Measurements of conducted and radiated emissions from solar panel installations

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Titel	Mätningar av ledningsbunden och utstrålad emission från solcellsinstallationer
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Sammanfattning

Rapporten sammanfattar resultat från mätningar på solcellsanläggningar som genomfördes i Bergshamra i Solna under 22–23 juni 2021. Solcellsanläggningar i tre bostadsrättsföreningar omfattades och samtliga var uppbyggda på samma sätt med solcellspaneler med optimerare.

Emission från solcellsanläggningar har tidigare stört radiokommunikation och syftet med mätningarna var att kartlägga hur emission från solcellsanläggningar kan uppträda.

Mätningar gjordes både på ledningsbunden och utstrålad emission. Ledningsbunden emission mättes för frekvenser 10 kHz–200 MHz och utstrålad emission för 10 kHz–1 GHz. Mätningar genomfördes när växelriktare i anläggningarna var på- respektive avslagna. De ledningsbundna mätningarna visade att även om växelriktaren är avslagen så finns signaler i anläggningen. När växelriktaren var på genererades ett antal karaktäristiska signaler som var repetitiva i frekvens, exempelvis med 200 kHz mellanrum. Dessa signaler fanns även i flera av emissionsmätningarna på olika frekvensband. De uppmätta störningsnivåerna varierade för de olika frekvensbanden, de olika installationerna och de olika mätplatserna, men visade på en tydlig ökning då växelriktaren slogs på.

Nyckelord: solceller, EMC, EMI, störningar, emissionsmätning

Summary

The report summarizes results from measurements at photovoltaic systems that were carried out in Bergshamra in Solna during 22–23 June 2021. Photovoltaic systems in three tenant-owner associations are covered and all were using optimizers at the solar panels.

Emissions from photovoltaic systems have previously disrupted radio communication and the purpose of the measurements was to map how emissions from photovoltaic systems can occur.

Measurements were made on both conducted signals and radiated emissions. Conducted signals were measured for frequencies 10 kHz–200 MHz and emission for 10 kHz–1 GHz. Measurements were carried out with inverters in the facilities both on and off. The conducted measurements showed that even if the inverter is turned off, there are signals in the system. When the inverter was on, a number of characteristic signals were generated which were repetitive in frequency, for example at 200 kHz intervals. These signals were also present in several of the emission measurements on different frequency bands. The measured disturbance levels varied for the different frequency bands, the different installations and the different measuring points, but showed a clear increase when the inverter was switched on.

Keywords: photovoltaic systems, PV, EMC, EMI, interference, radiated emission measurement

Contents

1 Introduction

Solar cell systems have been shown to generate electromagnetic emissions that can interfere with, for example, nearby radio receivers. In order to quantify the emissions and investigate the cause of interference problems, measurements need to be performed. The overall experience so far is that the interference levels can differ considerably between different facilities. The reason for this is that a solar cell system both can have different constituent components with diverse EMC properties and installed with different layouts and cabling. Measurements is a way to gain knowledge of how the type of components and the type of installation affect the levels of disturbances.

This report presents in-situ measurements from several different photovoltaic (PV) systems. The facilities are located in three different tenant-owner associations in Bergshamra outside Solna. Common to all facilities is that the panels are equipped with optimizers on each individual solar panel on the roof, a construction that has previously been shown to cause significant interference problems. Both conducted and radiated emissions have been measured for a number of different cases and geographical locations. The conducted emissions was measured from 10 kHz up to 200 MHz and the radiated emissions were measured up to 1 GHz. Measurements were carried out of an installation where the inverter is first on and then off, to compare the resulting conducted and radiated emission from the installation. At the measurements, the Swedish National Electrical Safety Board were present and operated the solar installations/inverters.

There are several reasons why a PV system can generate electromagnetic emissions, which can then create interference in radio systems. The system often consists of large amounts of cabling and, in a typical installation a number of panels are connected in a closed loop. This loop can, in worst case, function as a loop antenna that radiates any wired interference (from, for example, inverters and optimizers). To avoid this, cable installations should be carried out to minimize the “antenna properties” of the wiring, including use of twisted cables. It is also of great importance to limit as much as possible the amount of conducted interference in the DC wiring, among other things by using suitable filters on wiring that goes from inverters to panels to avoid interference caused by the switched electronics finding its way into DC loops. Another reason why this type of plant can create disturbances is that EMC standards rather regulate EMC emissions from components and do not cover requirements for entire plants. In the latest version of CISPR 11 (EN55011:2016), requirements on the DC-side of inverters are included, but optimizers are still not covered.

Examples of interference incidents on radio receivers include disturbance of digital radio and TV (DAB and DVB-T) and mobile systems [1, 2]. In the Netherlands, the ambient noise increases of 10–15 dB at daytime compared to at night have been reported for frequencies used by the communication system for emergency services (C2000) [3, 4]. Radio amateurs reported problems early, mainly in the HF band, but also at other frequencies.

This report does not include from analyses of the impact on different communication systems, but frequency bands for some important communication systems are included in the measurements. Some examples are: 380–400 MHz for the emergency service radio Rakel; the shortwave band 1–30 MHz for, among other things, military communication; and aircraft radio communication at 118–136 MHz.

2 Measurement setup

The measurement setup, measurement equipment and measurement cases are described in this chapter.

2.1 Measurement equipment

For the measurements, a measuring receiver was used together with three different antennas for the radiated emission measurements and a current probe for the conducted emission measurements. Cables and various other equipment was also used for the measurements. Details of the measuring equipment is given in this section. The measurement results are compensated for all gains, losses and antenna factors/k-factor for the used equipment.

2.1.1 Measuring receiver – R&S ESRP

The measuring receiver used is of the model ESRP from Rohde & Schwarz (R&S), with serial number 20-300450811. The measuring receiver was used in receiver mode, which means that preselection filters were used to filter out interference from other frequency bands. The receiver was used in time-domain mode, which is based on FFT and measures several frequencies simultaneously. In time-domain mode, the receiver automatically divides the current frequency range into several sub-bands that are measured sequentially. The FFT method usually leads to considerably shorter measurement times than frequency-sweeping measurements. This also means that the measurement of all sub-bands does not take place simultaneously and since the measured signal can vary rapidly (due to movements of the measuring object or varying signal environment), measurements of different sub-bands can have abrupt shifts in signal level. Similar problems exist, of course, for a sweeping spectrum analyzer as well, but then the change takes place continuously over frequency, which does not create as abrupt shifts in measured levels.

2.1.2 Antennas

Below is a list of the antennas used to measure field strength in each frequency range, as well as their sensitivity. The frequency range in parentheses is the range in which the antenna is used in the measurements. The antennas in Table 1 are antennas with known antenna factors, of which the two first are calibrated measuring antennas.

Table 1. Calibrated measurement antennas used in the measurements.

Model	Frequency range	Sensitivity
R&S HFH2-Z2, active loop antenna	9 kHz–30 MHz (10 kHz–30 MHz)	Figure 1
ETS Lindgren 3104C, biconical antenna	20–200 MHz (30–200 MHz)	Passive
R&S HL023, log-periodic antenna	80–1300 MHz (200–1000 MHz)	Passive

2.1.2.1 Loop antenna – R&S HFH2-Z2E

For the lower frequencies, an active loop antenna from Rhode &Schwarz of type HFH2-Z2E was used. The antenna covers the frequency range 9 kHz to 30 MHz and is powered by a IN600 Bias Unit from Rhode & Schwarz. The sensitivity of HFH2-Z2 is shown in Figure 1 and the antenna factor is presented in Figure 2 from the calibration at Rhode & Schwarz 2021-04-30.

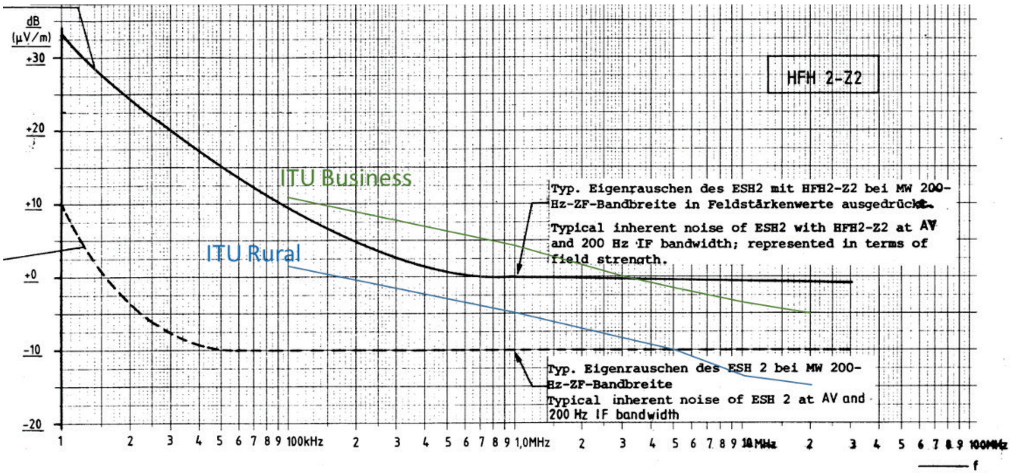

Figure 1. HFH2-Z2 noise factor. The solid black line indicates the noise factor of the antenna together with the receiver ESH2. The dashed line indicates the noise factor for only ESH2. (Source: Manual Loop antenna HFH2-Z2, Rohde & Schwarz, 335.5347)

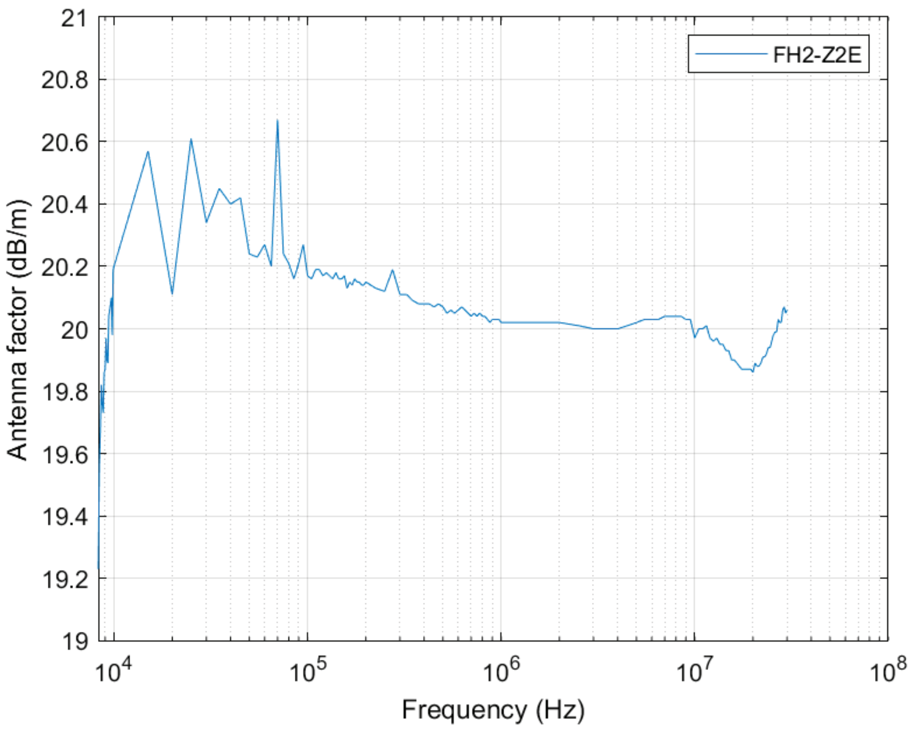

Figure 2. Antenna factor for loop antenna HFH2-Z2E.

