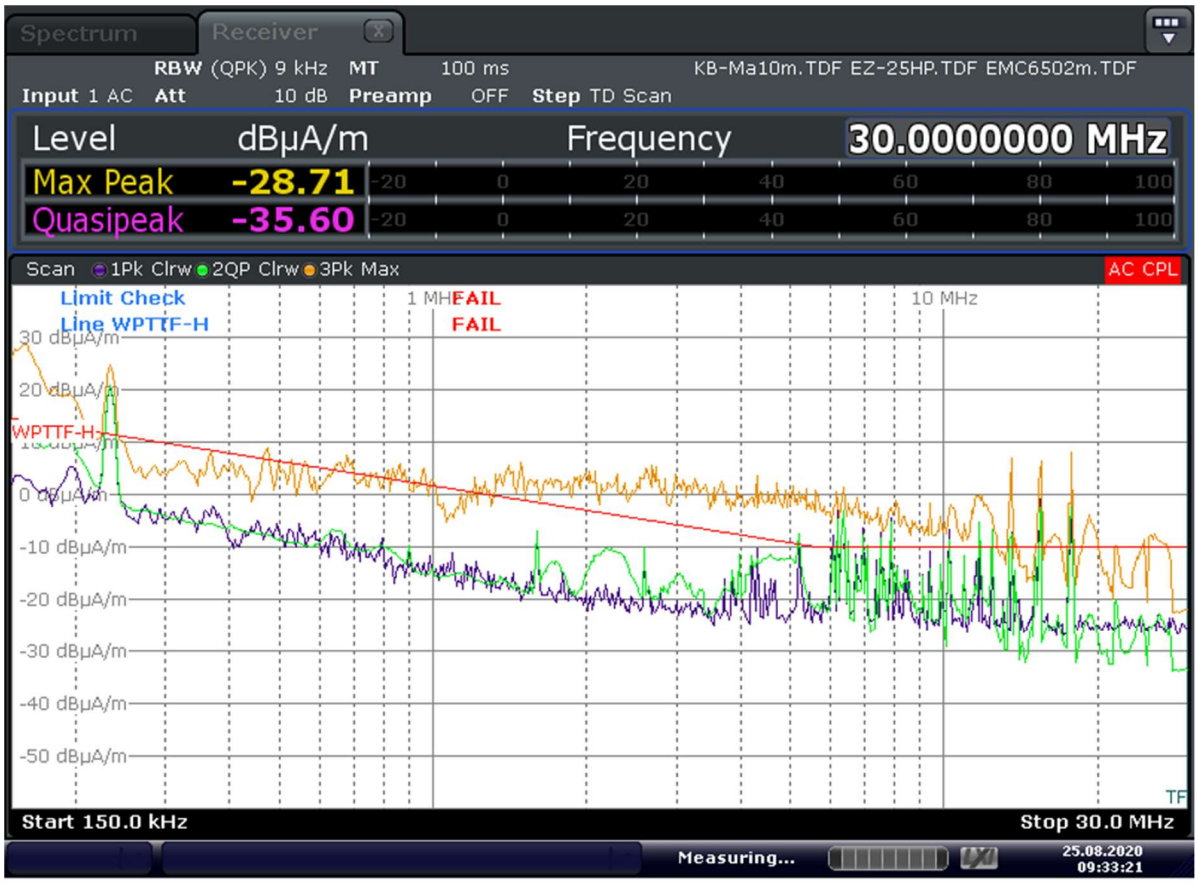
***Figure 16**: ID-Numbers indicating input Current (proportional to power), time and WPT operation state (OFF and ON)*

5.2 Measurements of Magnetic Field Strength H

The ".dat" files of the measurements of OFCOM were made available to all participants to allow individual evaluations and presentations according to their preferences. ***Measuring distance between OFCOM's loop antenna and WPT was always 10 m.*** Figure 17 in this chapter has been generated by **OFCOM,** figures 18 and 19 by **BRUSA** and figures 20 to 37 by **USKA**. Many more figures with spectra have been included by BRUSA and OFCOM in their respective reports [5], [6].

5.2.1 General consideration about the measurements and the results

The measurements were done with peak detector (Pk) and quasi peak (QP) detector in real time mode. The frequency band from 9 kHz to 30 MHz is covered by two separate measurements, the first one from 9 kHz to 150 kHz with a bandwidth of 200 Hz and the second, above 150 kHz, with 9 kHz bandwidth. Three traces were recorded for each measurement (example below in Figure 17), **trace 1 (purple)** is the actual Pk measurement (clear write, Clrw), **trace 2 (green)** is the actual QP measurement (clwr) and **trace 3 (orange)** is the max hold of Pk measurement. The limit shown in the plot is the proposed limit for class B WPT from the newest stage of revision of CISPR 11, document CIS/B/737/CDV (Table C and F). The measurements done during this campaign are not intended to assess the conformity of the WPT but only to collect information about emission of a WPT system actually available on the market. The limit shown in the plot shall only provide a reference. Each measurement was stored as plot (.png file) and as table (.dat file).



Date: 25.AUG.2020 09:33:22

***Figure 17**: Example of Background emission (WPT off) 150 kHz – 30 MHz, axis X, charging location 1 (30m), Time slot identification ID5*

For easier presentation in their reports, BRUSA combined the measured values for the three axes x, y and z in one trace by taking for each frequency the maximum value from the three results [6].

In the reports compiled by USKA, separate values for x, y, and z are indicated for each frequency.

Furthermore, in all figures measurements with WPT OFF and WPT ON were placed in the same graphic in order to allow a better comparison.

5.2.2: Magnetic Field Background Emissions

As the radiated emission measurements were done in situ and not in a semi anechoic chamber (SAC), the measurements include (besides the emission produced by the equipment under test) all wanted or unwanted emissions from the environment. A background emission measurement (with tested equipment turned off) gives an impression of the emission on a given time, but new disturbance sources can appear (or, less problematic, disappear) at each time. This makes the identification of the emission of the WPT more difficult, and even more when this emission is low.

Two main sources of unwanted emission were identified at the measuring place, an electric fence (at 45 m) and power line communication (PLC) devices. These sources give a very broadband emission with high levels but are not permanently present. These sources could not be supressed during the measurements.

The presence of these two disturbance sources explains some unusual characteristics in Figure 17. The actual peak measurement **trace 1 (purple)** shows the background emission in a time slot with no electric fence and no PLC. As the QP measurement **trace 2 (green)** takes longer time, it is much more unlikely to catch a time slot without PLC and fence signals. This explains the unusual situation that at some frequencies the QP value is higher than the actual Pk value. But the QP value is correctly always lower than the Pk max hold **trace 3 (orange).**

5.2.3 Evaluations by BRUSA of OFCOM's H-Field measurements (WPT ON and OFF at charging location 1)

In this report only some examples of spectra of measured H-Fields (QP) between 10 kHz and 30 MHz, which were generated by BRUSA, are shown**.** The WPT transfer power during these measurements was 2.6 kW. ***Many more figures of spectra have been included by BRUSA in their report [6].***

It must be noted, that in the spectra produced by BRUSA, for each axis (x, y, z), *the maximum value* of all three measured QP-values Hx, Hy and Hz are shown. In these spectra also the proposed limit value according to the Draft CIS B 737 CDV (rejected) is also indicated (green line).

In the following figures 18 and 19 measured QP emissions **with (blue line)** and **without (red line)** WPT operation are shown. Figure 18 shows emissions from 10 kHz to 30 MHz. Figure 19 is an expanded version for HF from 5 MHz to 30 MHz.

The difference between the WPT operating states ON and OFF are very low. Therefore, it can be expected that in this case the disturbances on amateur radio reception will probably be rather low.

Similar measurements were also performed with the WPT at charging location 2. Here also the difference between WPT ON and WPT OFF was quite low, because the distance between disturbance source and receiver was equal (10 m) for all measurements performed by OFCOM(CH) [5].

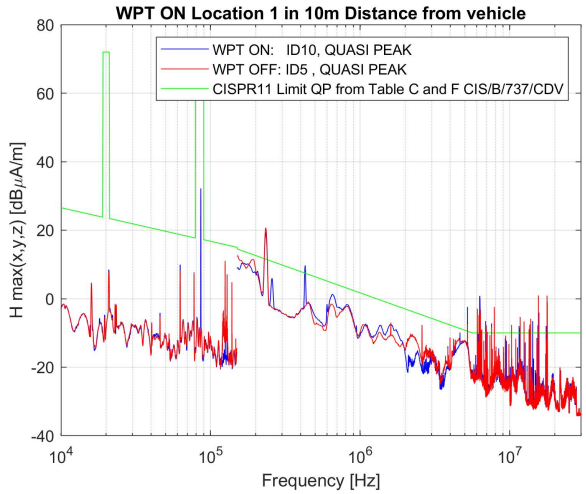


Figure 18: *Emissions from 10 kHz to 30 MHz (LF to HF) measured with OFCOM's loop test antenna 10 m from WPT. WPT basic frequency about 32 dBμA/m at 88 kHz.*

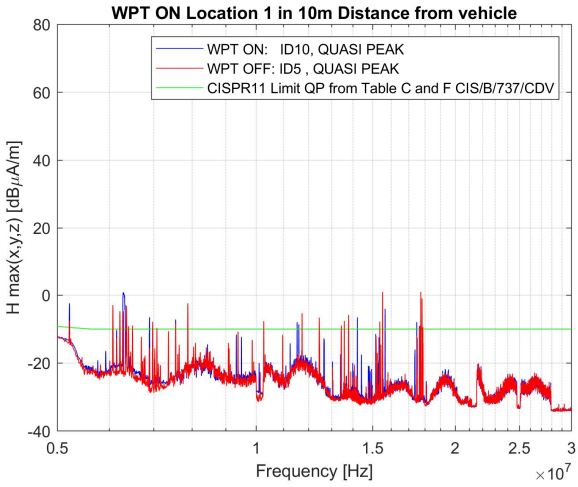


Figure 19*: Expanded Fig. 18 for HF Emissions between 5 MHz to 30 MHz.*

5.2.4 Evaluations by USKA of OFCOM's H-Field measurements (WPT ON and OFF at charging location 1)

The HF spectra shown in this section are all based on data from measurements with professional equipment performed by OFCOM(CH) on Aug. 23, 2020. They were created by USKA members HB9AZO and HB9BKT using these data and are shown in this report. They were all obtained from measurements with a converted power of **0 kW** in time slots ID9 (WPT OFF, green lines) and **2.6 kW** in time slots ID10 (WPT ON, red lines).

In some spectra notches from PLC or VDSL2 in the amateur bands can clearly be seen. Besides the common time slots with WPT OFF and WPT ON, the field intensity measurements of OFCOM(CH) [5] were independent from the measurements of the noise disturbance measurements at the antennas of the amateur radio station (at a horizontal distance of 30 m or 11 m from the WPT) during the same time slots. The **distance between WPT and loop antenna** (diameter 0.6 m) of the measuring equipment was **always 10 m** (independent from the measurements at the amateur radio station).

For each frequency H-values (QP) of all three components H_X , H_Y and H_Z are shown in separate diagrams. Besides the overall HF-spectrum in all three directions also expanded versions around the most important HF amateur bands are displayed.

5.2.4.1 Magnetic Field intensity H_X (QP) 3 MHz to 30 MHz)

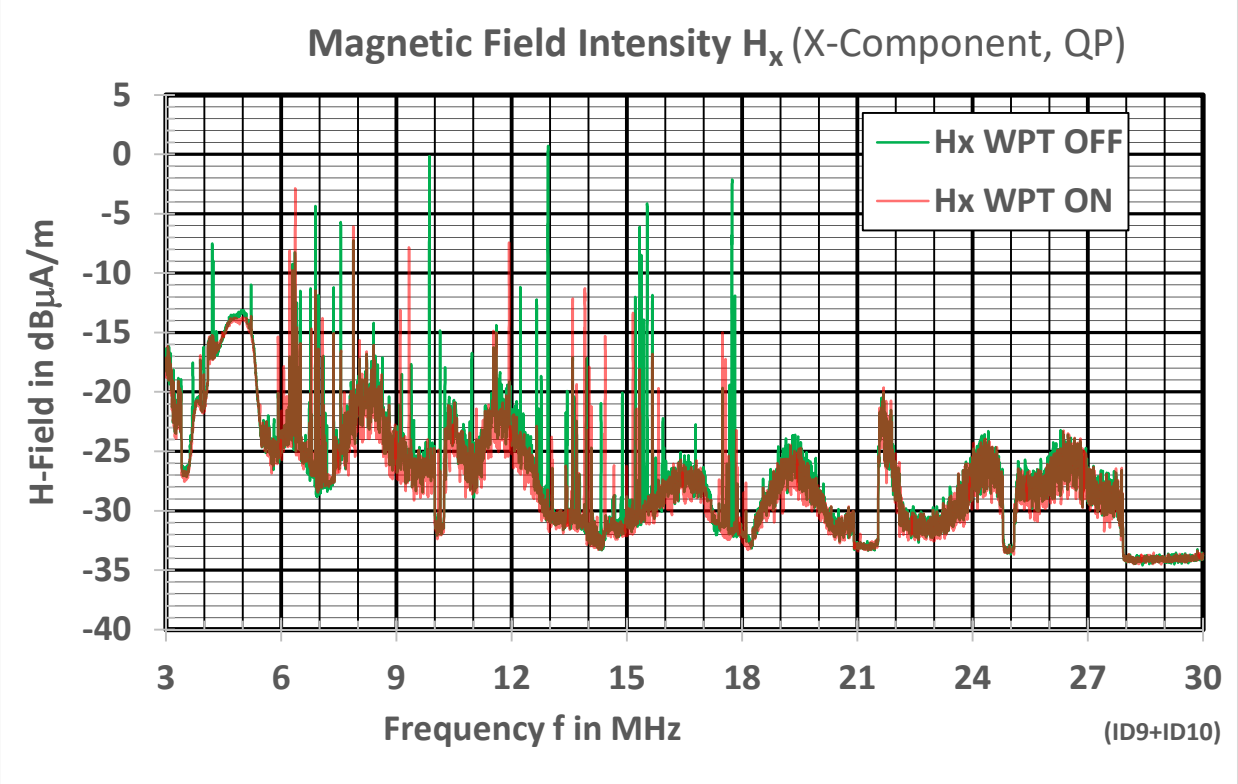


Fig. 20: X-Component QP, B = 9 kHz, HF frequency 3 MHz to 30 MHz.
Notches by PLC/VDSL2 on 7, 10, 14, 18, 21, 24 and 28 MHz.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