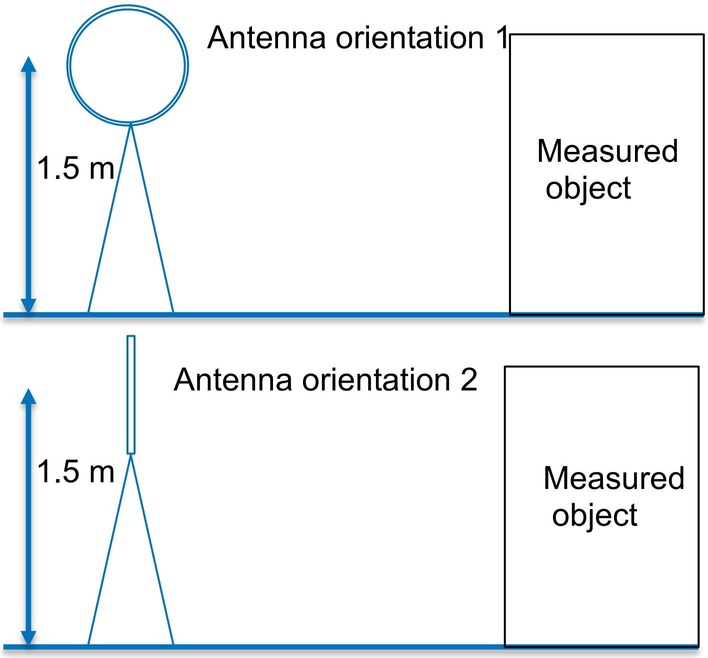

Figure 3. Antenna orientation 1 and 2 for the loop antenna.

During the measurements, the antenna was used in two orientations see Figure 3.

2.1.2.2 Biconical antenna – ETS Lindgren 3104C

For frequencies between 30 and 200 MHz, a calibrated antenna from ETS Lindgren of type 3104C was used. The antenna factor is shown in Figure 4.

2.1.2.3 Log-periodic antenna – R&S HL023-A1

For frequencies above 200 MHz a log-periodic antenna from Rhode & Schwarz of type HL023-A1 was used. The antenna factor is shown in Figure 5.

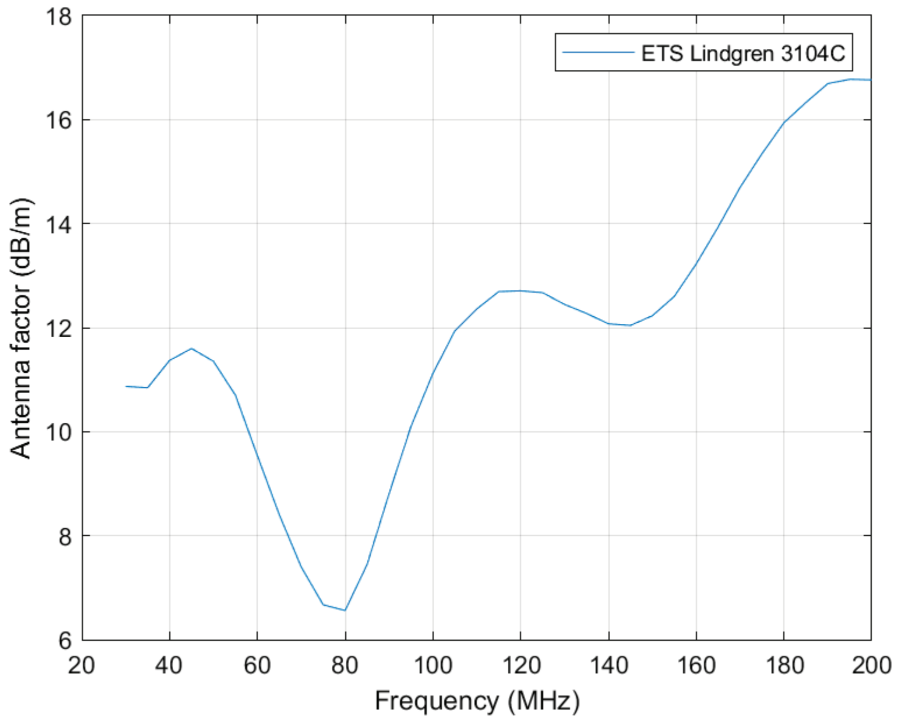

Figure 4. Antenna factor for the biconical antenna ETS Lindgren 3104C.

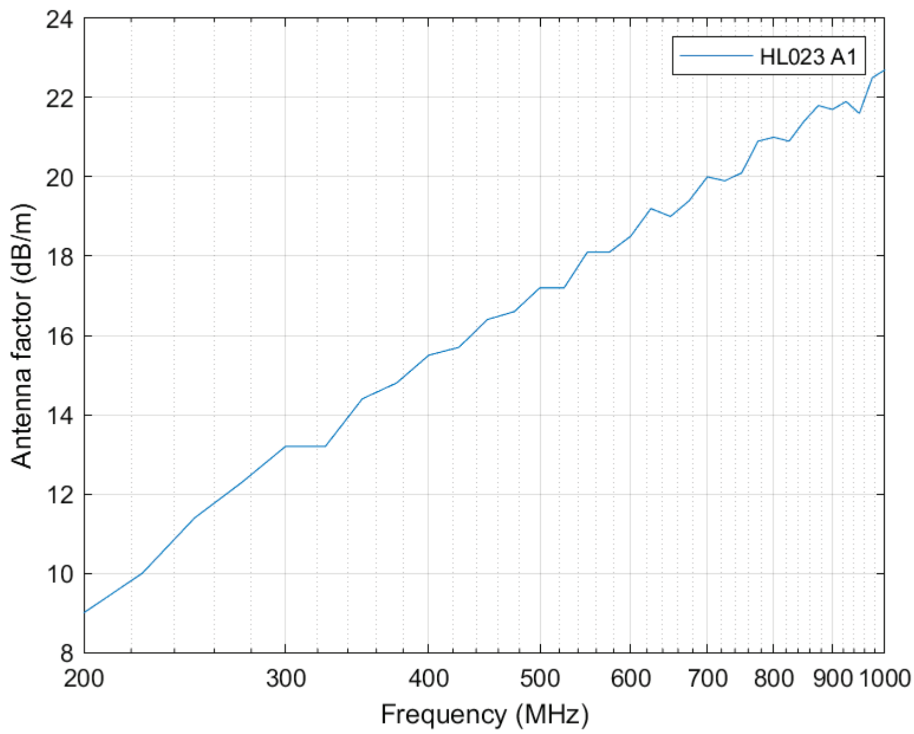

Figure 5. Antenna factor for the log-periodic antenna HL023 A1.

2.1.3 Other equipment

For some of the measurements other equipment as a preamplifier, current probe and a filter were used.

2.1.3.1 Preamplifier – Schwarzbeck BBV 9744

A broadband preamplifier from Schwarzbeck of the type BBV 9744 was used in some of the measurements with the passive antennas for frequencies 30 MHz–1 GHz. The preamplifier has a frequency range of 9 kHz–6 GHz.

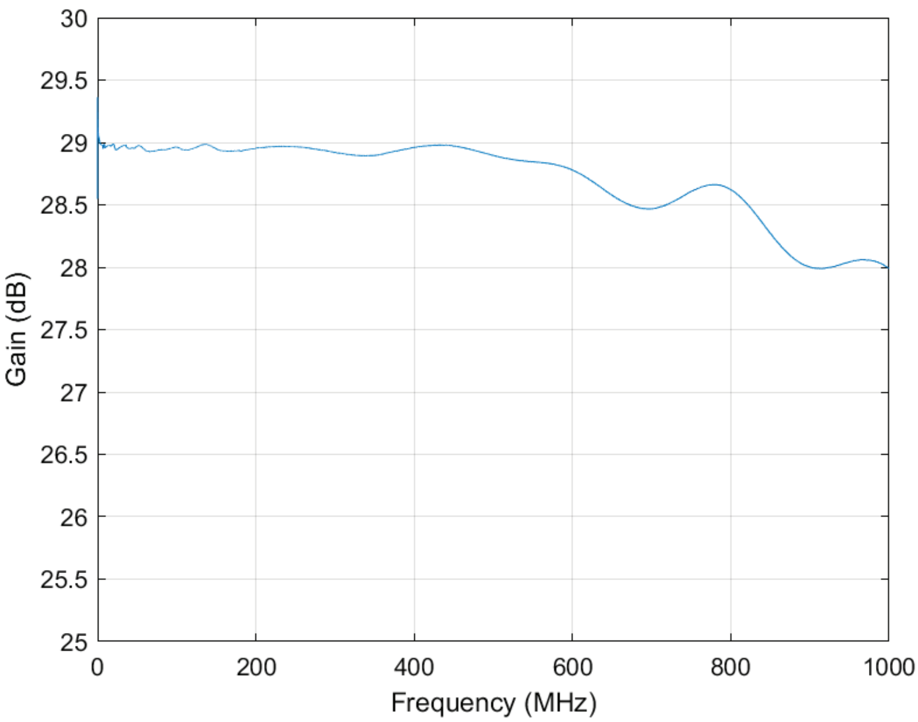

Figure 6. Measured gain for BBV 9744

2.1.3.2 Current probe – R&S EZ-17

When measuring conducted emissions, an EZ-17 current probe from Rohde & Schwarz with serial number 100379 was used. The current probe was calibrated by Rohde & Schwarz on 11 Dec 2018, for the frequency range 20 Hz–200 MHz, see Figure 7.

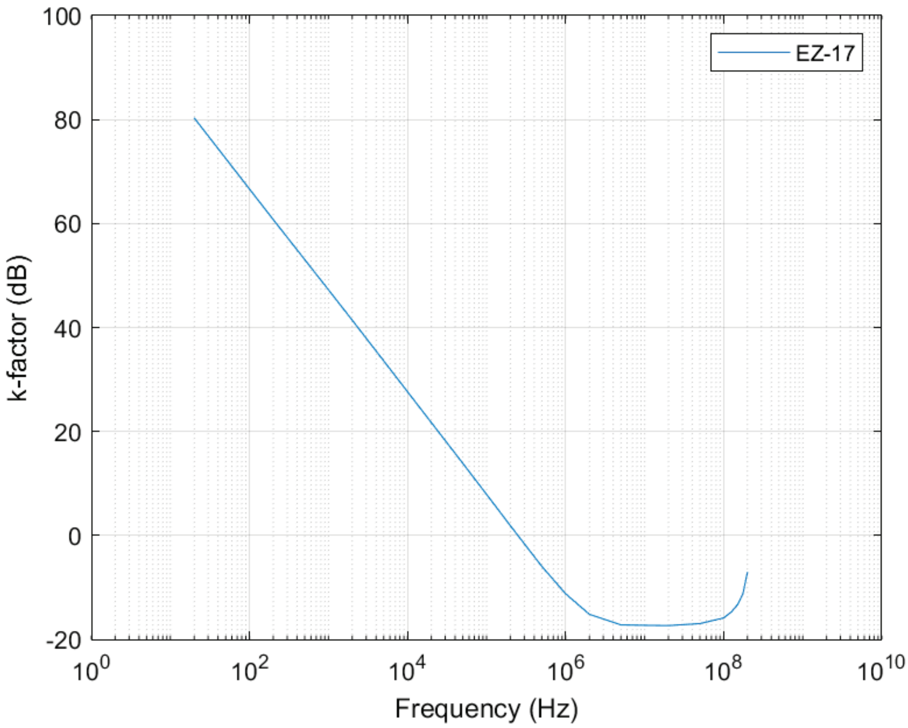

Figure 7. K-factor for the current probe EZ-17.

2.1.3.3 FM filter – NSBP-108+

When measuring emission for frequencies over 30 MHz, an FM filter was used to filter out strong radio transmissions to avoid that the preamplifier or measuring receiver was overloaded.

The filter used was an NSBP-108 + Band Stop Filter 88–108MHz from Mini-Circuits. Gain for the filter is shown in Figure 8.