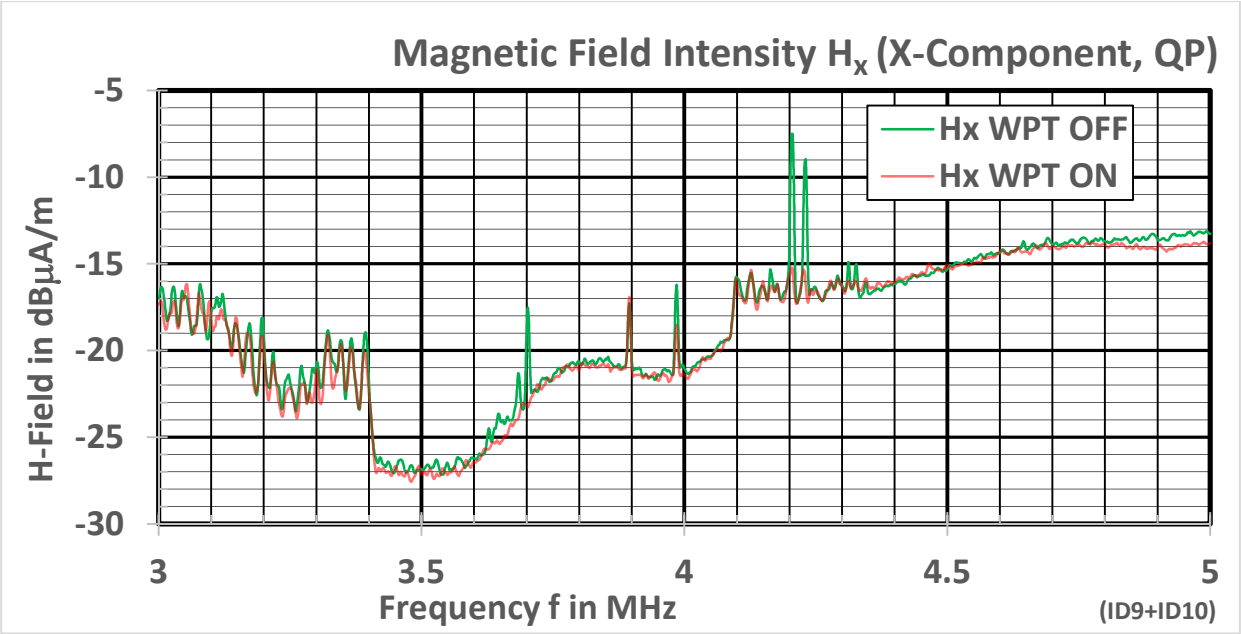


Fig. 21: X-Component QP, B = 9 kHz, HF frequency 3 MHz to 5 MHz.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

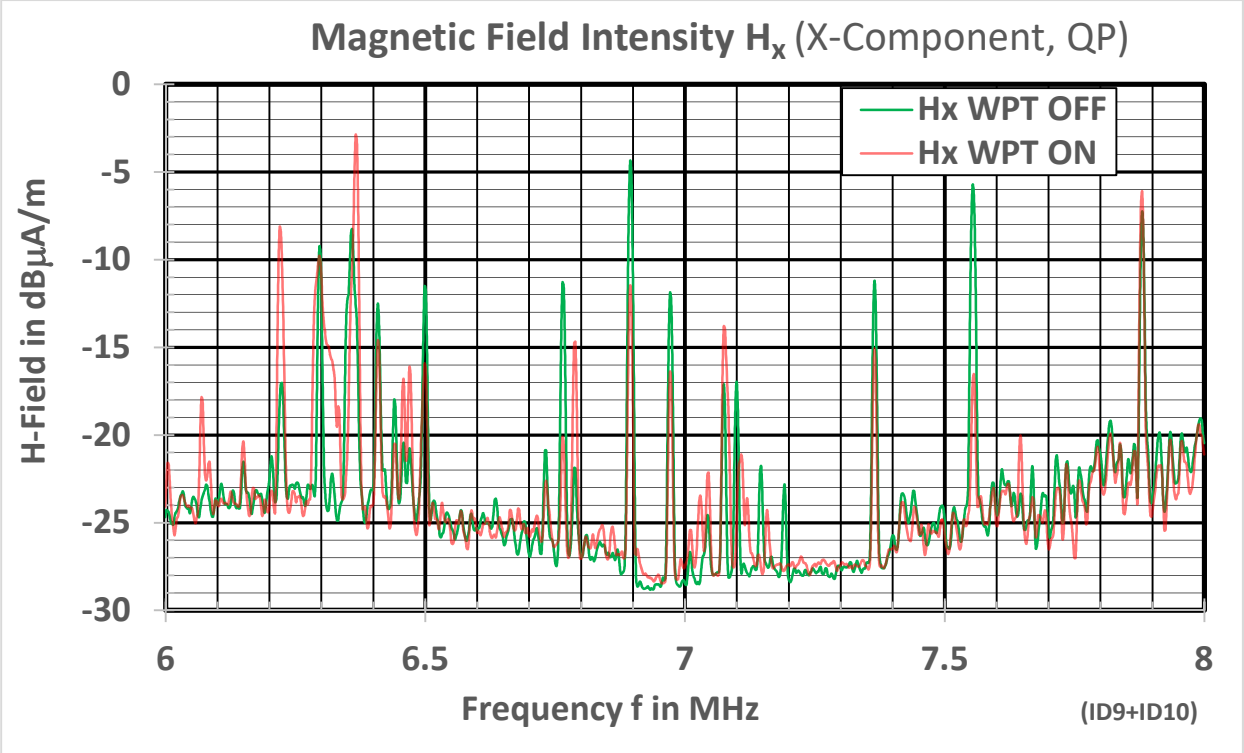


Fig. 22: X-Component QP, B = 9 kHz, HF frequency 6 MHz to 8 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

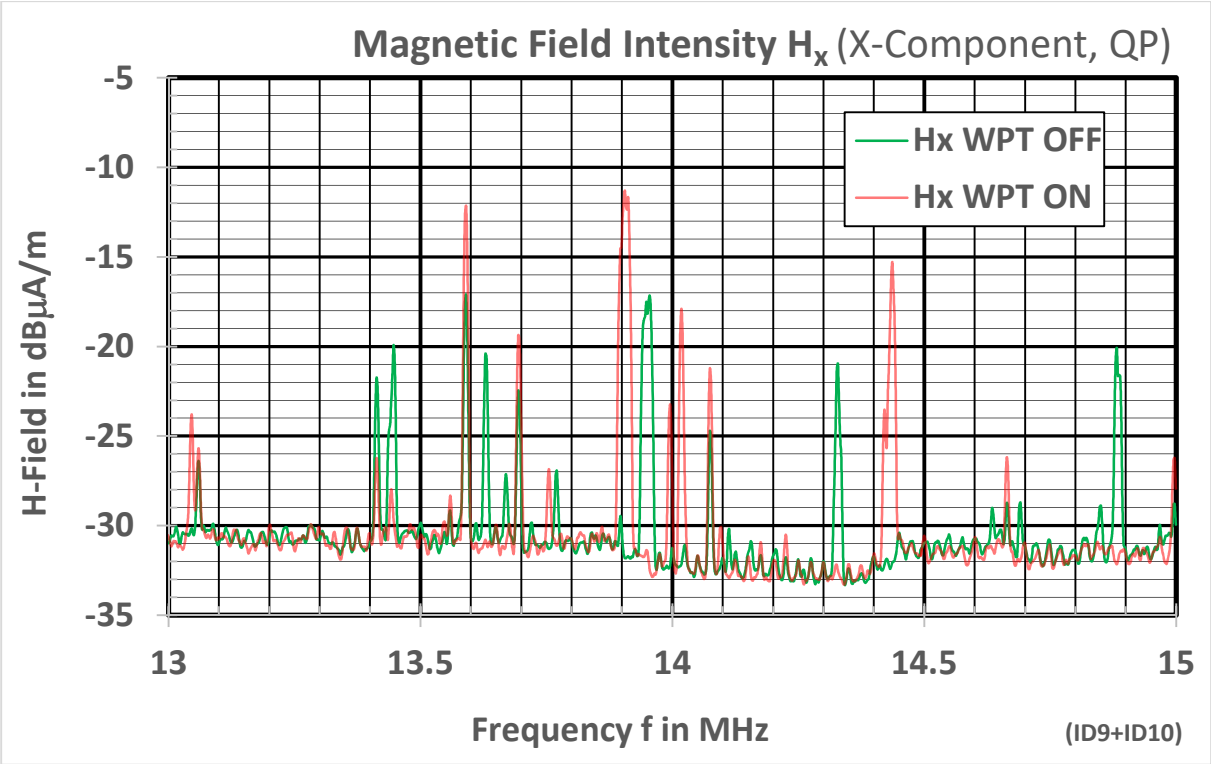


Fig. 23: X-Component QP, B = 9 kHz, HF frequency 13 MHz to 15 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

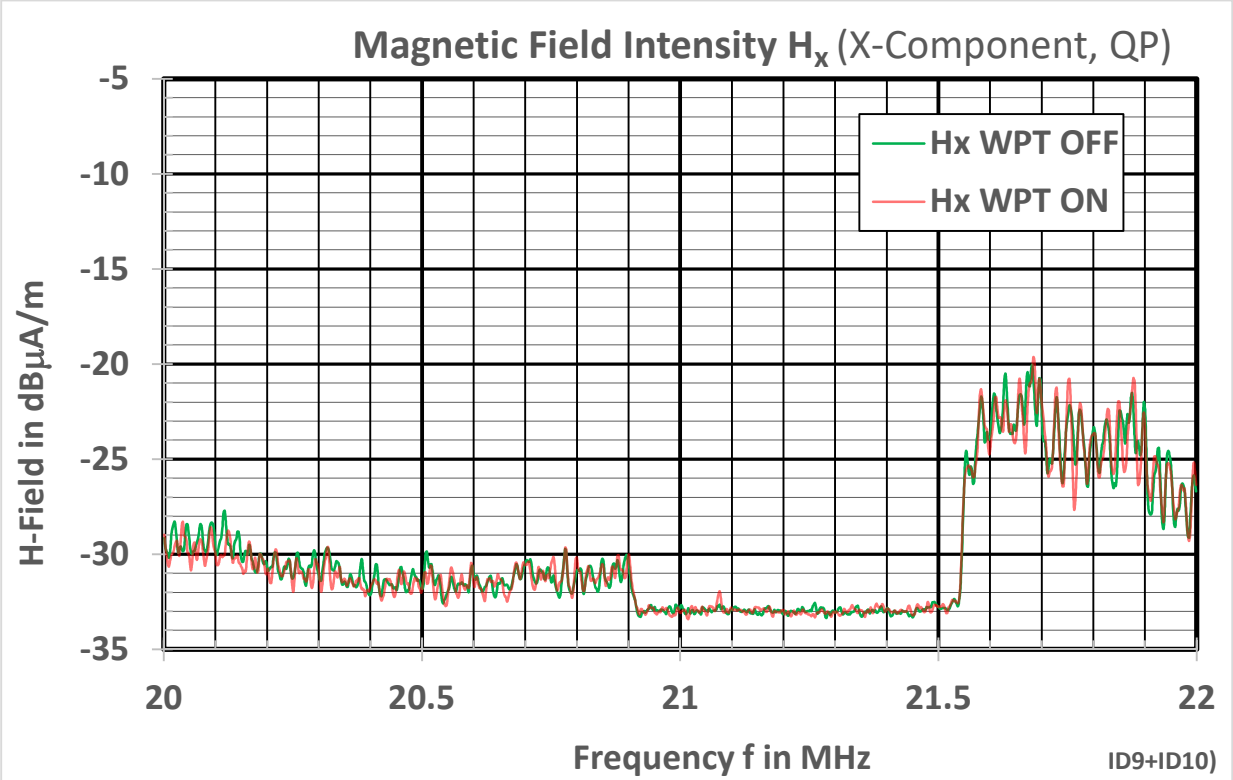


Fig. 24: X-Component QP, B = 9 kHz, HF frequency 20 MHz to 22 MHz.
Clean notch on 15m band (down to noise level at -33dBµA/m).
Time difference between measurements with WPT ON and WPT OFF about 1 h.