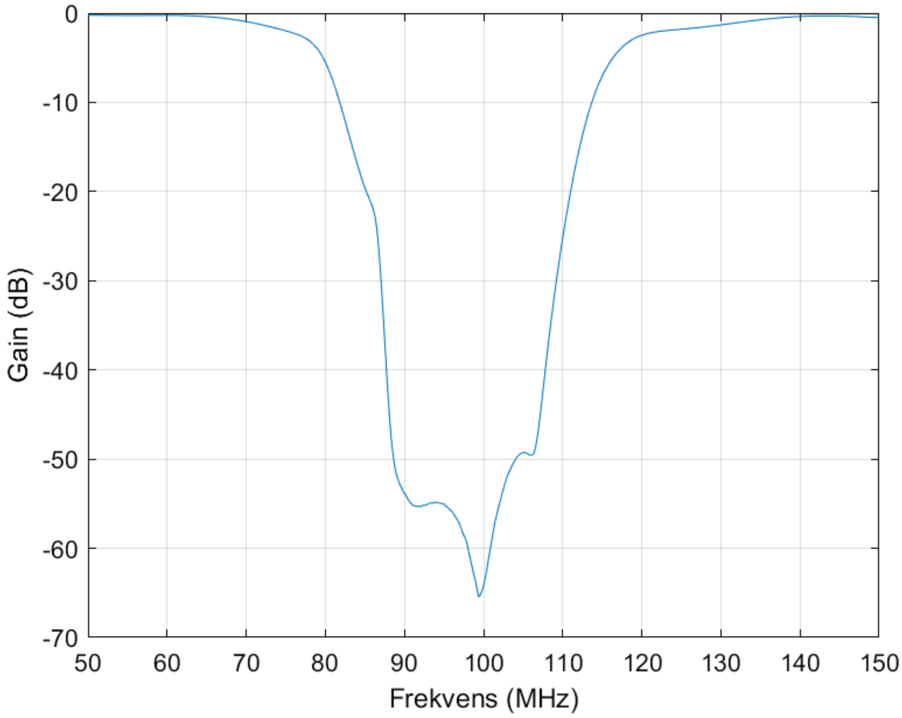

Figure 8. Measured gain for FM-filter NSBP-108+.

2.1.4 Cables

Coaxial cable was used between antennas and measuring receivers. In the measurements, cables were used according to the table below. Losses for these cables have been measured and the presented results are calibrated with these losses.

Table 1. Cables used in the measurements.

Measurement antenna	**Cable**
HFHF2-Z2E	LMR400 (50 m), RG400 (1 m)
ETS-Lindgren 3104C	LMR400 (15 m)
HL023-A1	LMR400 (15 m)

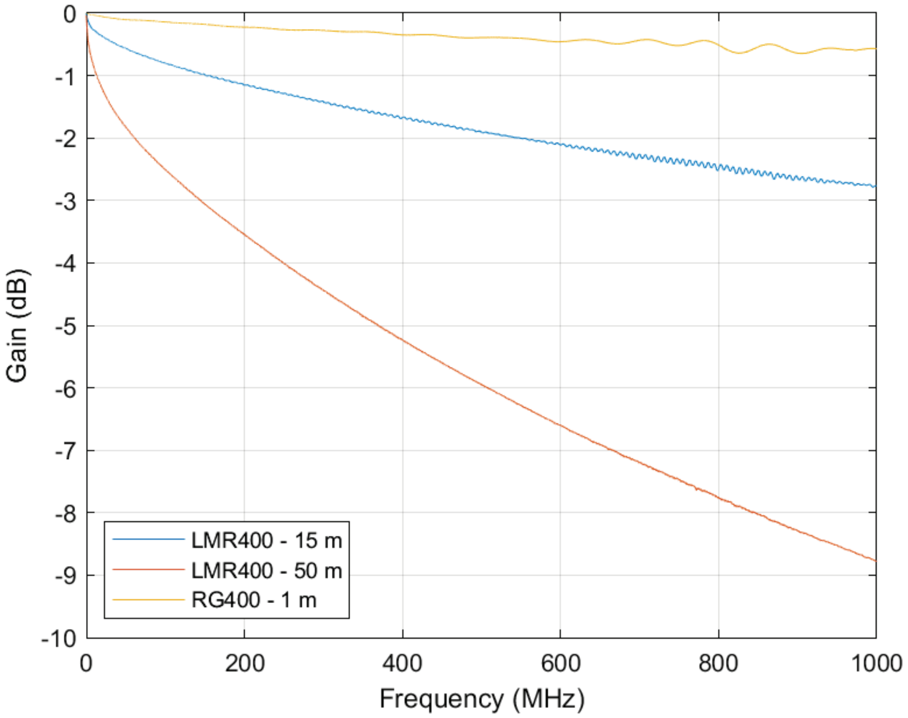

Figure 9. Measured gain for used cables.

2.2 Frequency range and measurement bandwidths

At the measurements, measurement settings according to Table 2 were used for radiated emission and according to Table 3 for conducted emissions. The measurement bandwidths were adapted to common bandwidths in communication systems. The measurement time is the time to measure a specific sub-band, i.e. the time that a FFT is performed on. To measure the total frequency range takes longer time. The specified measurement times are those used in a majority of the measurements, but were changed for some measurements.

Table 2. Measurement settings for radiated emission.

Frequency range	Bandwidth	Measurement time	Antenna
10 kHz–1 MHz	200 Hz	100 ms	Loop
1 MHz–30 MHz	3 kHz	100 ms	Loop
20 MHz–200 MHz	30 kHz	50 ms	Biconical
200 MHz–1 GHz	30 kHz	100 ms	Log-periodic

Table 3. Measurement settings for conducted emissions.

Frequency range	Bandwidth	Measurement time	Probe
10 kHz–1 MHz	200 Hz	100 ms	EZ-17
1 MHz–100 MHz	3 kHz	100 ms	
100 MHz–200 MHz	30 kHz	50 ms (100 ms)	

2.2.1 Data registration

The measuring receiver, ESRP, was controlled from a program on a connected laptop. For each measurement, a frequency range and settings were chosen, according to Table 2 or Table 3.

For each measurement, the frequency range was measured a number of times, usually 10 times, and the result was saved both as a spectrogram and in a result file.

The spectrogram consists of several sweeps for the Peak detector, for example for 10 sweeps. In the result file, the max hold was saved for the detectors Peak and RMS, which means that the highest value during the different sweeps was saved for each frequency and detector. Clear / write for the Peak detector (i.e. the last sweep) was also saved. The current settings used in the measurement was also saved.

2.3 Measurement cases

It was desirable to carry out a measurement when as much as possible of the PV installation was turned off and then measure again with the PV installation in full operation. The motivation was to be able to determine what was caused by the plant itself in operation and not by other disturbance signals present in the surroundings. Unfortunately, the optimizers could not be turned off completely; it was only possible to turn off the inverter. When the inverter was turned off, the optimizers were partially running (but delivered a maximum of 1 V) and during these measurements it was observed that some communication takes place regularly.

The two measurement cases are for the inverter turned off and with the inverter turned on. For some the measurements, all inverters in the area were turned off and then, systematically turned on, one at a time.

2.4 Measurement site and date

The measurements were carried out in Bergshamra in Solna during 22–23 June 2021, that hade alternating sunny and cloudy weather.

Mikael Alexandersson, Sara Linder and Kia Wiklundh from the Swedish Defence Research Agency performed the measurements with valuable help from Rolf Källkvist from the Swedish National Electrical Safety Board.

In total, solar cell facilities in three tenant-owner associations were included, BRF Bladet, BRF Bergshamra gård and BRF Brunnsviken. All solar cell installations had the same type of equipment from SolarEdge.

BRF Bladet had solar panels on the roofs of the buildings at Barks väg 6–16, furthest north in Figure 12. There were solar panels on the roofs of the five high buildings and also on a lower building, with inverters in each building.

BRF Bergshamra gård had solar panels on the southeast side of the building at Pipers väg 147–163, with the inverter placed in the laundry room at Pipers väg 167. There were also solar panels at the roof at the building at Carl Malmstens väg 40–50, with the inverter on the outside wall of no. 40.

BRF Brunnsviken had solar panels at two buildings at Bergshamra allé 43–49 and 175.

Figure 10. Photo of the area. (Source: Lantmäteriet).

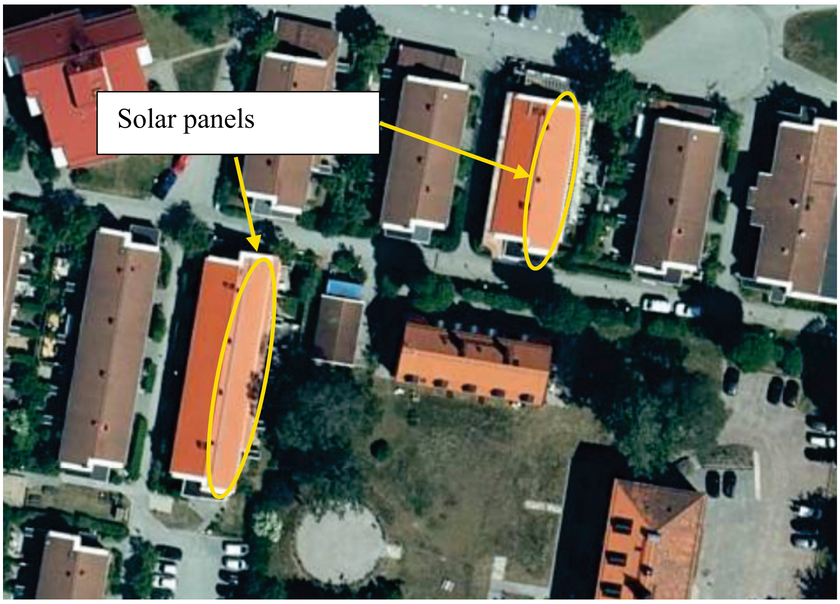

Figure 11. Photo of BRF Bergshamra gård. (Source: Lantmäteriet).

Figure 12. Photo of BRF Brunnsparken. (Source: Lantmäteriet).

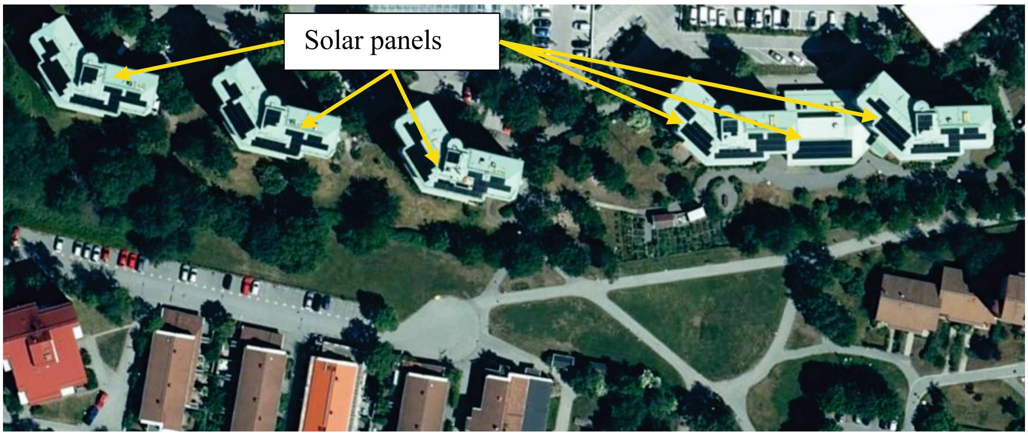

Figure 13. Photo of BRF Bladet. (Source: Lantmäteriet).

3 Measurement results

3.1 Conducted measurements

Conducted measurements were performed on two occasions on two different inverters. On Tuesday 2021-06-22, measurements were performed on the inverter located on Pipers väg 167 belonging to the photovoltaic plant on Pipers väg 147–163. On Wednesday, the inverter on Bergshamra allé 43–49 was measured.

The conducted measurements were performed with the current probe around one or two conductors. The measurements were on the DC-side of the inverter, i.e. on the conductors from the inverter to the panels on the roof. In the case with two conductors, the orientation of them was the same or opposite to give results proportional to common and differential mode noise, respectively.

Measurements were carried out both with inverters on and off. The measurements that in some figures are called background are measured with the inverter turned off, although the optimizers are not completely turned off.

3.1.1 Frequency range 10 kHz–1 MHz

This section presents results for conducted measurements in the frequency range 10 kHz to 1 MHz. Figure 14 shows the measured current with a current probe around a conductor for two different conductors, 1 and 2, to the inverter in BRF Bergshamra gård compared to the same type of measurement of an inverter in BRF Brunnsviken.

The same type of measurement was performed with the inverter turned off in Bergshamra gård and is called Background. During the measurements, it is clear that emissions with certain frequency content appears throughout the band. Figure 15 shows a magnification for 10–100 kHz. It can be seen that there are two clear frequency peaks around either 58 or 73 kHz. There are also a 16.7 kHz peak and multiples of that frequency. These are also clearly visible in Figure 14 in the entire frequency band, especially for the measurements in Bergshamra gård. There is also a peak at 200 kHz and multiples of the frequency, i.e. at 200, 400, 600 kHz and so on. In addition, there are also peaks at 100, 300, 500, 700 kHz, etc., but these are weaker than those at multiples of 200 kHz and are not visible at the higher frequencies for the inverter in Brunnsviken. The multiples of 200 kHz are visible for all measurements with the inverter on.

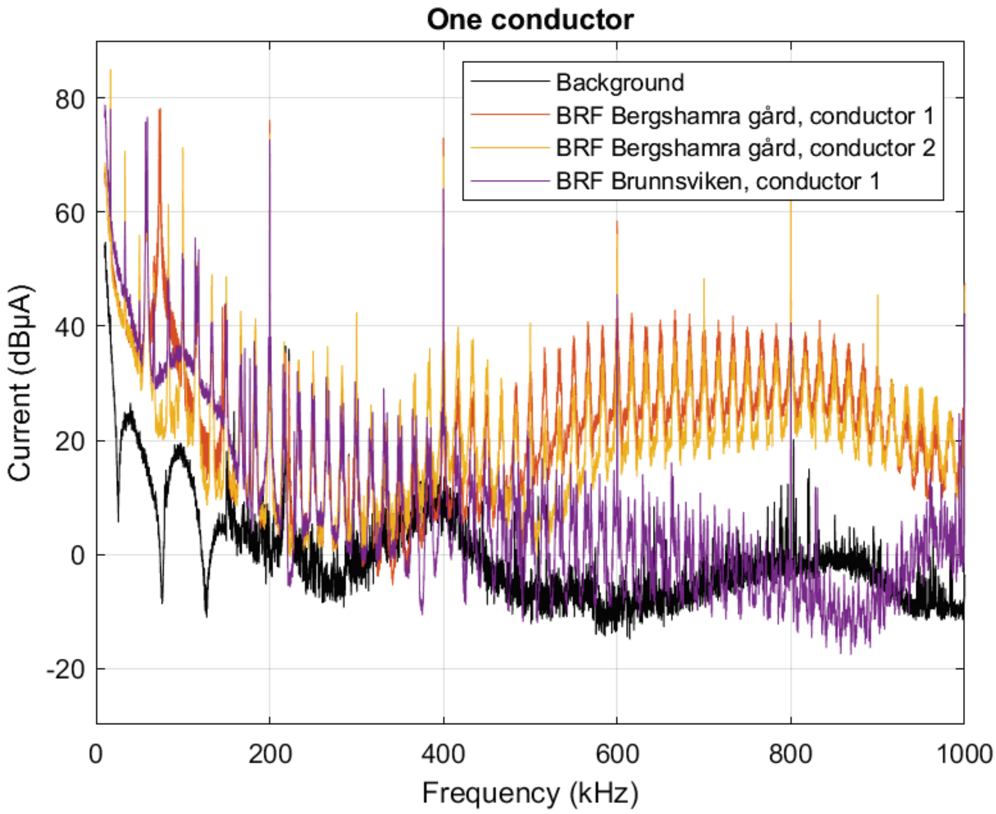

Figure 14. Measurement around one conductor with inverter on.

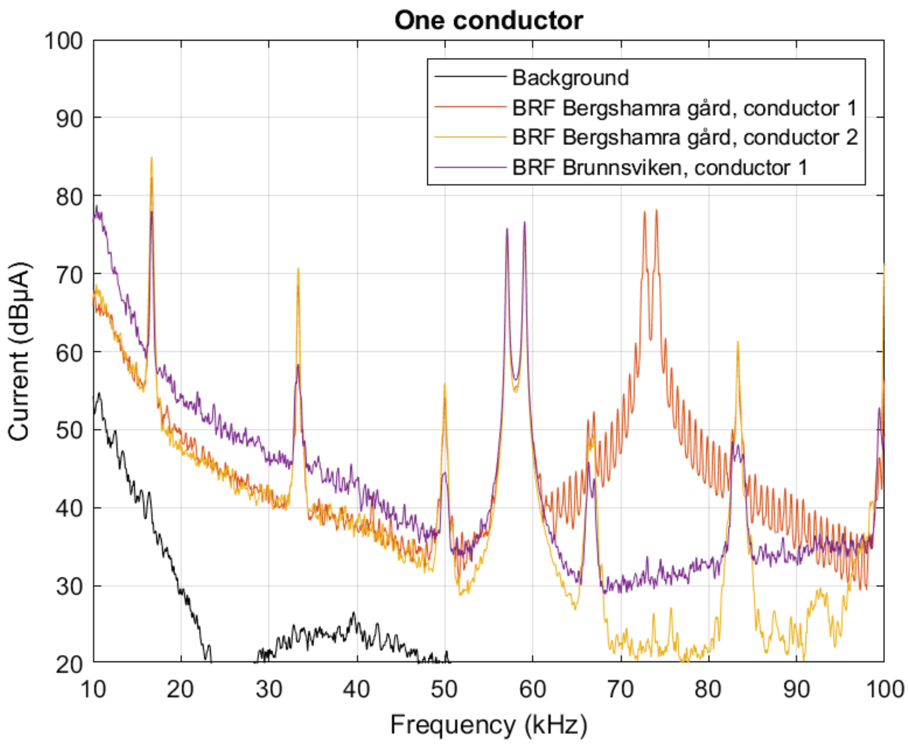

Figure 15. Magnification of the frequency range 10–100 kHz of the measurements in Figure 14.

Figure 16 shows measurements when the inverter was turned off. It is clear that there are signals in the system even when the inverter is turned off. There are two peaks around 73 kHz that are especially clear and that are visible at multiples of the frequency. However, the components at multiples of 100 and 200 kHz that were clear when the inverter was on are not visible. Here, the measurement in Brunnsviken shows the highest levels at low frequencies. The measurements in Bergshamra gård are reported in chronological order and the first measurement is only after the inverter has been turned off. In one of the measurements, a clear jump is seen just below 600 kHz, which is probably due to a short-term disturbance during the time that the sub-band was measured.

Figure 17 and Figure 18 show measurements with the current probe around two conductors and thus proportional to common mode. Figure 17 shows results with the inverter turned on and the behaviour is broadly the same as when measuring around one conductor (Figure 14). The same repetitive disturbances with multiples of 16.7, 100 and 200 kHz are found in the measurements. For low frequencies below 250 kHz, however, the levels of the repetitive 16.7 kHz peaks are lower. Figure 18 shows results when the inverter is turned off and there are clear emissions also for this case.

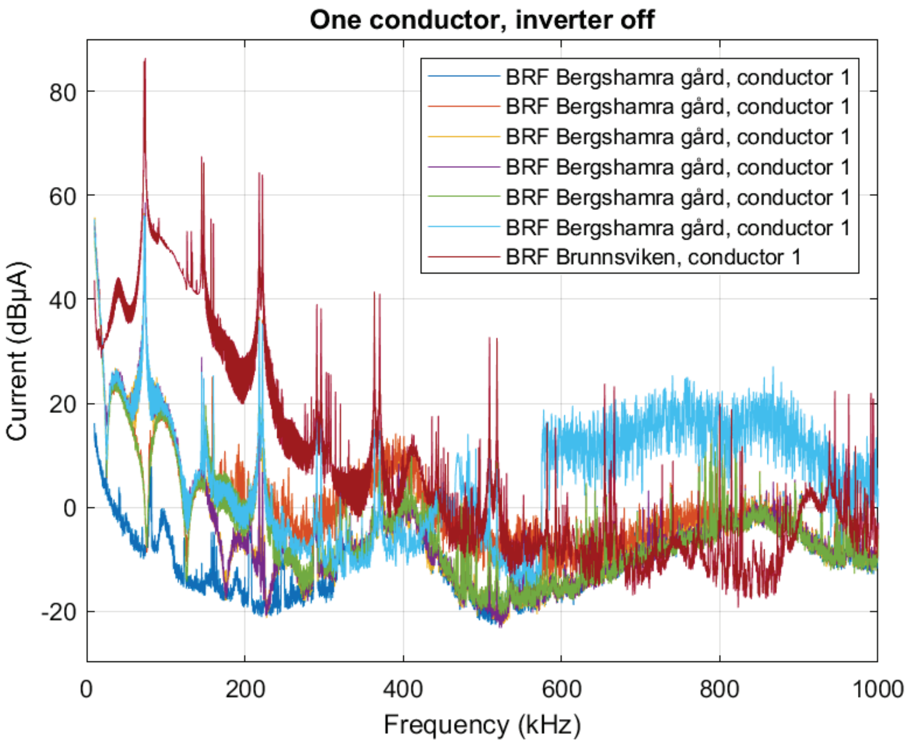

Figure 16. Measurement around one conductor with inverter off.

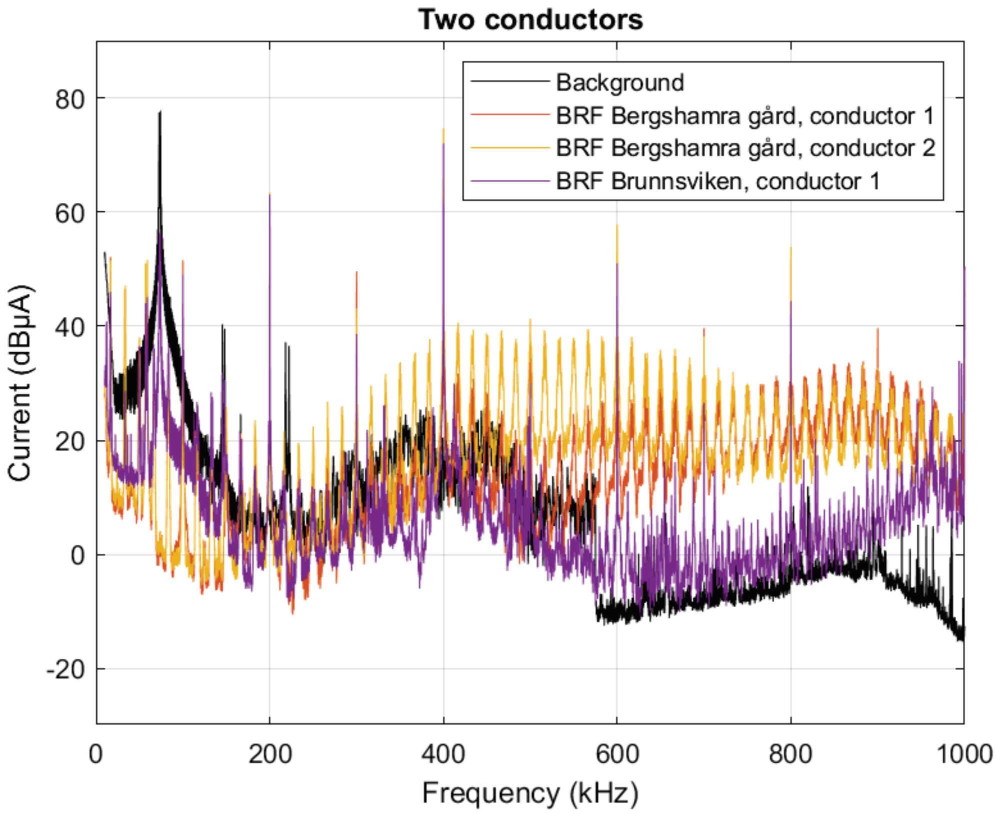

Figure 17. Measurement around two conductors with inverter on.