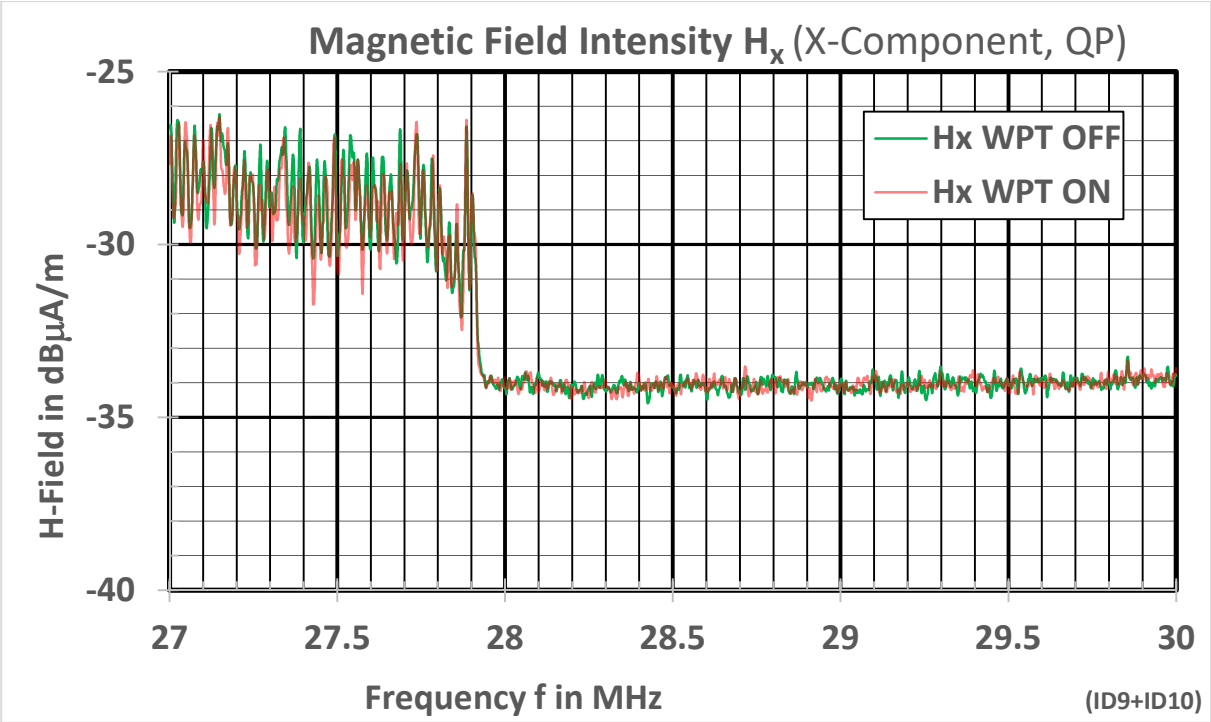


Fig. 25: X-Component QP, B = 9 kHz, for HF frequency 27 MHz to 30 MHz
(Internal noise level at about -34 dBµA/m).
Time difference between measurements with WPT ON and WPT OFF about 1 h.

5.2.4.2 Magnetic Field intensity H_Y (QP) 3 MHz to 30 MHz)

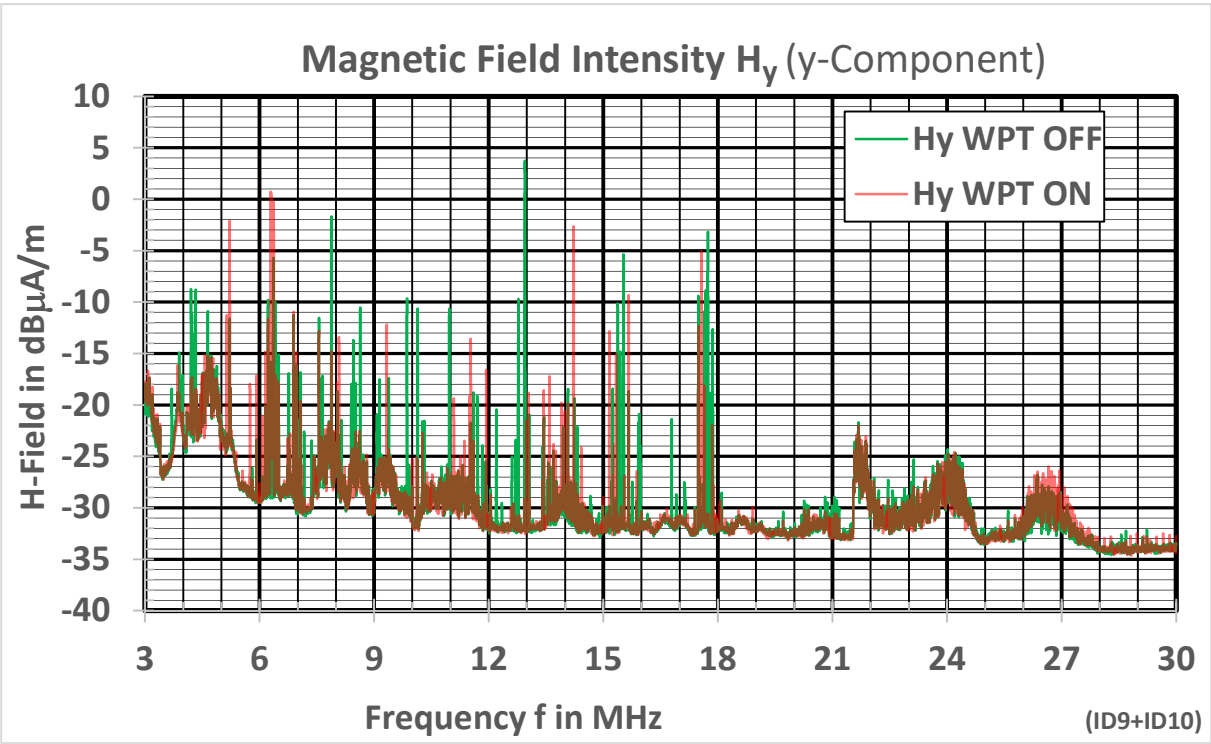


Fig. 26: Y-Component QP, B = 9 kHz, HF frequency 3 MHz to 30 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

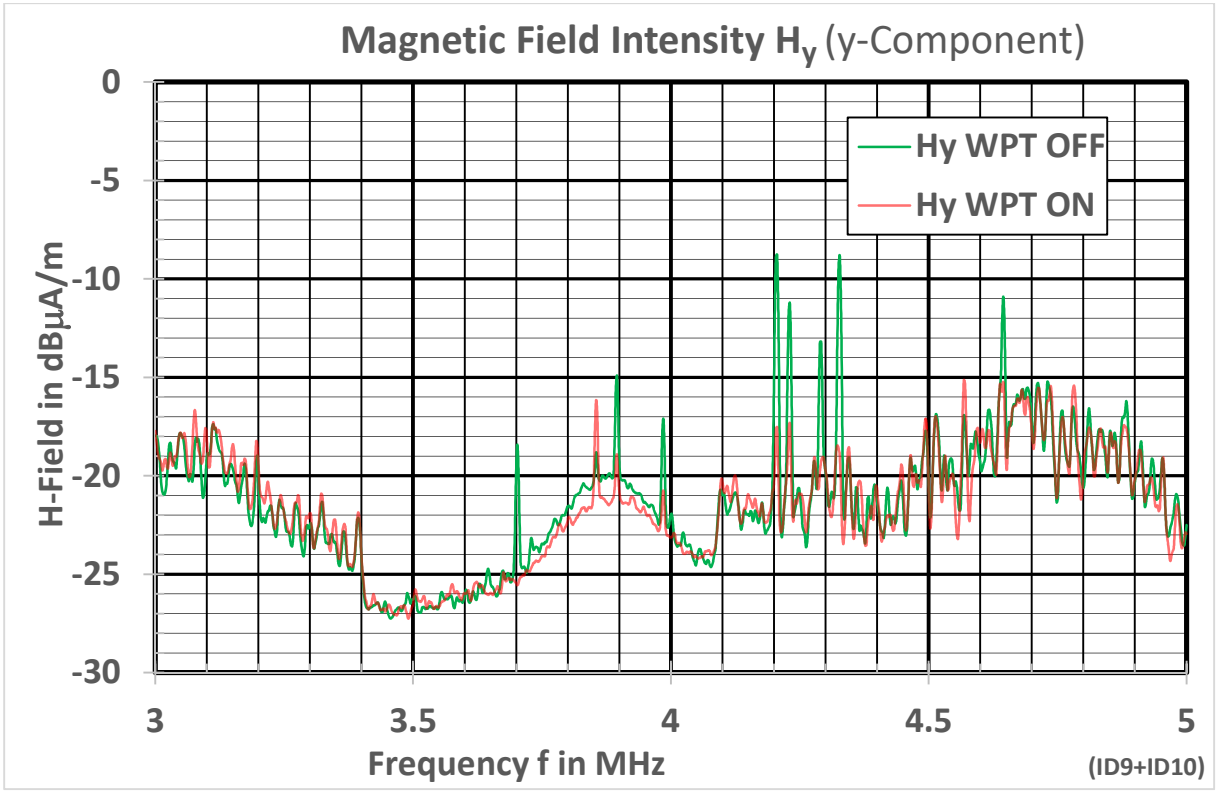


Fig. 27: Y-Component QP, B = 9 kHz, HF frequency 3 MHz to 5 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

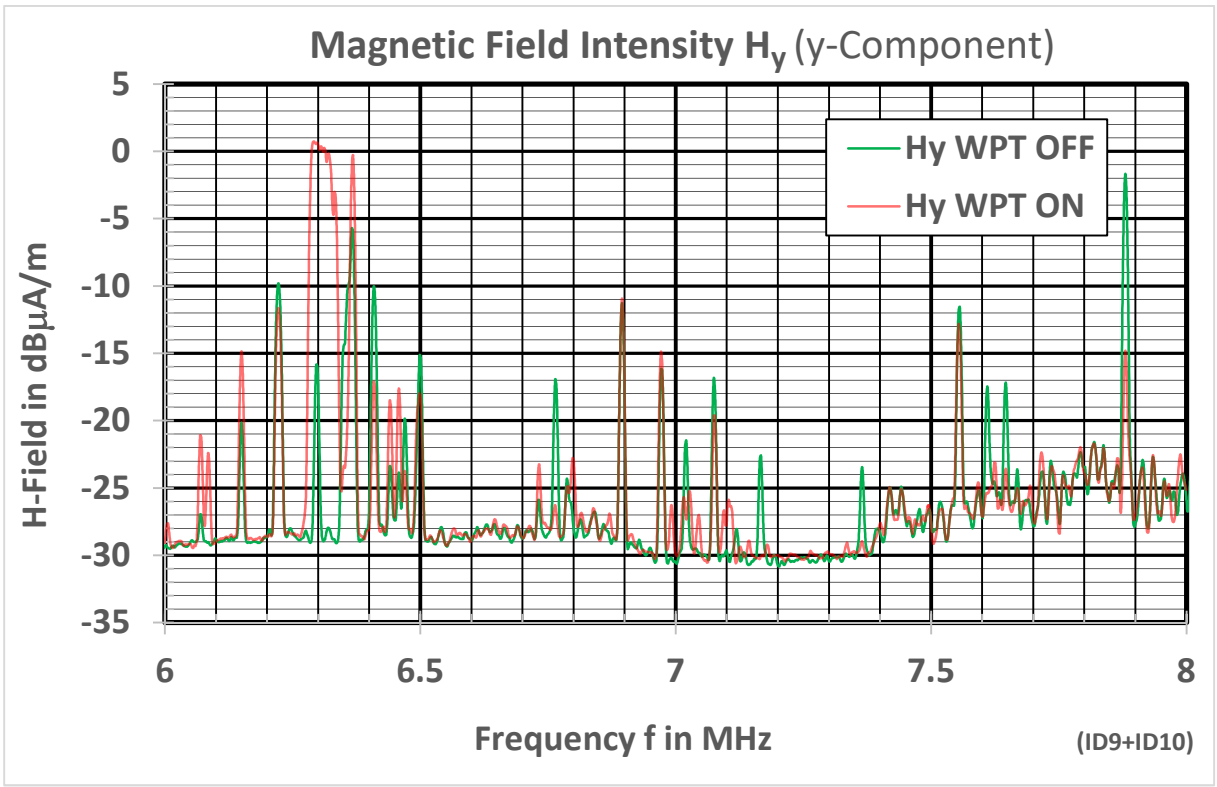


Fig. 28: Y-Component QP, B = 9 kHz, HF frequency 6 MHz to 8 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