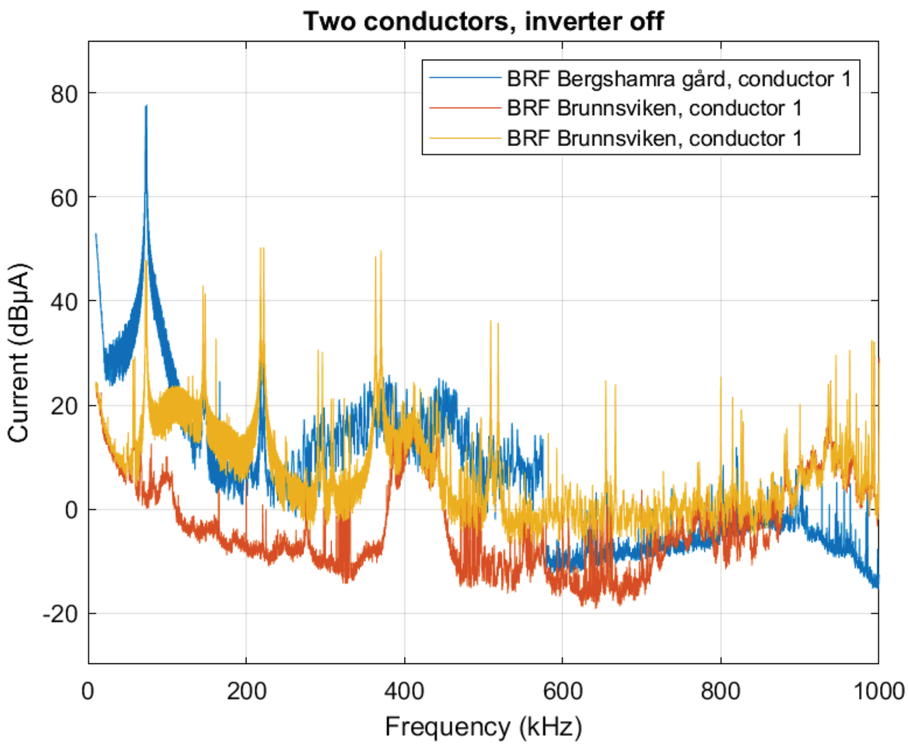

Figure 18. Measurement around two conductors with inverter off.

Figure 19 and Figure 20 also show measurements with the current probe around two conductors but with one conductor in the opposite direction to measure the current proportional to the differential mode. The measurements largely correspond to the measurements made around one conductor (Figure 14) in terms of both frequency content and levels of the emissions. One difference is that the peaks at 100 kHz, 300 kHz etc are higher when measuring the differential mode (around two conductors with one twisted) than when measuring one conductor. The results from when the inverter is turned off also correspond to the previous measurement cases, with a peak of 73 kHz and at multiples of that frequency in some measurements.

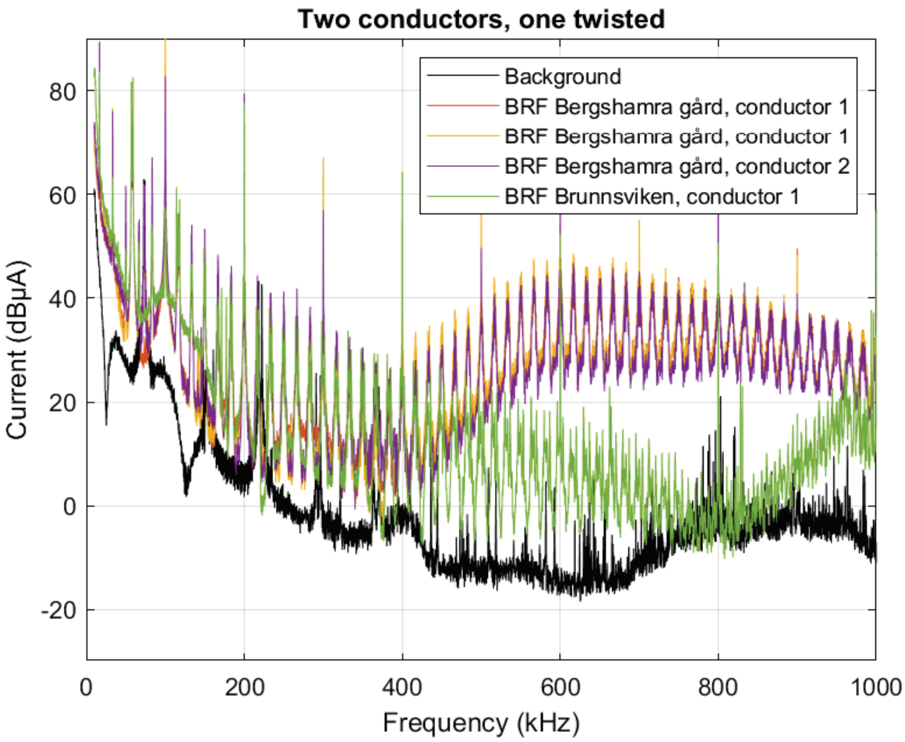

Figure 19. Measurement around two conductors, one of which is in the opposite direction, with inverter on.

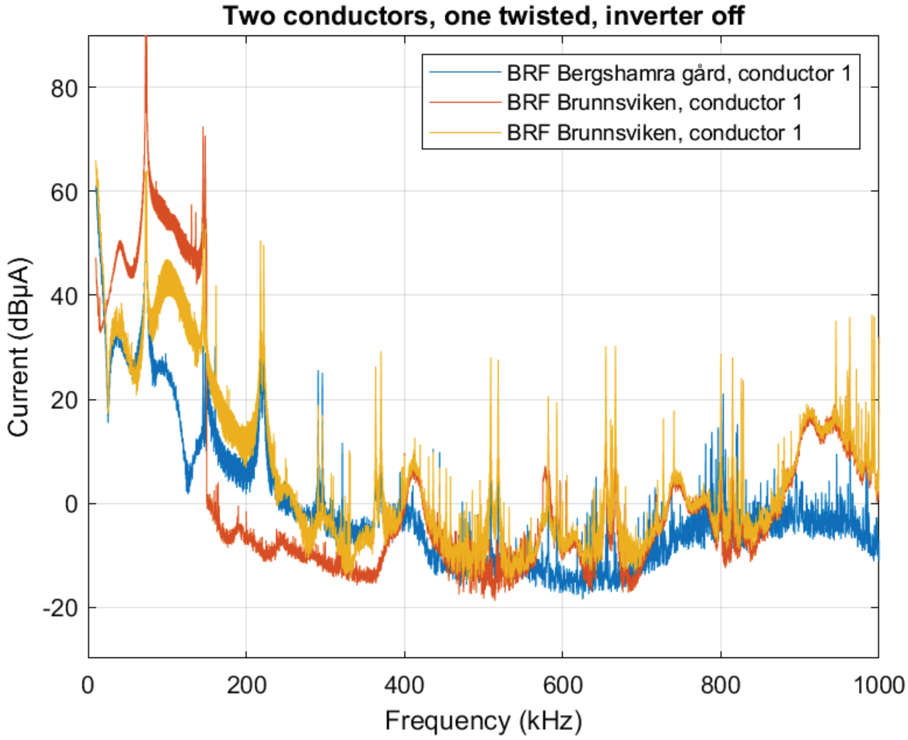

Figure 20. Measurement around two conductors, one of which is in the opposite direction, with inverter off.

Figure 21 to Figure 23 show spectrograms for measurements around one conductor with inverters on and off, respectively. Figure 21 shows 10 sweeps when the inverter is on and the repetitive disturbances of 16.7 and 200 kHz are seen continuously over time, while the peak around 73 kHz is only present at a few times. When the inverter is off, the measured levels are lower and the strongest emissions are relatively short in time.

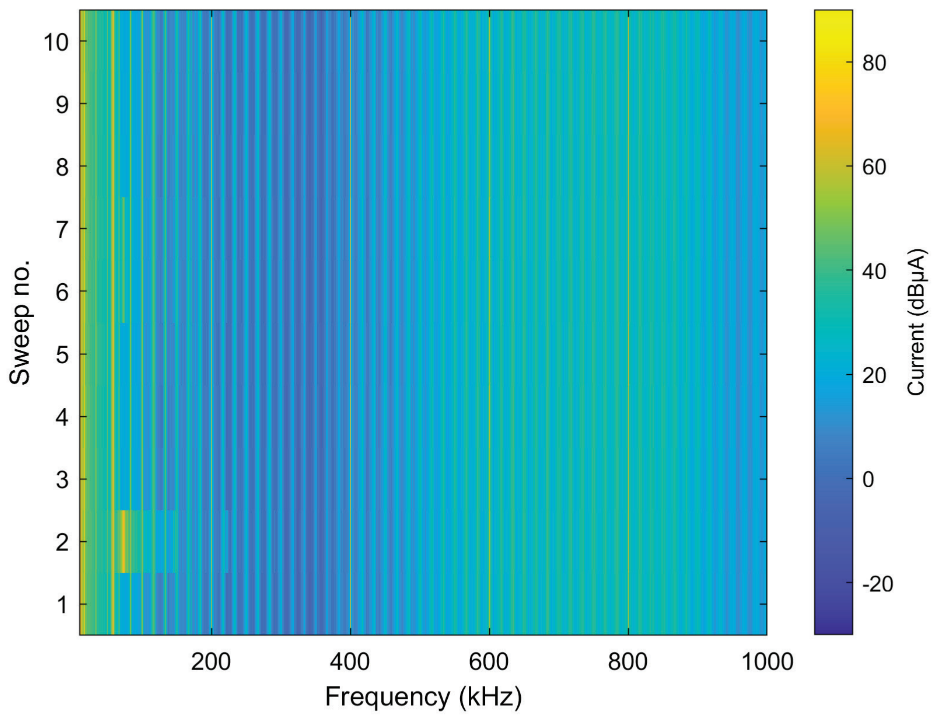

Figure 21. Spectrogram for measurement around one conductor with inverter on.

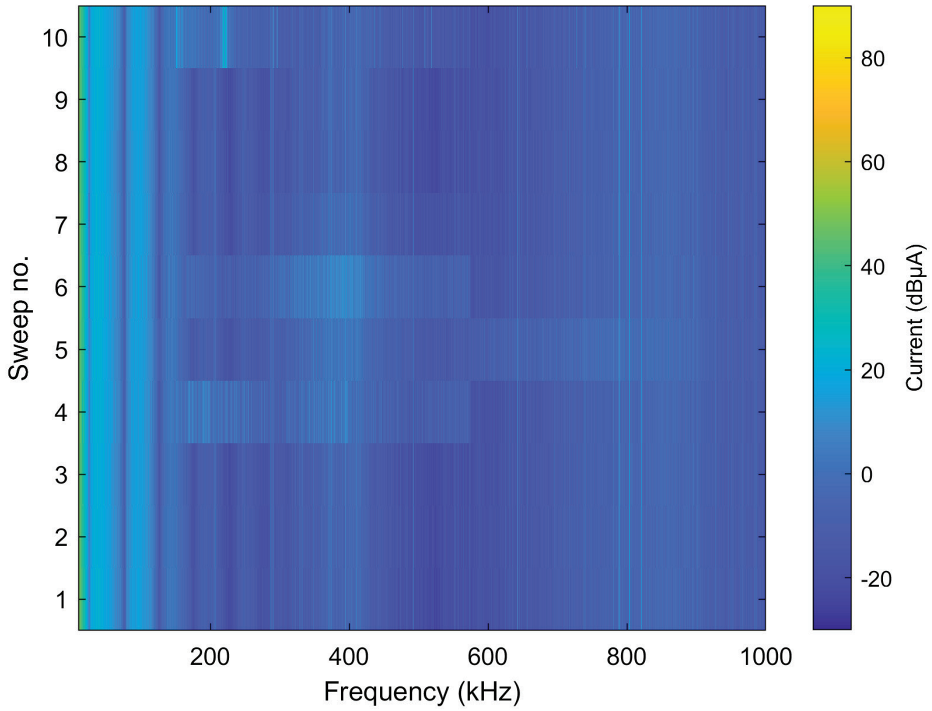

Figure 22. Spectrogram for measurement around one conductor with inverter off (used as background).