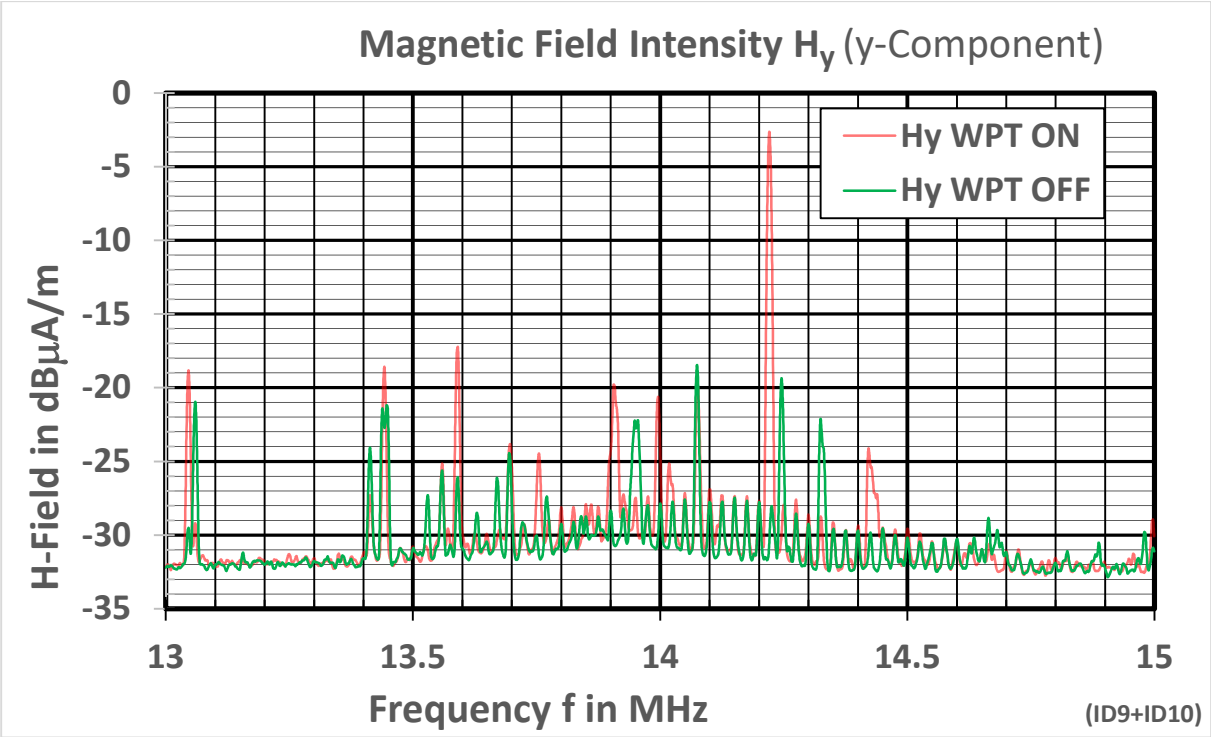


Fig. 29: Y-Component QP, B = 9 kHz, HF frequency 13 MHz to 15 MHz.
On 14.22 MHz there is a relatively high peak of -3 dBµA/m for WPT ON. This is the highest peak registered in an amateur band. However, as there is only a single event, and as there is a time difference between measurements with WPT ON and WPT OFF of about 1 h, it is believed that this is a legal amateur signal registered by chance during the measurement. To be absolutely sure, this frequency should be looked at during future measurements.

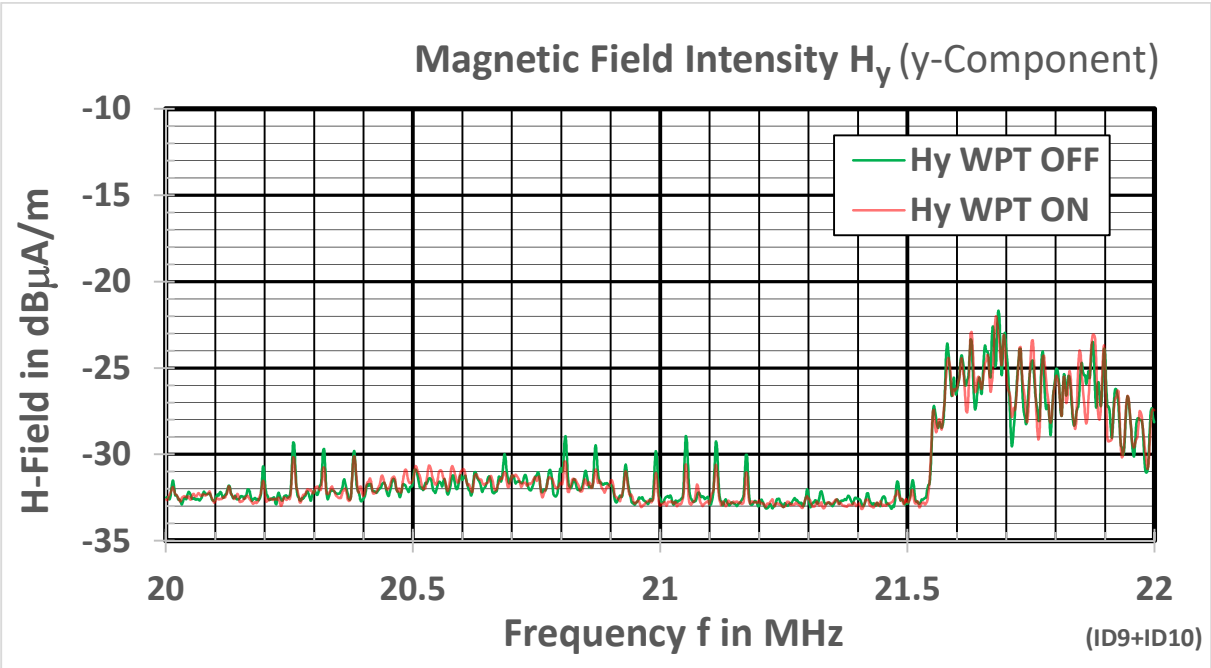


Fig. 30: Y-Component QP, B = 9 kHz, HF frequency 20 MHz to 22 MHz.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

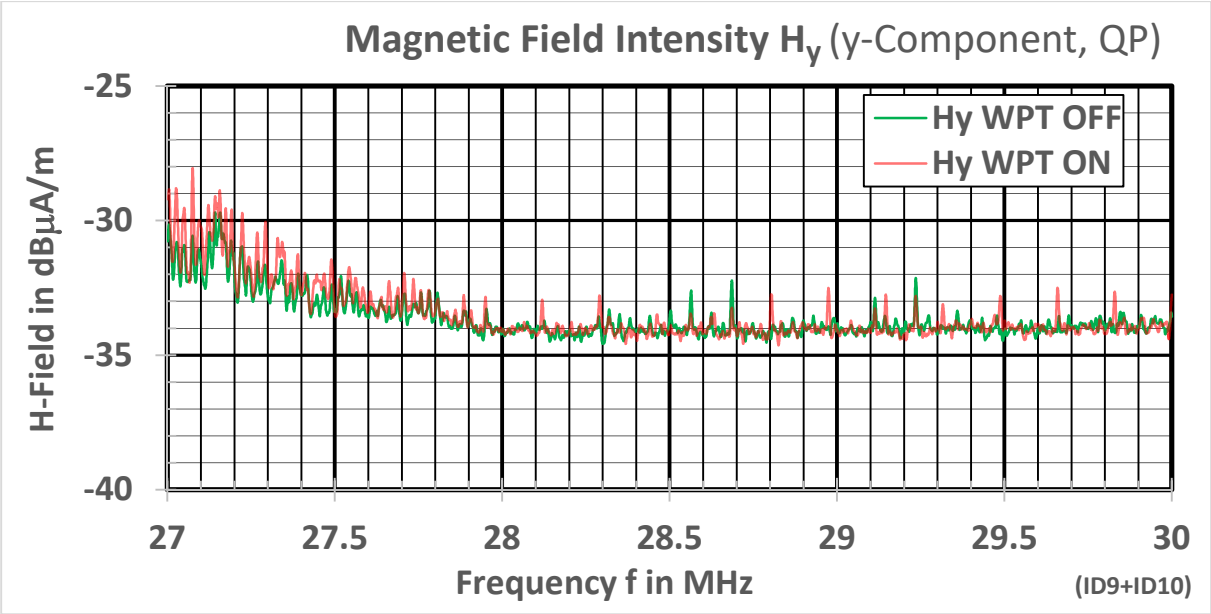


Fig. 31: Y-Component QP, B = 9 kHz, for HF frequency 27 MHz to 30 MHz
With WPT ON, odd harmonics with spacing of 171.2 kHz are clearly visible (e.g. on 28.119, 28.292, 28.805, 28.974, 29.145, 29.316, 29.487, 29.660 MHz) with levels up to 1.5 dB higher than for WPT OFF.
The basic WPT-switching frequency here is about $\Delta f/2$ = 85.6 kHz.
This is the only diagram with directly measured WPT disturbance peaks at about -32.5 dBµA/m.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

5.2.4.3 Magnetic Field intensity H_Z (QP) 3 MHz to 30 MHz)

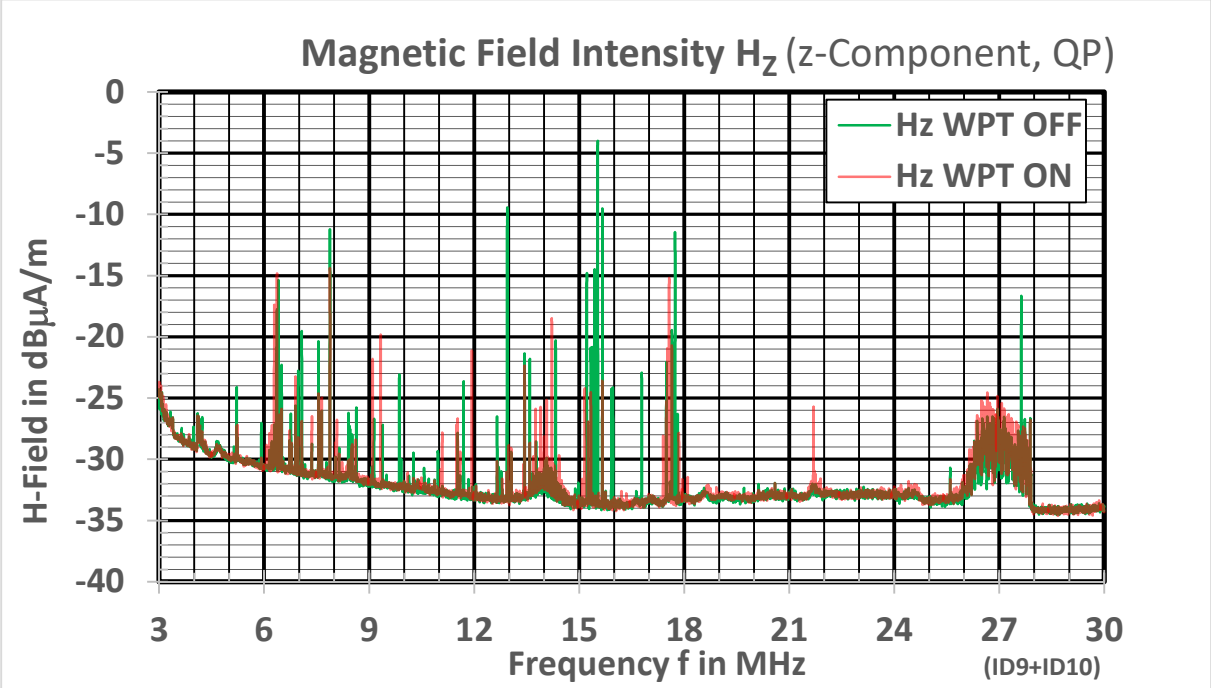


Fig. 32: Z-Component QP, B = 9 kHz, HF frequency 3 MHz to 30 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

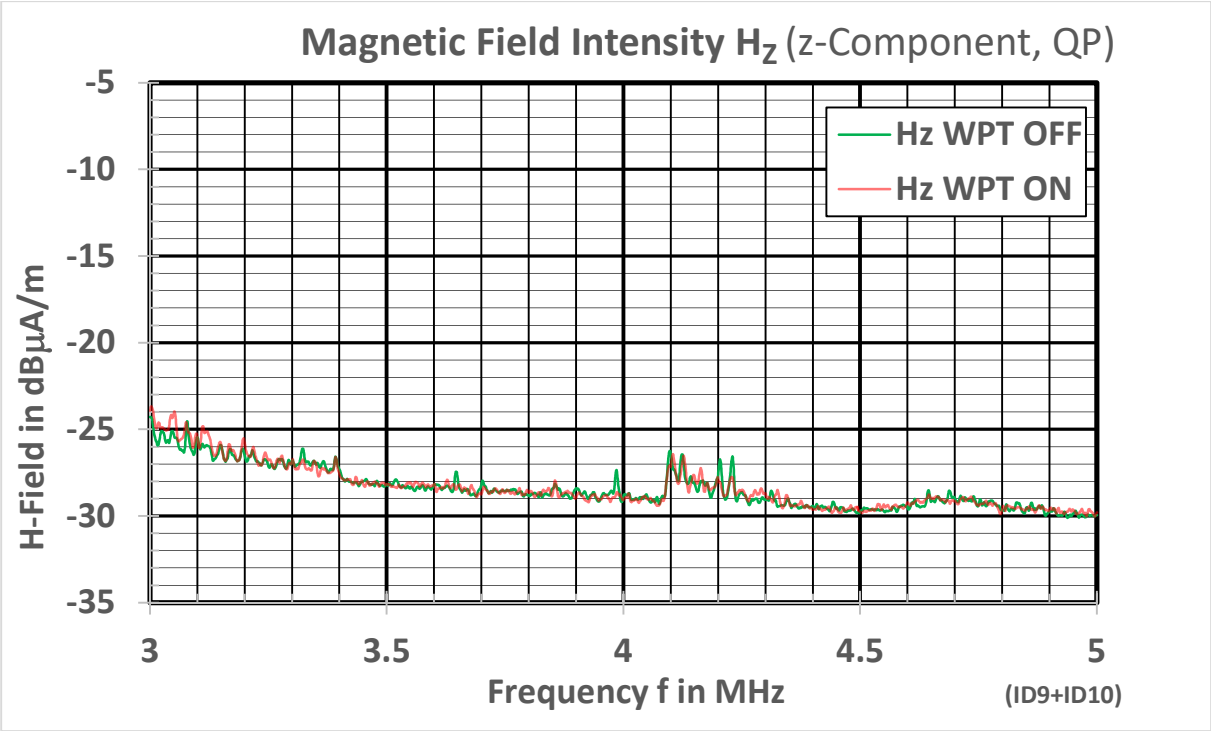


Fig. 33: Z-Component QP, B = 9 kHz, HF frequency 3 MHz to 5 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

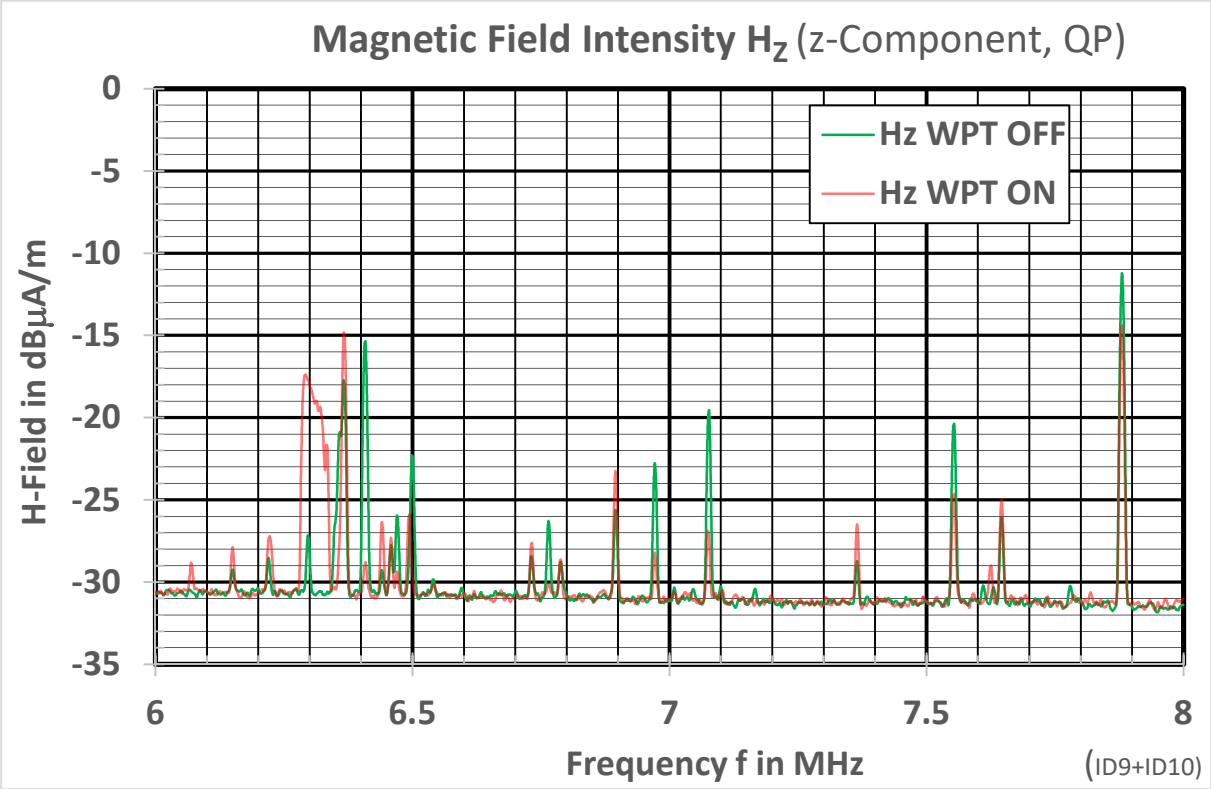


Fig. 34: Z-Component QP, B = 9 kHz, HF frequency 6 MHz to 8 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

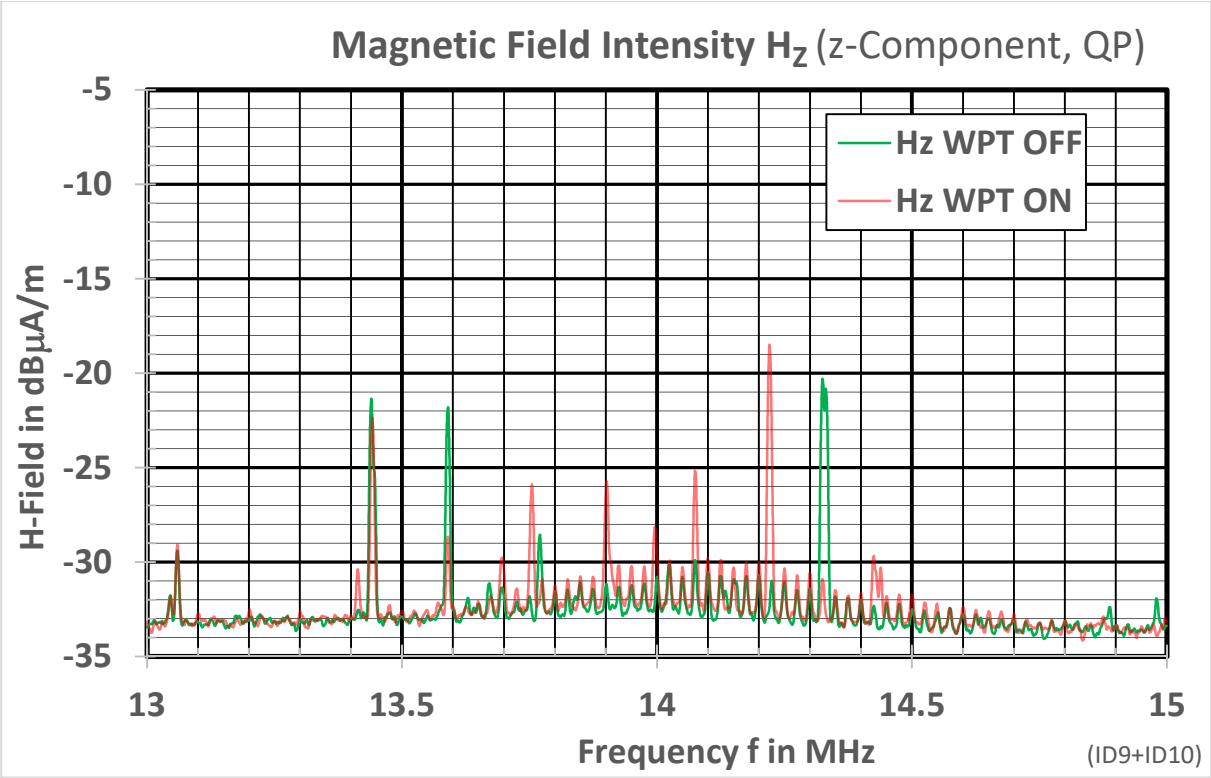


Fig. 35: Z-Component QP, B = 9 kHz, HF frequency 13 MHz to 15 MHz
Time difference between measurements with WPT ON and WPT OFF about 1 h.

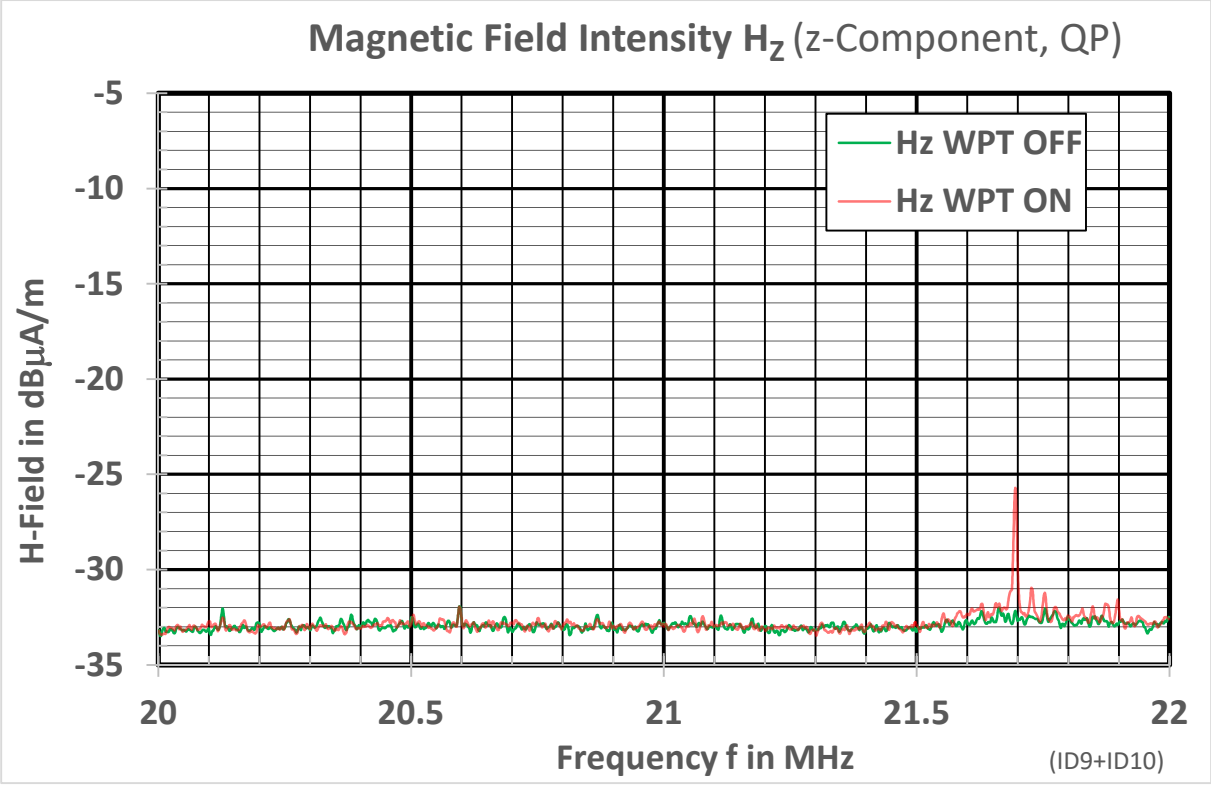


Fig. 36: Z-Component QP, B = 9 kHz, HF frequency 20 MHz to 22 MHz.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

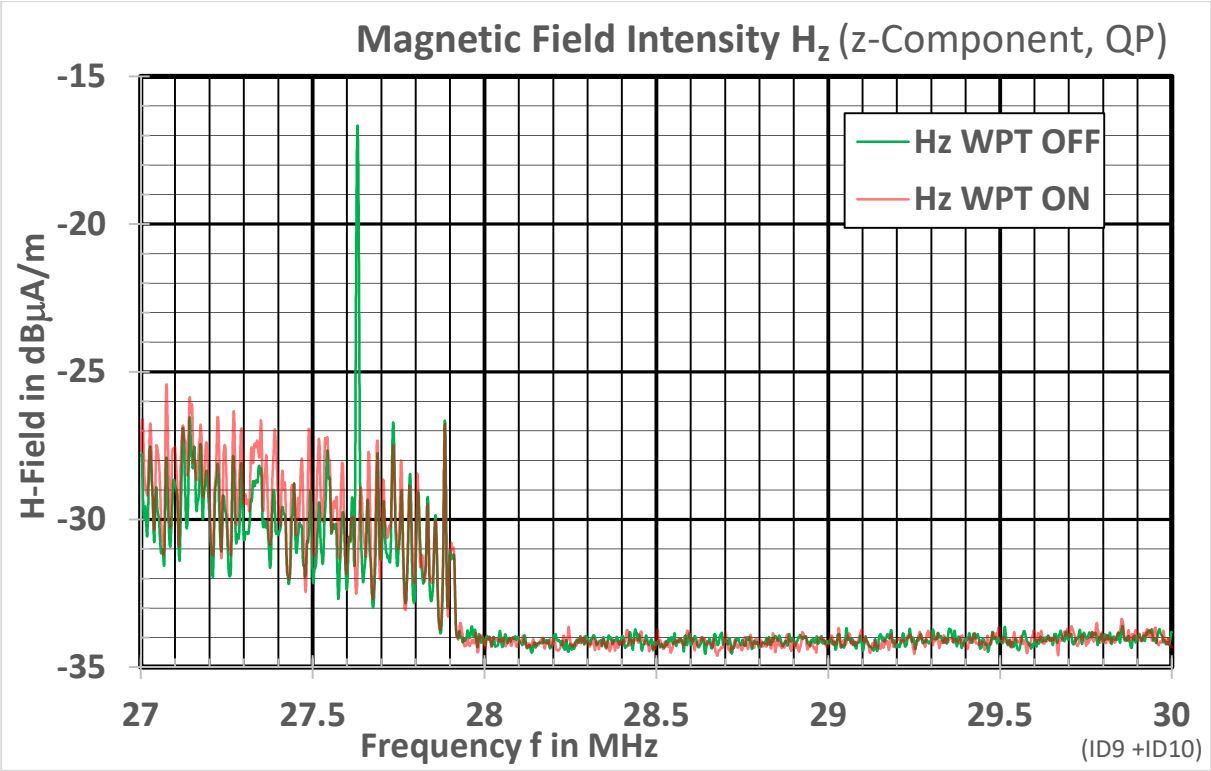


Fig. 37: Z-Component QP, B = 9 kHz, HF frequency 27 MHz to 30 MHz.
Time difference between measurements with WPT ON and WPT OFF about 1 h.