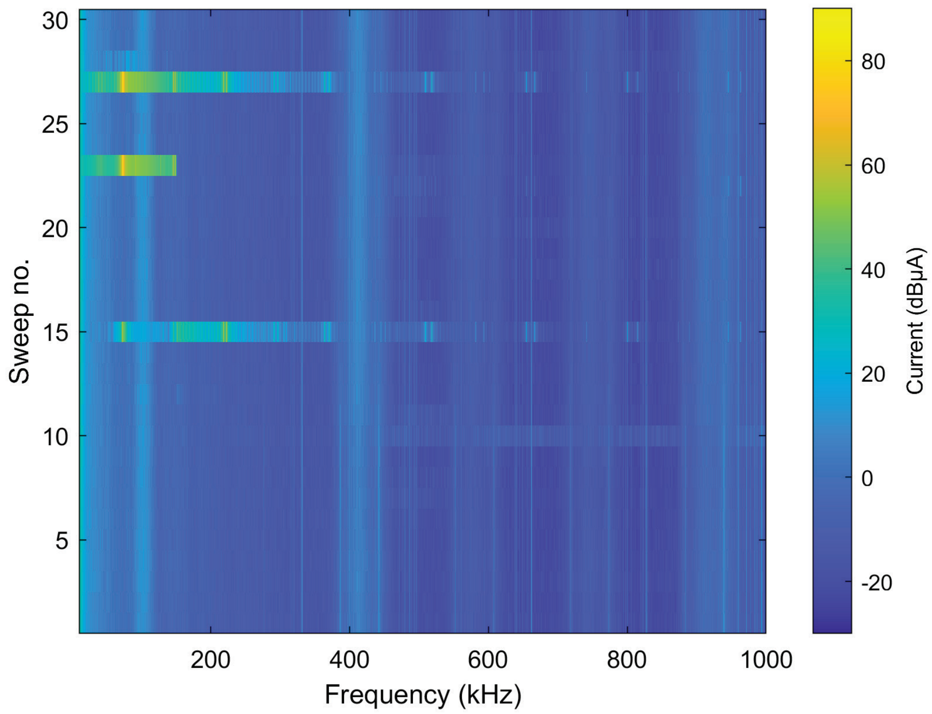

Figure 23. Spectrogram for measurement around one conductor with inverter off (BRF Brunnsviken conductor 1).

3.1.1.1 Conclusions for the frequency range 10 kHz–1 MHz

The measurements were performed at two different locations; at BRF Bergshamra gård June 22 2021 and at BRF Brunnsviken June 23 2021.

Common to the measurements is that they show significant levels at multiples of 100 kHz when the inverter is on. The highest peaks are typically for lower frequencies, but there is a variation with frequency. There are also clear peaks with 16.6 kHz intervals.

It is also clear that the levels are much lower at the BRF Brunnsviken facility, i.e. the one that was measured on June 23, for higher frequencies. The difference is about 30–40 dB in level.

The levels are higher for differential mode noise than for common mode noise, especially for lower frequencies. It is also clear that the measurement on one conductor is similar to that for differential mode noise. Differential-mode noise occurs when only one of the two conductors is exposed to noise. This can happen when the wires are not placed close to each other or when noise is generated in the voltage source or in components in the load.

When the inverter is turned off, the levels are generally lower and the components with 16 kHz and 200 kHz intervals are not visible. On the other hand, the peak around 73 kHz and its harmonics become more visible, sometimes a similar peak around 58 kHz occurs.

3.1.2 Frequency range 1–100 MHz

In this section conducted measurement results are presented in Figure 24 to Figure 31 for the frequency range 1 to 100 MHz. Figure 14 Again, the figures show the measured current with a current probe for two different conductors to the inverter in BRF Bergshamra gård and in BRF Brunnsviken. The measurements are performed for the cases with the inverter turned off and turned on.

Figure 24 show the results with one conductor. Compared to the background levels, the measurements with the inverter on exhibit higher levels. The measured levels are higher in the lower part of the frequency band and decrease with increasing frequency. Figure 25 presents the levels for the case when the inverter is off at the two locations. These are considered as background, and are used for comparisons.

Figure 26 shows measurements around two conductors. The levels are clearly higher than the background levels. The figures show that there are peaks at 200 kHz intervals in large parts of the frequency band when the inverter is turned on. This can be seen clearly in the magnification of the frequency band in the Figure 27. The peaks with 200 kHz spacing is however also present in the measurement at BRF Brunnsviken when the inverter is turned off, although it has a lower level. This can be seen in Figure 28 and in the magnification of the frequency band in Figure 29.

Finally, the results are shown in Figure 30 and Figure 31 for measurements around two conductors, where one is twisted. The first figure shows the case when the inverter is on and the second when the inverter is off. Again, a substantial contribution appears in the interference level in particular for the lower frequencies when the inverter is on.

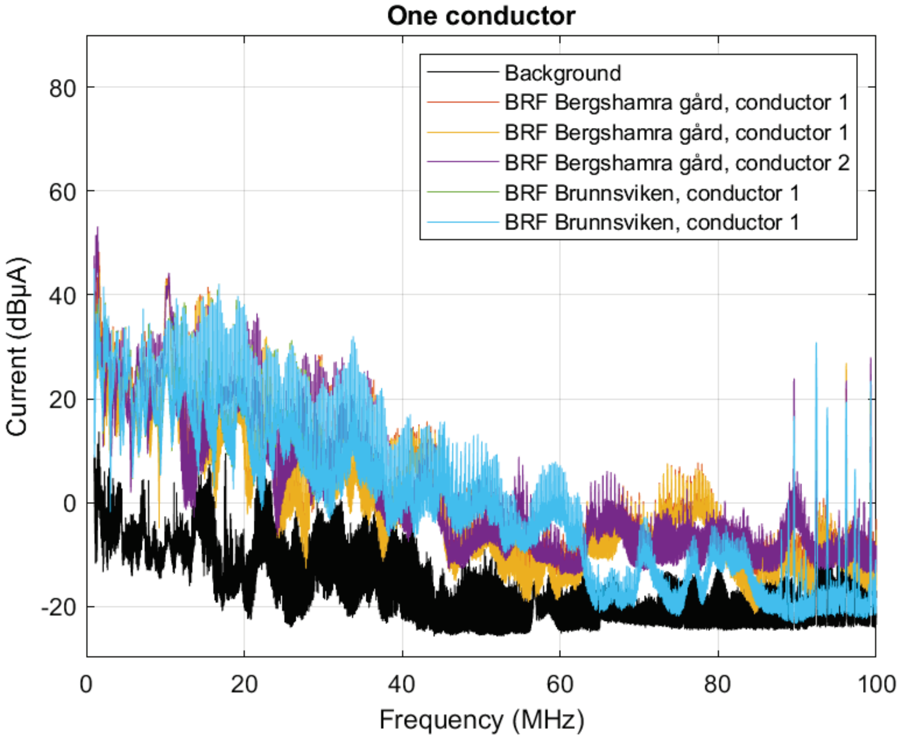

Figure 24. Measurement around one conductor with inverter on.

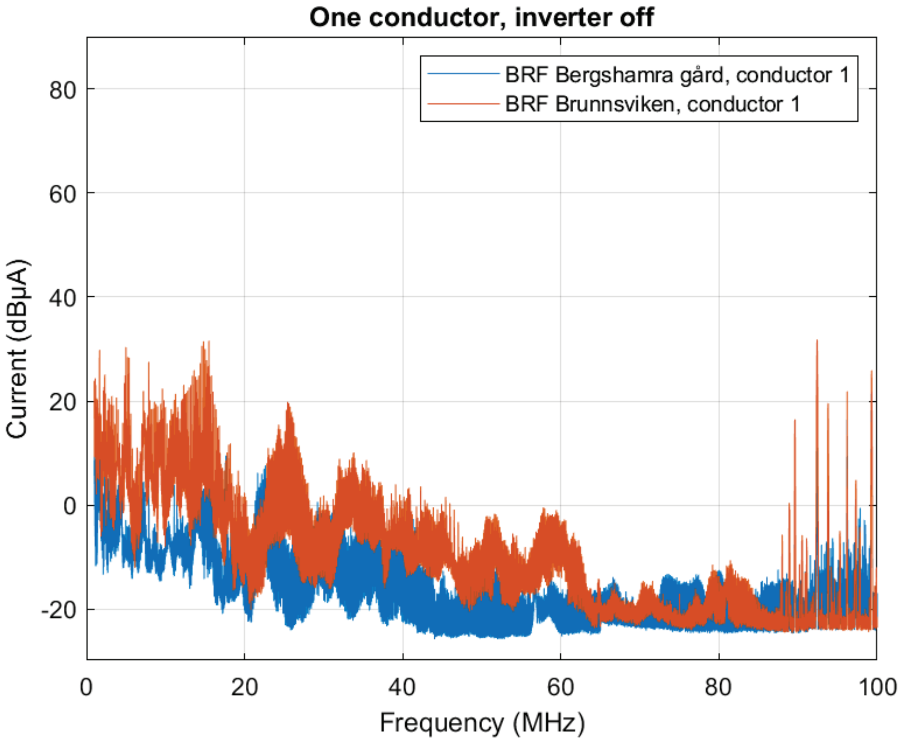

Figure 25. Measurement around one conductor with inverter off.

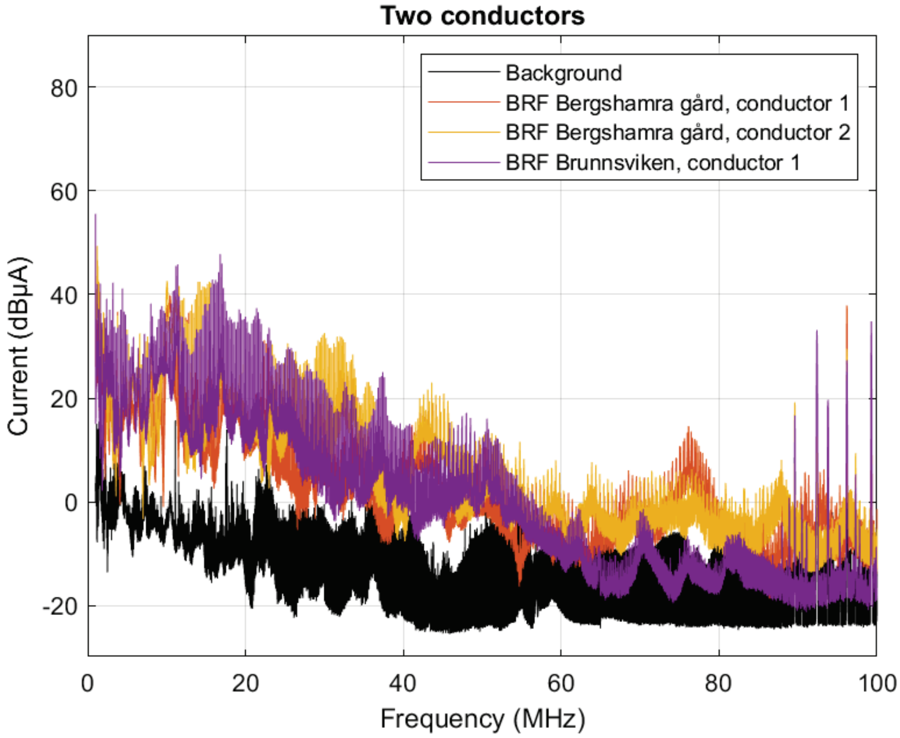

Figure 26. Measurement around two conductors with inverter on.