5.2.5 Conclusions from the Measurements of Magnetic Field Intensity H

Despite the fact, that there was a time difference of up to 1 h between the measurements with WPT ON and WPT OFF, the measured differences between the ON and OFF state were often pretty small, especially on the bands with no sky wave propagation on the 15m-band (21.0 to 21.45 MHz) and 10m-band (28.0 to 29.7 MHz).

The spectra with green traces (WPT OFF) represent the background emissions observed. In principle, only red traces registered during WPT ON, which are higher than the green lines at WPT OFF, could originate from the WPT, but owing to the time difference between the two measurements could also have come from another source, which was only active during the measurement on the same frequency. On all frequencies, at which WPT emissions during WPT ON are lower or equal to those at WPT OFF, their exact value cannot be determined. Therefore, in order to enhance precision at low H values during WPT ON, it is essential to have WPT OFF disturbance levels as low as possible.

Overall assessment:
The measurements of the spectra for WPT ON and WPT OFF performed give another clear hint that the spurious emissions from the WPT are likely quite low, but a formal proof is not possible.

In order to obtain more emission data of the WPT, it would be very interesting to perform similar measurements at a remote location (quiet rural) with considerably lower background disturbances, e.g. several 100 m away from all other electrically active equipment. Devices used for measurements should be with battery supply. Measurements should preferably be made during time periods without sky wave propagation and time differences between ON and OFF measurements should be as small as possible.

5.3 Interference with Radio Communication (USKA)

To locate and assess nearby local disturbance sources on HF during periods of low solar activity, it is useful to use higher frequencies in this range, because there the number of transmitters is low due to low sky wave propagation. Therefore, at the beginning, often the spectra on 15 m and 10 m bands were recorded and used for a first assessment. For these spectra often frequencies in the middle of the bands allocated to amateur radio were used. With spectra measured by means of the IC7600, which show the input signal at the receiver, mostly a reference yield of -50 dBm (except for the spectra at 7 MHz: -40 dBm), a RBW of 2.4 kHz, a vertical scale of 10 dB per division and beam direction NE (beam heading directly towards WPT) were used. An **RBW of 2.4 kHz** was chosen in order to see directly the **real impact of the WPT RFI disturbance to SSB operation.** The noise blanker of the IC7600 is very efficient and eliminates nearly all short impulses caused by the nearby farmer's electric fence (at 45 m and more). However, the spectrum analyser FPC1000 from R&S does not have this feature and therefore records all these impulses.

5.3.1 WPT at Charging Location 1 (30 m horizontal Distance to Amateur Antenna 1)

All bands between 3.5 MHz and 29.7MHz (80 m and 10 m) allocated to amateur radio were inspected at least by a careful manual scan. For space limitations, not all spectra can be shown here. All measurements with a distance of 30 m were performed on Aug. 25, 2020 before noon. Fig. 38 to Fig. 41 are examples of these measurements on 15m band. Increasing QRN in the afternoon (example see Fig. 40) made further correct quantitative measurements impossible. These measurements were postponed to Sept. 23, 2020. The measurements in Fig. 38 to Fig. 41 were made with P_{AC} = 2.6 kW.

WPT OFF



***Fig. 38**: IC7600: ID25, 21.2 MHz, Span 200 kHz, BW 2.4 kHz, Max Pk -102 dBm = 5 dBµV*

WPT ON



***Fig. 39**: IC7600: ID10, 21.2 MHz, Span 500 kHz, BW 2.4 kHz, Max Pk -101 dBm = 6 dBµV (Radio traffic on 21.076 MHz)*

WPT OFF

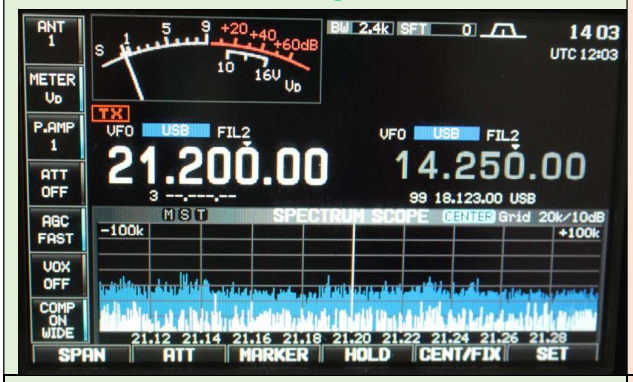


***Fig. 40:** IC7600: ID17, 21.2 MHz, Span 200 kHz, BW 2.4 kHz, Max Pk -90 dBm = 17 dBµV ➔ QRN, too high!*

WPT ON



***Fig. 41:** IC7600: ID10, 21.2 MHz, Span 200 kHz, BW 2.4 kHz Max Pk -101 dBm = 6 dBµV.*

In Fig. 39 there is some radio traffic on 21.076 MHz, i.e. the signal level there is not caused by the WPT. With WPT at a horizontal distance of 30 m from beam antenna (height 17 m), **spectra with WPT ON and OFF are nearly identical**, no audible or in spectra visible interference of WPT on the 15 m band.

5.3.2 WPT at Charging Location 2 (11 m horizontal Distance to Amateur Antenna 1)

Due to the local situation, a minimum horizontal distance of 10 m between the WPT at charging location 2 and amateur radio antenna 1 could not be realized exactly. Therefore, a minimum horizontal distance of 11 m was chosen instead of 10 m. Moreover, for these measurements P_{AC} was 3.7 kW.

5.3.2.1 Tests with IC7600 connected to antenna 1 (Beam)

15 m band (21.0 MHz to 21.45 MHz, P_{AC} = 3.7 kW)

WPT OFF



Fig. 42: *IC7600, ID28, 21.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -105 dBm = 2 dBµV*

WPT ON



Fig. 43: *IC7600, ID27, 21.2 MHz, Span 500 kHz, BW 2.4 kHz, Max Pk -103 dBm = 4 dBµV*



Fig.44: *IC7600, ID28, 21.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -103 dBm = 4 dBµV*



Fig.45: IC7600, ID29, 21.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -103 dBm = 4 dBµV

With WPT at a horizontal distance of only about 11 m from beam antenna, **spectra with WPT ON and OFF are also nearly identical**, there is no audible or in spectra visible interference from the WPT on the 15 m band. Possible remaining very low disturbance signals from the WPT could be buried in the local noise floor.

The overall electrical antenna factor of the 5-el. Beam for 21 MHz is about $\boldsymbol{AF_E = -11\ dB/m}$. With measured values ***V*** (RX input voltage taken from the spectrum) and using the equation $\boldsymbol{AF_E = E/V}$, the E-field at the antenna can be calculated: $\boldsymbol{E = V * AF_E}$ or in dB: $\boldsymbol{E[dB\mu V/m] = V[dB\mu V] + AF_E[dB/m].}$

A typical value according to Fig. 44 and Fig. 45 is V = 4 dBµV, which gives E = -7 dBµV/m [peak value].
Note: For comparison of disturbance, electrical E-fields at antennas of receivers are often indicated in **dBµV/m** and voltages in **dBµV.**

20 m band (14 MHz to 14.35 MHz, P_{AC} = 3.7 kW):

WPT OFF



Figure 46: *IC7600, ID26, 14.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -98 dBm = 9 dBµV*



Figure 48: *IC7600, ID32, 14.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -98 dBm = 9 dBµV*

WPT ON



Figure 47: *IC7600, ID31, 14.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -97 dBm = 10 dBµV*



Figure 49: *IC7631, ID31, 14.2 MHz, Span 500 kHz, BW 2.4 kHz Max Pk -97 dBm = 10 dBµV*

During the measurement there was radio traffic on the 20 m band. Spectra for WPT ON and OFF are still somewhat similar, but there are no obvious differences between the OFF and ON diagrams (Fig. 46 compared to Fig.47 and Fig. 48 compared to **Figure** 49). For determination of the Max Pk values indicated on the figures mostly the value of the Max Pk strip (in blue, without traffic peaks) was used. The Max Peak level is somewhat higher than for the 15 m band. Actual noise level in ranges without traffic is flat and with no audible WPT harmonics. Only noise, no typical harmonics in the gaps between peaks caused by radio traffic. Comparable situation also on 40 m band (see figures below).

40 m band (7.0 MHz to 7.2 MHz, P_{AC} = 3.7 kW) at inverted V Antenna (top at 15 m):

WPT OFF



Figure 50: *IC7600, ID34, 7.098MHz, Span 500kHz, BW 2.4kHz Max Pk -85 dBm = 22 dBµV (Ref. Yield -40dBm)*

WPT ON



Figure 51: *IC7600, ID35, 7.098MHz, Span 500kHz, BW 2.4kHz Max Pk -85 dBm = 22 dBµV (Ref. Yield -40dBm)*

Spectra for LF < 140 kHz (P_{AC} = 3.7 kW) with IC7600 at Antenna 1 (inverted V):

Some tests were also carried out in order to see if some spectra with the fundamental frequency of the WPT equipment can be registered. The allowed band for WPT is 79 kHz to 90 kHz, which is pretty close to frequency of the time reference transmitter DCF77 at 77.5 kHz.

The signal of DCF77 could be easily detected in the spectra (see peaks of about -95 dBm at 77.5 kHz). It could also detected audibly by tuning the receiver in SSB to a frequency around 77.5 kHz because it turns on and off in intervals of 1 s.

In the same spectra there is also a signal at the *fundamental frequency of the WPT* operation. At this antenna it was very weak (about -100 dBm). During this test, the fundamental WPT frequency was about 88 kHz.

WPT Fundamental Frequency and DCF 77 measured with IC7600 at Antenna 1

WPT OFF



Figure 52: *IC7600, ID36, DCF77 on 77.5 kHz, -95 dBm, fundamental frequency of WPT field 88 kHz off. Max Pk of DCF 77 about -95 dBm = 12 dBµV.*

WPT ON



Figure 53: *IC7600, ID35, DCF77 on 77.5 kHz, -95dBm fundamental frequency of WPT field 88 kHz on. Max Pk of WPT ca. -100 dBm = 7 dBµV.*

5.3.2.2 Tests with Spectrum Analyser FPC 1000 connected to Antenna 1 (Beam)

As mentioned previously, at a distance > 45 m of the QTH of HB9AZO there is an electric fence surrounding a grazing field for cattle. This fence is connected to a device creating about every second a short high voltage peak. Therefore, this fence radiates many short impulse disturbances which are picked up by radio amateur antenna 1. While in the IC7600 an efficient noise blanker eliminates nearly all these impulse disturbances, the FPC1000 has not this feature and therefore records all these peaks. Therefore, the spectra do not look very nice because the curves have many very sharp peaks.

An approximation of the development of the undisturbed curves can be obtained by clipping these sharp peaks of the Max Peak Hold curve over 10 s (green) and actual value (yellow) in the Figure 54 and Figure 55. It seems that in the direction of the main lobe of the beam (NE) for this measurement there is probably a PLC or VDSL2 transmission in the neighborhood.

In both spectra the amateur band from 21.0 MHz to 21.45 MHz is notched as it should be according to the requirements of the regulation authority (OFCOM) and the relevant PLC standards. At higher and lower frequencies, the signals are about 20 dB higher and would disturb reception. In Figure 55 the PLC or VDSL2 signals for < 21 MHz are nearly on the same level like in the notch. The full bandwidth of the VDSL2 system is obviously not always used but seems to depend on time or on traffic intensity.

WPT OFF



Figure 54: *FPC1000, ID26, 20.7 – 21.7 MHz , Span 1 MHz, BW 3kHz,*
Max Pk about 4 dBµV at 21 MHz decreasing to 0 dBµV at 21.45 MHz. 15 m Amateur band notched.

WPT ON



Figure 55: *FPC1000, ID29, 20.7 – 21.7 MHz , Span 1 MHz, BW 3 kHz*
Max Pk about 0 dBµV at 21 MHz decreasing with frequency to -3 dBµV at 21.45 MHz. 15 m Amateur band notched.

5.3.2.3 Tests with IC-705 on Antenna 2 (home brewed Loop) at 10 m distance from WPT

WPT OFF

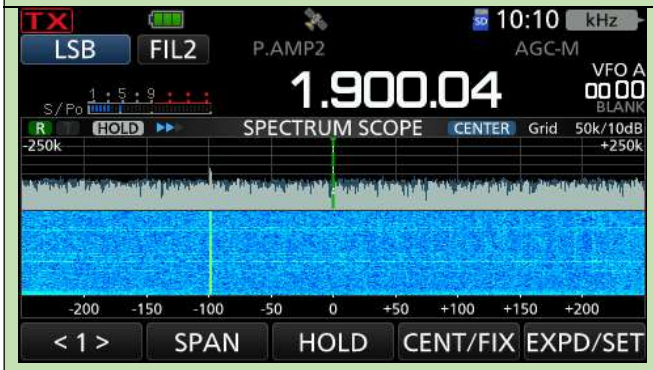


Figure 56: *IC705, 1.900 MHz, Span 500kHz, BW 2.4k. Measured with home-brewed Loop Antenna (circumference 2m), antenna factor unknown.*

WPT ON

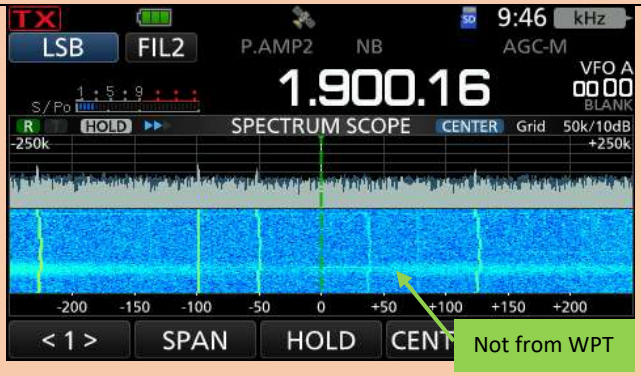


Figure 57*: IC705: 1.900 MHz, Span 500kHz, BW 2.4kHz. Measured with home-brewed Loop Antenna (circumference 2m), antenna factor unknown.* ***Visible: Harmonics f_{21}, f_{22} and f_{23}.***

WPT OFF

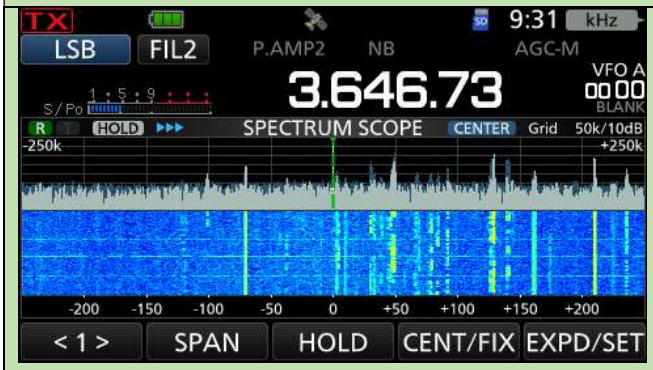


Figure 58: *IC705, 3.647 MHz, Span 500kHz, BW 2.4k. Measured with home-brewed Loop Antenna (circumference 2m), antenna factor unknown.*

WPT ON

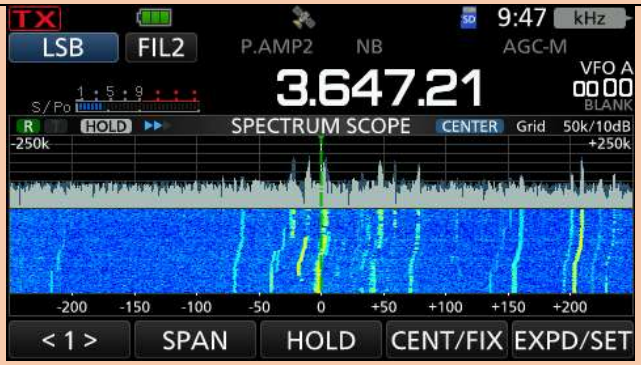


Figure 59: *IC705, 3.647 MHz, Span 500kHz, BW 2.4k Measured with home-brewed Loop Antenna (circumference 2m), antenna factor unknown.*

As the ordinary antennas of the station were large in proportion to the distances to the WPT, additional measurements on the lower bands (1.8 MHz – 2 MHz) and 3.5 MHz – 3.8 MHz with a home brewed loop antenna (circumference about 2m) and the IC 705 were also carried out. Unfortunately the antenna factors of this antenna were unknown, therefore a direct comparison with measured H-field values was not possible. However, it could be used as a qualitative indicator of harmonics, see fig. 56 to 59.

Only in fig. 56 and fig. 57, the spectra for 1.900 MHz, for WPT OFF and WPT ON some signals for WPT ON can be recognised as harmonics of the WPT basic frequency f_1.

For basic frequency f_1 = 88 kHz (see figure 53):

- for n=21 -> f_{21} = 1850 kHz
- for n=22 -> f_{22} = 1938 kHz
- for n=23 -> f_{23} = 2026 kHz.

In the 2 MHz band the background emission floor regularly surpassed the signals generated by the WPT system on a broad-spectrum disturbance (marked in fig. 57 with a green arrow).

6 More Detailed Discussion of the Measurement Results obtained

6.1 Near Field and Far Field Definitions for Electromagnetic Fields

Because of the size of the corresponding wavelength λ, disturbance emissions of HF frequencies < 30MHz are often measured by magnetic loop antennas, which are considerably smaller than λ, and the radiated magnetic fields H-field emissions are indicated in dBμA/m.

However, for comparison of performance of receivers and assessments of the receiving situation at antennas, voltages V at receiver inputs are often indicated in dBμV and electrical E-field intensities at antennas are often indicated in dBμV/m.

Depending on the distance d between disturbing source and receiver (centre of receiving antenna), three different regions of the electromagnetic field around a disturbance source are distinguished: The far field (distance d > 2λ), the transition region with $\lambda/2\pi$ < d < 2λ and the near field with d < $\lambda/2\pi$, see fig. 60 below.

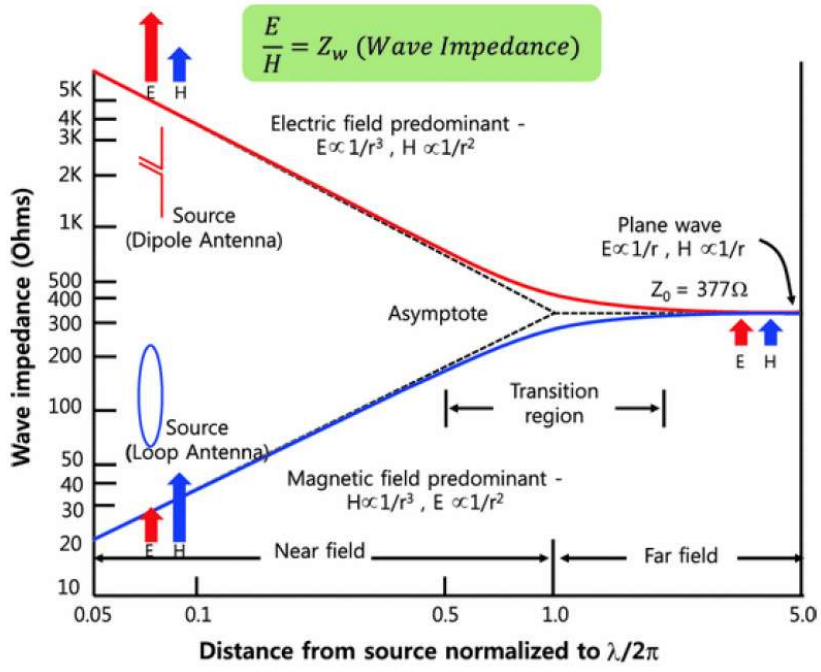


Figure 60:
Wave impedance Z_W in near field, transition region and far field depending on the normalised distance $\lambda/2\pi$ between the source and the receiver [6], [4].

During the measurements with antenna 1 and the IC7600, the slant distance between the WPT at charging location 2 and the antenna 1 was about d = 20 m (antenna height 17 m, horizontal distance 11 m). The WPT seen by the antenna was about at an angle of 57° below horizontal (see figure 9). The analyzed disturbing WPT frequencies were between 7 MHz and 30 MHz, i.e. all in the transition region. In this region, the wave impedance Z_W is already pretty close to 120 Ω = 377 Ω (see figure 60).

For λ = 10 m: near field limit: $\lambda/2\pi = 1.68$ m.
For λ = 15 m: near field limit: $\lambda/2\pi = 2.25$ m.
For λ = 20 m: near field limit: $\lambda/2\pi = 3.36$ m.

6.2 Relation between H-Field and E-Field in the far Field

In the far field (distance d > 2λ , i.e. relatively far away from the transmitter (here the WPT)), H-fields in dBµA/m can be converted into E-fields in dBµV/m by using the simple equation **$E = Z_W * H$.**

(Note: Z_W = 120 Ω = 377 Ω (wave Impedance of free space)).

This equation can also be written in dB: → **E[dBµV/m] = 20 Log(377) dB/m + H[dBµA/m]**

→**E[dBµV/m] = 51.5 dB/m + H[dBµA/m]**.

With a somewhat reduced accuracy, these relations can also be used already in the upper range of the transition region close to the beginning of the far field (see Fig. 60).

If measured H-field intensities are converted to corresponding E-field intensities by simply using the formula above, one often gets relatively high E-field intensities, with which a significant disturbance would be expected (see Fig. 20 to Fig. 37). A measured H-field intensity of -10 dBµA/m would result in a high E-field intensity of 41.5 dBµV/m, an H-field intensity of -35 dBµA/m would result in an E-field intensity of still 16.5 dBµV/m. However, in the Figures 43, 44 and 45 in chapter 5.3 it can be seen that voltages at the receiver input down to V = 4 dBµV with a corresponding E-field value of noise down to -7 dBµV/m could be registered on 15 m. Therefore this simple approach is not appropriate for the situation of this amateur radio station.

The actually measured E-field values at antenna 1 were much lower than the values that could be calculated by using the simple approach given above.

6.3 Some Antenna Theory to Explain the Difference

In order to understand better what really happens, in the present case a somewhat deeper analysis of the situation is needed, by using some antenna theory, in order to estimate if the results obtained make sense and are not opposed to field theory. It is also necessary to consider the influence of the different bandwidth and detection modes used for the E- and H-field measurements.

During practical measurements of many noise signals (e.g. white noise, sounding like a waterfall), Max Pk values are often roughly a few dB higher than QP values. On the other hand, measurements of such noise signals with a BW of 2.4 kHz (or slightly rounded also 3 kHz) are often roughly a few dB lower than measurements with a BW of 9 kHz used in standards. Therefore, as a very rough approximation, in this report it is assumed for simplification that QP values at 9 kHz can be approximately compared with Max Pk values at 2.4 kHz or 3 kHz. Of course, this rule of thumb can be used only **as *a very rough approximation***, which is not always correct, especially for special cases with stable harmonics. As mentioned in Chapter 5.2, some additional errors in the registered QP-values might also be caused by the disturbances due to the voltage impulses on the nearby electrical fence of the farmer's grazing field. This was really bad luck, because a few months later the fences were removed and the field prepared for other crops in the coming year, i.e. the disturbance was gone.

The spectra shown in chapter 5.3 show voltages vs. frequency. For converting voltages V to corresponding E-field intensities at the antenna, the following relations are useful:

→ **E[dBµV/m] = V[dBµV] + AF_E[dB/m]** and also → **V[dBµV] = E[dBµV/m] - AF_E[dB/m]**

where AF_E = E/V = Electrical Antenna Factor of the antenna (< 0 dB for HF).

Electrical antenna factor AF_E-values for beam antenna 1 used (including cable losses):
For 10 m: AF_E = -9 dB/m, for 15 m: AF_E = -11.5 dB/m, for 20 m: AF_E = -13.5 dB/m.
As for most examples the 15m band is used, mostly **AF_E = -11.5 dB/m** is used for these calculations (see examples in chapter 6.4).

Tentative explanations for the reasons for the differences between measured and calculated values:

a) The slant distance D between WPT and the centre of antenna 1, horizontal distance 11 m, 17 m above the ground, is about 20 m instead of 10 m used for the measurements with the magnetic loop antenna (→ **Distance Attenuation** A_D = 6 dB). If the horizontal distance is 30 m instead of 11 m, the slant distance is increased to 32 m (→ **Distance Attenuation** A_D = 10 dB).

b) The sensitivity of the beam antenna 1 for disturbances from the WPT is certainly reduced, because disturbance signals from the WPT are not received in the direction of the highest beam gain (beam heading), but in the direction of a side lobe, which is inclined by an angle α (57° for horizontal distance 11 m, 30° for horizontal distance 30 m) below the plane of the yagi beam antenna. This reduction of sensitivity can be taken into account either by using an angle dependent AF_E or by using a fixed AF_E–value for the direction of maximum antenna gain (beam heading) and introducing a new quantity called side lobe attenuation **A_{SL}**, which takes into account this reduction of the sensitivity. In the present report this second possibility is used:
→ There is is **an additional side lobe attenuation A_{SL}** on the signal arriving from the WPT. **A_{SL}** depends on the angle α between the direction of this side lobe and the plane of the beam antenna. Depending on α, A_{SL} can vary between about 0 dB and the front to back ratio A_{FB} of antenna 1.

For the antenna 1 (FB DX 660) the manufacturer Fritzel indicates on his data sheets a front to back ratio A_{FB} of 18 dB for 14 MHz, 22 dB for 21 MHz and 16 dB for 28 MHz.

Note: For omnidirectional vertical antennas (e.g. like λ/4 ground plane antennas) mounted close to the ground, the side lobe attenuation **A_{SL}** according to b) will probably be very low. Stations using such antennas will be much more likely disturbed by WPT-EV disturbances. On the other hand, this effect (increasing antenna height) can be used to reduce disturbance problems caused by nearby disturbance sources close to the ground.

6.4 Some Example Calculations for Spectra on 21 MHz and 14 MHz

After these general considerations example estimations for 21 MHz and 14 MHz can be tried. ***Due to lack of more details, for simplicity for H and E maximum values of X-, Y- and Z-values are used:***

For 21 MHz and horizontal distance of 30 m from WPT location 1 to centre of antenna 1:

According to Fig. 24, Fig. 30 and Fig. 36 the measured disturbance in the 21 MHz band is not higher than H_{10} = -33 dBµA/m in a distance of 10 m from the WPT (noise limit of test equipment). As a worst case, it shall be assumed that all this disturbance comes from the WPT, i.e. the WPT disturbance in a distance of 10 m would be H_{10} = -33 dBµA/m.