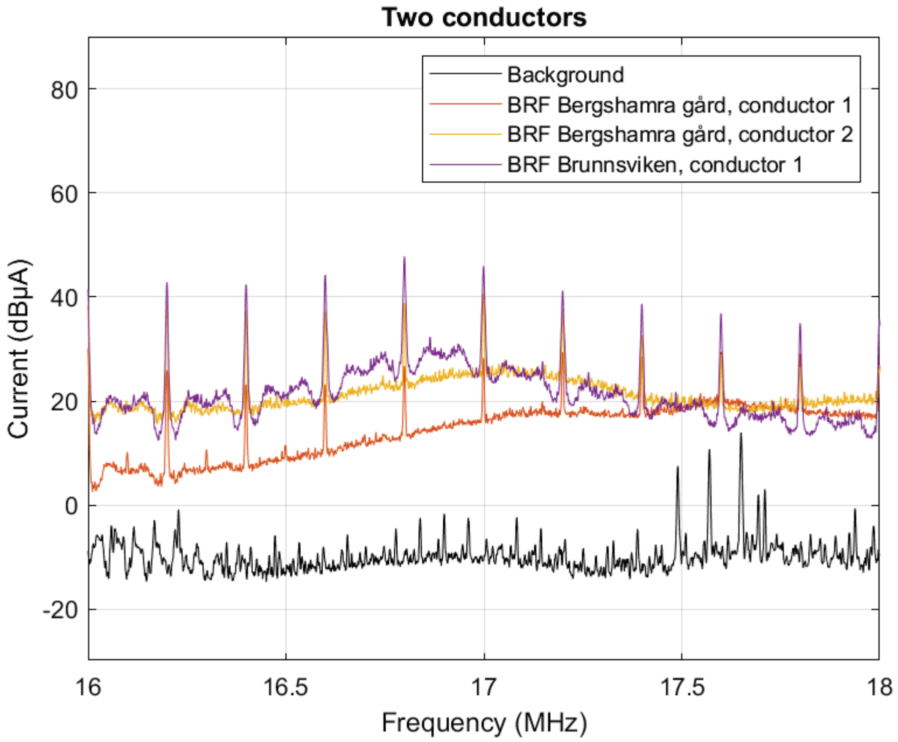

Figure 27. Magnification of 16–18 kHz for measurement around two conductors with inverter on.

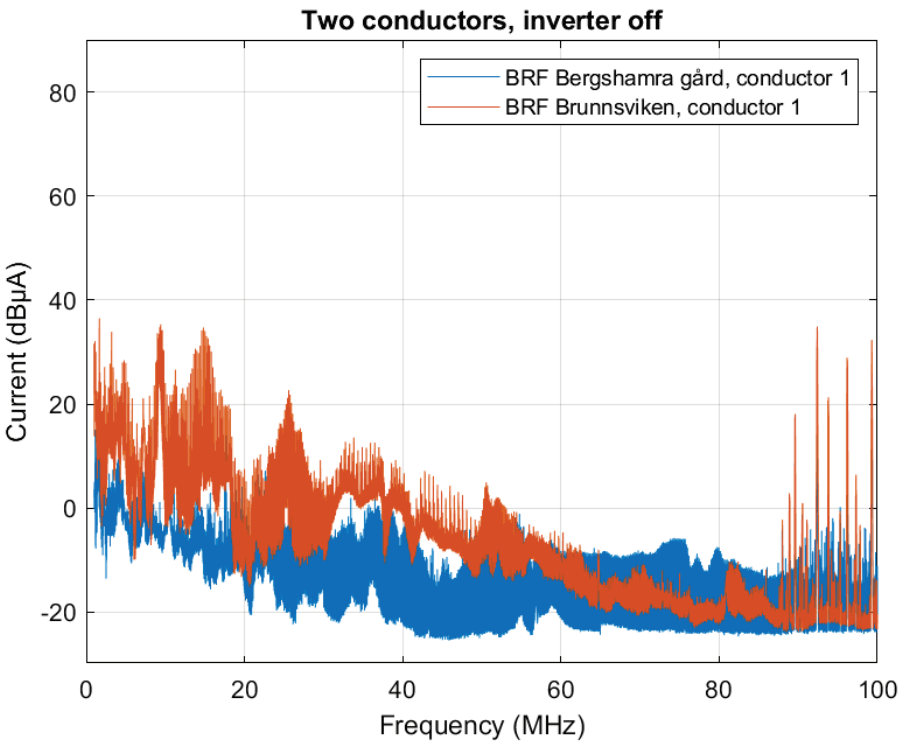

Figure 28. Measurement around two conductors with inverter off.

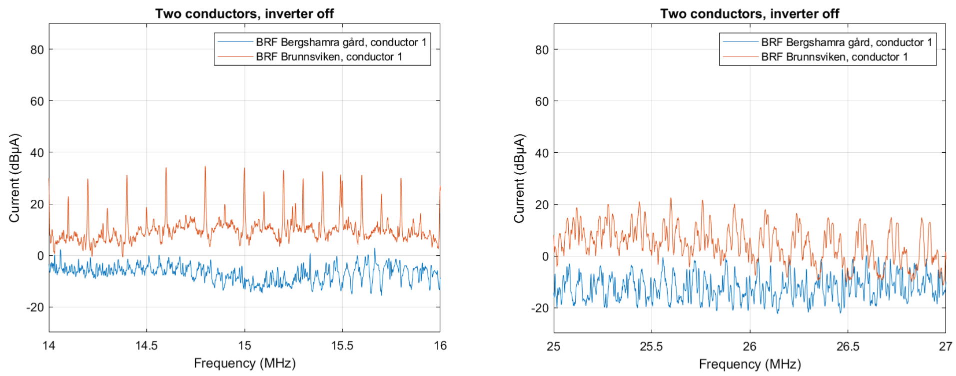

Figure 29. Magnification of frequencies around 15 and 26 MHz. Around 15 MHz, there are peaks with 200 kHz separation at BRF Brunnsviken. Around 26 MHz, there are peaks with about 160 kHz separation.

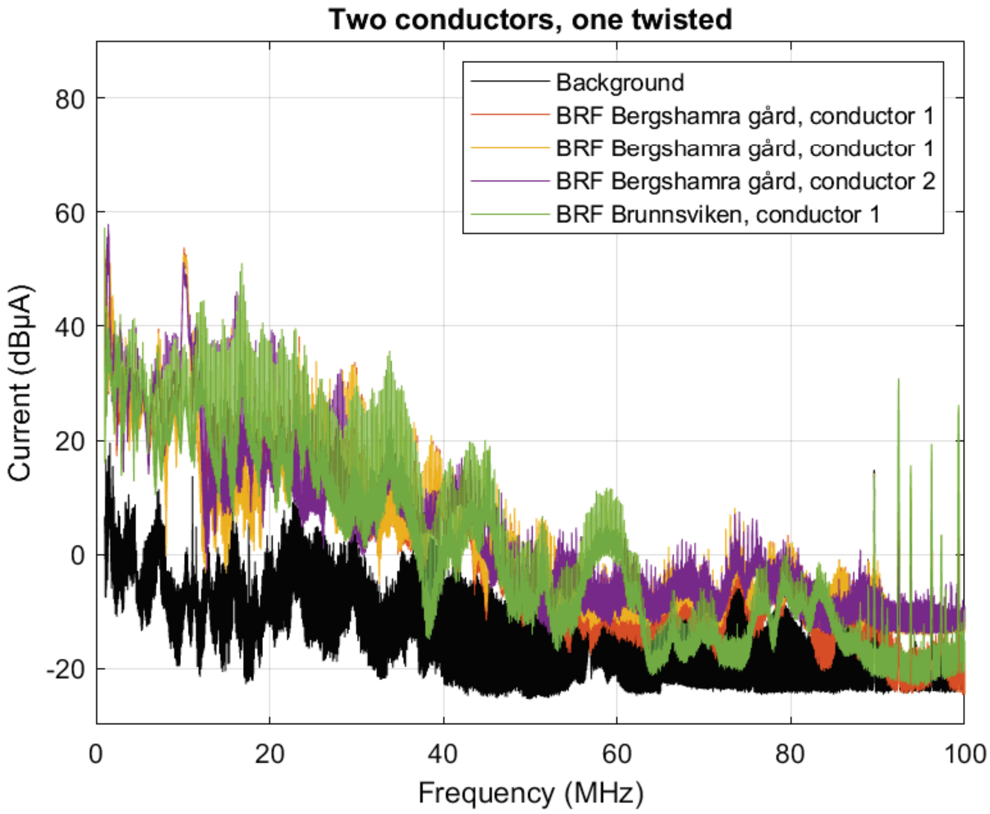

Figure 30. Measurement around two conductors, one of which is in the opposite direction, with inverter on.

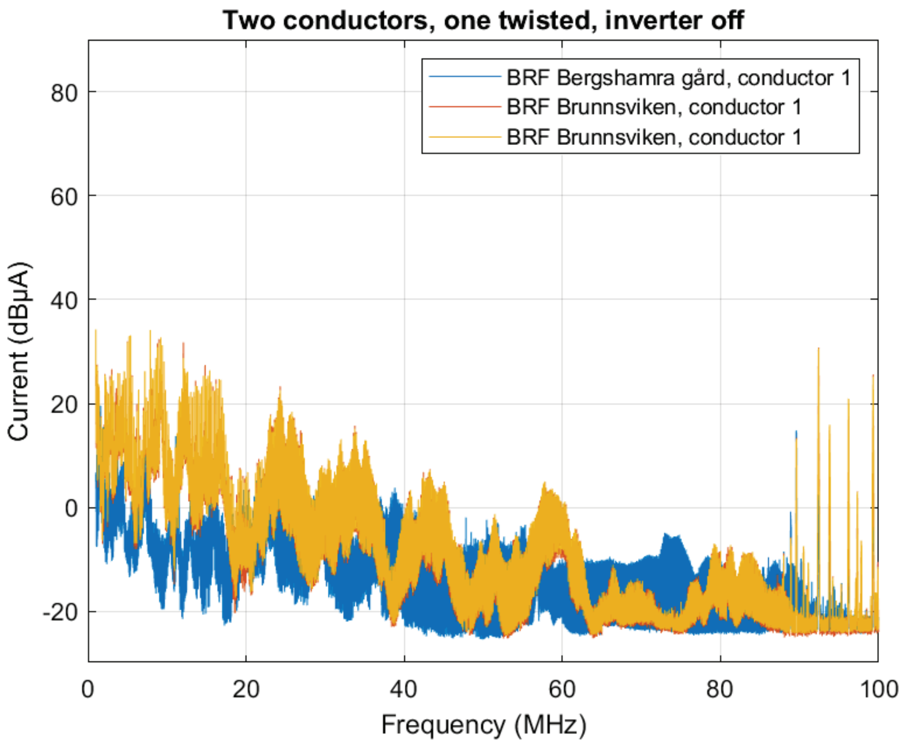

Figure 31. Measurement around two conductors, one of which is in the opposite direction, with inverter off.

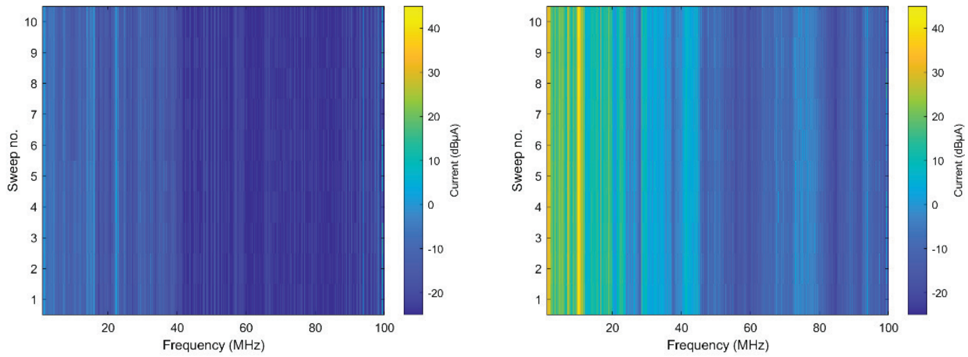

Figure 32. Spectrogram measured around one conductor with inverter off and on in Bergshamra gård.

3.1.2.1 Conclusions for the frequency range 1–100 MHz

The three different types of measurements show significant emission levels, especially in the frequency range 1–40 MHz, but there are also significant peaks higher up in frequency.

The measurements show a clear repetition of certain frequency components: When the inverter is turned on, there are peaks at 200 kHz intervals in large parts of the frequency band and with the highest levels for lower frequencies.