In a horizontal distance of 30 m and an antenna height 17 m, the slant distance is D = 32 m and therefore the distance attenuation A_D is 10 dB. The corresponding magnetic field intensity would be **$H_{32} = H_{10} – A_D$ = -43 dBµA/m**. Due to the relatively low value of the angle α = 30° in this case, the side lobe attenuation A_{SL} is also moderate (assumption: 12 dB). The H-field can now be converted into a corresponding = E-Field by adding 51.5 dB: **$E_{32} = H_{32}$ + 51.5 dB** = **8.5 dBµV/m** at the centre of the antenna 1. However, for the calculation of the antenna voltage **V** only the effective component **E_{BH}** of E_{32} in the in direction of the beam heading must be used, i.e. **A_{SL} must be subtracted from E_{32}**. For this effective component we obtain **$E_{BH} = E_{32} - A_{SL}$ = -3.5 dBµV/m.** Or in short form:

E_{BH}[dBµV/m] = 51.5 dB/m + H_{10}[dBµA/m] - A_D - A_{SL} = 51.5 dB/m -33 dBµA/m – 10 dB – 12 dB

→**E_{BH}[dBµV/m] = -3.5 dBµV/m**.

For 21 MHz the Electrical Antenna Factor is AF_E = -11.5 dB/m. Therefore V at antenna 1 becomes**:**

Corresponding voltage at antenna 1 is **V[dBµV] = E_{BH}[dBµV/m] - AF_E[dB/m] = 8 dBµV.**

There is a fairly good correlation with V = 6 dBµV calculated from the values in Fig. 39 and Fig. 41.

For 21 MHz and horizontal distance of 11 m from WPT location 2 to centre of antenna 1:

According to Fig. 24, Fig. 30 and Fig. 36 the measured disturbance in the 21 MHz band is not higher than H_{10} = -33 dBµA/m in a distance of 10 m from the WPT (noise limit of test equipment). As a worst case, it shall be assumed that all this disturbance comes from the WPT, i.e. the WPT disturbance in a distance of 10 m would be H_{10} = -33 dBµA/m.

In a horizontal distance of 11 m and an antenna height 17m, the slant distance is D = 20 m, and therefore A_D is only 6 dB. Due to the higher value of the angle α = 57° the side lobe attenuation A_{SL} is significantly higher, e.g. 18 dB. Therefore the corresponding magnetic field intensity is **$H_{20} = H_{10} – A_D$ = -39 dBµA/m**. This H-field can be converted into a corresponding E-Field by adding 51.5 dB: → **E_{20} = 12.5 dBµV/m** at the centre of the antenna 1. From this value, the side lobe attenuation A_{SL} (assumption: 18 dB for this situation) must be subtracted, which results in an effective **E_{BH}** (E-field-component in direction of beam heading) at antenna 1 of **E_{BH} = -5.5 dBµV/m**. Or in short form:

E_{BH}[dBµV/m] = 51.5 dB/m + H_{10} [dBµA/m] - A_D – A_{SL} = 51.5 dB/m -33 dBµA/m – 6 dB -18 dB

→ **E_{BH}[dBµV/m]** = **-5.5 dBµV/m**.

Corresponding voltage at antenna 1 is V[dBµV] = E_{BH}[dBµV/m] - AF_E[dB/m] = 6 dBµV.

There is a fairly good correlation with V = 4 dBµV calculated from the values in Fig. 43 and Fig. 45.

For 14 MHz and horizontal distance of 11 m from WPT location 2 to centre of antenna 1:

As there was some sky-wave propagation on 14 MHz and the time difference between the measurements of WPT OFF and WPT ON was up to about an hour, strong signals from measurements at 14 MHz cannot be clearly attributed to the WPT. Therefore the evaluation on 14 MHz is mainly based on relatively low signals for WPT OFF and WPT ON without prominent peaks.

According to Fig. 23, Fig.29 and Fig. 35 the measured disturbance of the WPT in the 14 MHz band is about H_{10} = -32 dBµA/m in a distance of 10 m from the WPT.

In a horizontal distance of 11 m and an antenna height 17 m, the slant distance is again D = 20 m and therefore A_D is again 6 dB. Therefore, for a distance of 20 m the magnetic field intensity is **$H_{20} = H_{10} - A_D$ = -38 dBµA/m.** Due to the somewhat lower directivity of the yagi beam on 14 MHz compared to 21 MHz, with the same value of the angle α = 57° the side lobe attenuation A_{SL} is probably also somewhat lower, assumption: **A_{SL} = 14 dB**.

This H-field can be converted into a corresponding E-Field by adding 51.5 dB → **E_{20} = 13.5 dBµV/m** at the centre of the antenna 1. From this value, the side lobe attenuation A_{SL} (assumption: 14 dB for this situation) has to be subtracted, which results in an effective **E_{BH}** at the antenna 1 of **-0.5 dBµV/m**. For 14 MHz the Electrical Antenna Factor is AF_E = -13.5 dB/m. Therefore:

Corresponding voltage at antenna 1 is V[dBµV] = E_{BH}[dBµV/m] - AF_E[dB/m] = 13 dBµV.

There is a fairly good correlation with V = 10 dBµV calculated from the values in Fig. 47 and Fig. 49.

In the calculations above, the disturbance signals used were very low. Figure 31 is the only spectrum with a clear distinction of about 1.5 dB between disturbance signals with WPT ON and OFF. Therefore it makes sense to assume that the disturbance signal was mostly a little lower than the level of the internal system noise. If as the worst case it is assumed, that the WPT disturbance is on the internal noise level, this would mean that the estimated real disturbance signal from the WPT in the system is somewhat lower (i.e. by a few dB) than the internal system noise, but the exact value is masked (otherwise it would be visible). Due to this assumption, in this report one is on the safe side for a rough estimation of the resulting WPT disturbance using the internal noise level in the spectra.

For the side lobe attenuations also rough assumptions were made, real values can certainly be up to a few dB higher or lower. Again the assumption that the real WPT disturbance level is lower than the lower noise limit makes sense. If it is actually lower (which is mostly the case), assumed A_{SL} values somewhat higher or lower than what they are in reality still ensure that the resulting disturbance is hidden in the noise level in the spectra at the receiving station.

There are other reasons why these calculations can only have a limited accuracy and mainly show, if the results obtained are not too far away from reality given by antenna theory:

- Negligence of influence of ground properties and reflexions:
  OFCOM's test antenna close to ground (h<< λ), antenna 1 much higher over ground (h > λ/2 and more).
- Possible Influence of different polarisation between emissions of WPT and antenna 1.
- Influence of antenna size compared to λ → different distance from WPT to antenna parts:
  Assumption: Distance d between WPT and antenna 1 is always measured to centre of antenna 1.
  This is correct for relatively small antennas like OFCOM's test antenna forming a loop.
  But for antenna 1 this is not correct for all parts of the antenna, there are different distances to different parts of the antenna (especially close to ends of elements).
- Indirect comparison of measured H-field QP-values with BW 9 kHz with calculated E-field Max Pk values with BW of 2.4 kHz.
- For electrical antenna factor AF_E values for full sized elements were used for elements with traps (all elements of beam antenna 1 had traps (parallel resonance circuits in the somewhat thicker parts of the elements to ensure multiband performance)).
- The time difference of measurements between WPT ON and WPT OFF (up to an hour, see Fig. 16) reduced the accuracy and significance of the measurements.
- WPT transfer power during the test was mostly only 2.6 kW instead of 7 to 11 kW (more realistic for future EVs in residential zones). Such WPT devices with the same design and higher power are likely to have somewhat higher emissions.

The calculations shown are certainly not exact, but only an estimations based on reasonable assumptions. They should give an idea, where the differences observed might come from. However, they show that the measured values of H- and E-fields, which were measured by two different teams and different methods, make sense. At other locations with different antennas and antenna positions other differences may result and other correction factors could be necessary.

The main differences between the simple approach described in chapter 6.2 and the more detailed example calculations in 6.4 is the introduction of the attenuation factors A_D (influence of distance) and A_{SL} (side lobe attenuation). Using reasonable values for these two factors would probably improve quick estimations of disturbance conditions in other cases.

6.5 Recapitulation of Reasons and Results of this Project

In course of repeated discussions about WPT limits between members of the Swiss national CISPR committee, the idea was born to obtain practical measurement results at a location with a typical amateur radio station with moderate equipment owned by one of the members (HB9AZO), where there were good possibilities for interference measurements with WPT sources at distances between 10 m and 30 m. The situation of this location (see chapter 4) was similar to a typical situation in the UK shown in fig. 2 in [1] or fig.31 in [2]. These measurements were especially interesting, because besides the measurements with amateur equipment, also a professional measuring team from BAKOM (Swiss OFCOM) kindly made measurements at the same time. As mentioned before, besides all the tests, which are described in detail in chapter 5.2 and 5.3, also manual scans with a bandwidth (BW) of 2.4 kHz (mode: LSB for f < 10 MHz, USB for f > 10 MHz) on the entire bands 80 m, 40 m, 30 m, 20 m, 17 m, 15 m, 12 m and 10 m were carried out. The EMC noise generated by the operating WPT system at frequencies above 150 kHz was comparable to (or even lower than) the observed background emission. Therefore, no clear distinction between the two conditions, i.e. WPT system ON or OFF, could be made. As announced earlier in the report from BRUSA, in this report the EMC group of USKA is presenting additional information and assessment of the results.

6.6 Final Conclusions from the Amateurs' Point of View

In this project not only theoretical calculations about disturbances from WPT were made, but real measurements at an active Amateur Radio Station in a typical residential environment, which has been owned and operated successfully for more than 37 years by the project leader. The available equipment and the noise situation was certainly not perfect, but typical for a middle class amateur radio station.

Two independent groups of measurement were performed. On Aug. 25, 2021 a team of two EMC specialists of the Swiss OFCOM performed H-Field measurements in the LF, MF and HF ranges with their professional equipment, which is used in case of complaints about EMC disturbances. At the same time, a team of two radio amateurs from USKA (HB9AZO and HB9BKT) made measurements with an ICOM transceiver IC7600 (SSB audio, with noise blanker and internal spectrum analyzer) and an external spectrum analyzer FPC1000 from R&S (no audio, without noise blanker) at antenna 1. On Sept. 23, some additional measurements were carried out by the USKA team in order to fill missing gaps and ensure reproducibility of the test results.

Result of all these tests:

In the configuration and at the location described in this report in chapter 4.2.1, no interference caused by the WPT mentioned to the receiver of the amateur radio station could be registered. However, this result cannot be generalized, it is only valid for the actual situation (e.g. antennas, positions, distances, receiver properties) and the environmental conditions there.

As far as EMC is concerned, the WPT-EV used for these tests is an important progress for the developing team involved. It can be concluded, that for a peaceful coexistence of WPT-EV and amateur radio, the limits for radiated disturbances in the HF bands (3 MHz to 30 MHz), which are actually discussed in standardisation committees, can be significantly tightened (i.e. lowered by at least 20 dB). Industry is capable to supply viable solutions!

6.7 Ideas for future further Tests and Improvements

- **Improvement of Measurement Procedure / Time Synchronisation at WPT ON and OFF:**
  Make the time difference between measurements of WPT ON and WPT OFF periods as close to each other as possible (fraction of minutes instead of up to an hour).
  However, it must be made sure that the WPT is given enough time for power ramp up and down.

- **Measurements at Locations with lower Background Noise and with other Antennas.**
  Perform similar tests at other amateur radio stations **at locations with lower background noise** and omnidirectional **vertical antennas** (e.g. $\lambda/4$ ground plane) at the same ground level like the WPT EV under test. An RX station at a remote farmhouse several 100 m from other buildings and electrically active structures (e.g. windmills) with an independent power supply (e.g. PV with battery storage) would be ideal.

- **Effect of Increase of WPT Transfer power**
  Increase of WPT transfer power to **7 kW or 11 kW** for faster charging and measure the impact on EMC.

- **Increase of Interference by several nearby WPTs**
  Measurements of the resulting increase of total disturbance in case of **several simultaneous charging WPT EVs** in the neighbourhood of an amateur radio station [3].

7 Important Notice

Information contained in this report is believed to be accurate. Measurements shown were performed partly with professional, but mainly with amateur equipment at a typical amateur radio station by experienced amateur radio operators.
The equipment was calibrated and checked as best we could by means of several independent measurement devices, but of course cannot have the accuracy of very accurate calibrated laboratory equipment. This means that absolute errors up to several dB are possible.

Therefore, any liability in a legal sense for correctness and completeness of this information or for any damage that might result from its use is formally disclaimed.

8 Measuring Staff

The following persons were present during the measurements on Aug. 25, 2020:

- Alfred Furrer (Electrosuisse)
- Carlo Compare (Electrosuisse)
- Emmanuel de Raemy (BAKOM/OFCOM)
- Hansrudolf Spring (BAKOM/OFCOM)
- Dr. Heinrich Häberlin (USKA, Project Lead, HB9AZO)
- Lukas Böhler (BRUSA Elektronik AG)
- Dr. Urs Lott (USKA, HB9BKT)

On Sept. 23, 2020 additional measurements were performed by a reduced team:

- Dr. Heinrich Häberlin (USKA, Project Lead, HB9AZO)
- Lukas Böhler (BRUSA Elektronik AG)
- Dr. Urs Lott (USKA, HB9BKT)

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