When the inverter is turned off, the emission levels are lower but there are still emissions present, especially at low frequencies.

3.1.3 Frequency range 100–200 MHz

The same type of measurements were also made for the frequency band 100–200 MHz. The results from these measurements are presented in Figure 33 to Figure 36. The results show that there appears interference in this frequency band also, although the levels are lower than for previous frequency bands. The interference seems to be higher for lower frequencies and is decreasing in level for the higher frequencies. When magnifying the frequency range 198 to 200 MHz, seen in Figure 36, the 200 kHz peak is again present in the measurement at Brunnsviken.

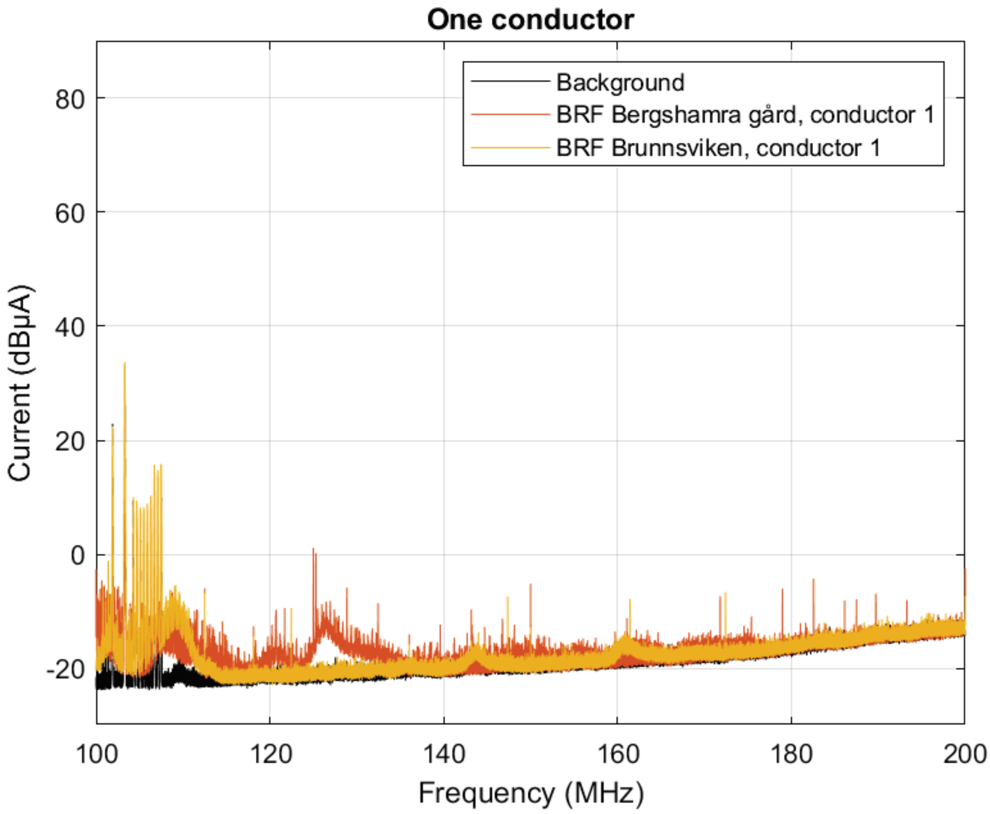

Figure 33. Measurement around one conductor.

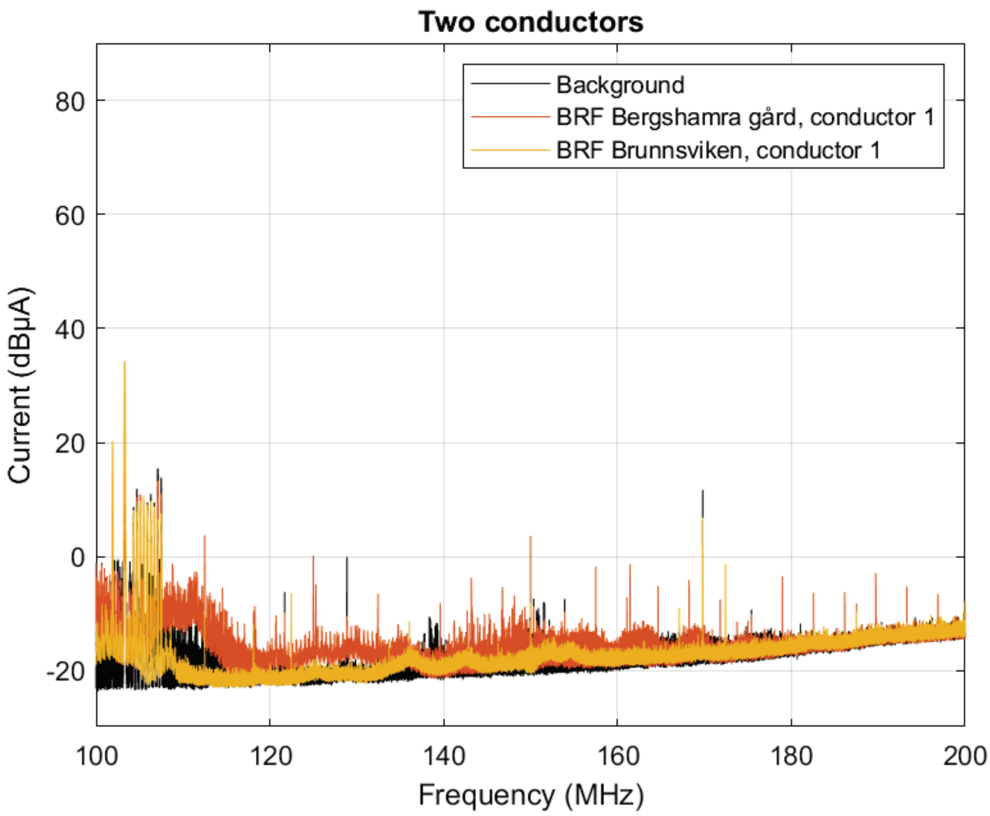

Figure 34. Measurement around two conductors.

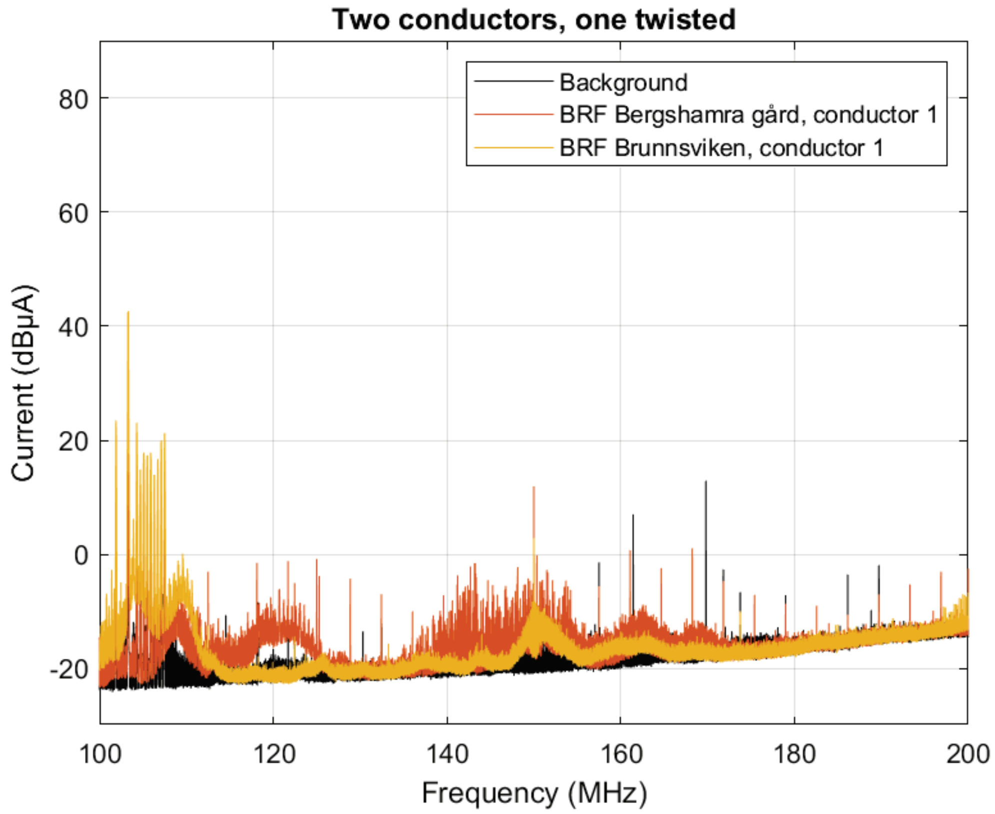

Figure 35. Measurement around two conductors, one of which is in the opposite direction.

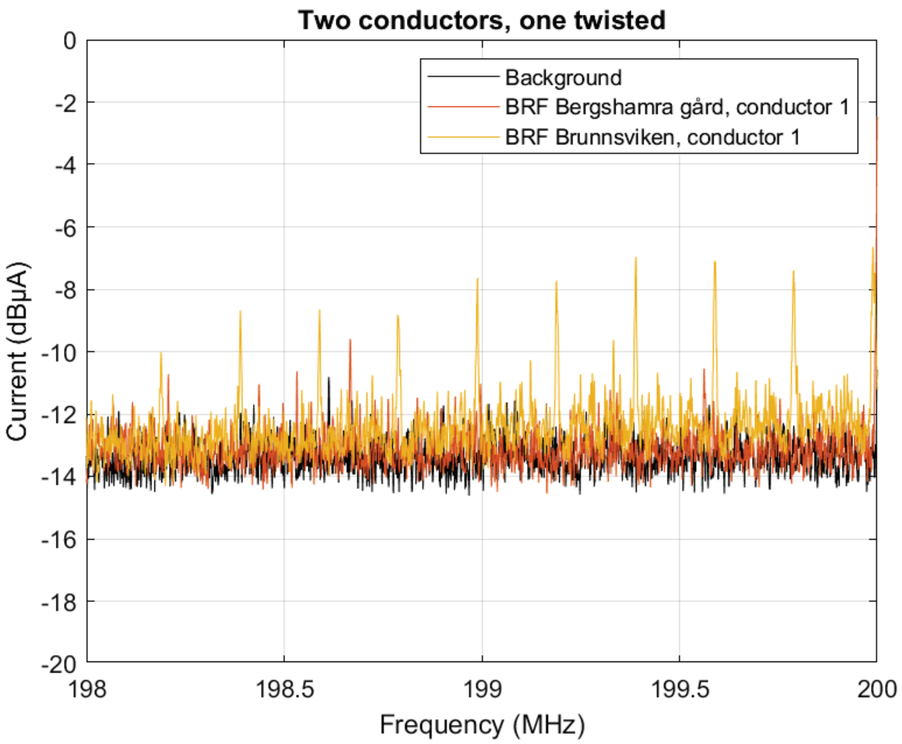

Figure 36. Magnification of frequencies around 199 MHz showing peaks with 200 kHz separation.

3.1.3.1 Conclusions for the frequency range 100 MHz–200 MHz

Usually, conducted interference decreases in magnitude above 30 MHz. In this case, surprisingly enough, the results indicate that there are interference signals on frequencies between 100 and 200 MHz.

Even though the measurements are performed at two different facilities, the behaviour is similar.

Similar to previous results, differential-mode noise seems to be the highest, but common-mode noise and emission in one conductor are also visible.

3.2 Radiated emission measurements BRF Bergshamra gård

The emission measurements were performed with the antenna relatively close to the solar panels. The antenna is about 20 m from the solar panels that are mounted on the roof of a two-storey house, see Figure 37. Measurements performed with the inverter off is denoted background.

3.2.1 Frequency range 10 kHz–1 MHz

This section presents results for radiated emission measurements in the frequency range 10 kHz to 1 MHz. Figure 38 and Figure 39 show the measured magnetic field strength for the cases when the inverter is on and off. The measurements are performed with the two defined antenna orientations. A representative measurement with the inverter turned off is called Background and is included in the figures.

Figure 37. About 20 meters between the solar panels and the measurement antenna.

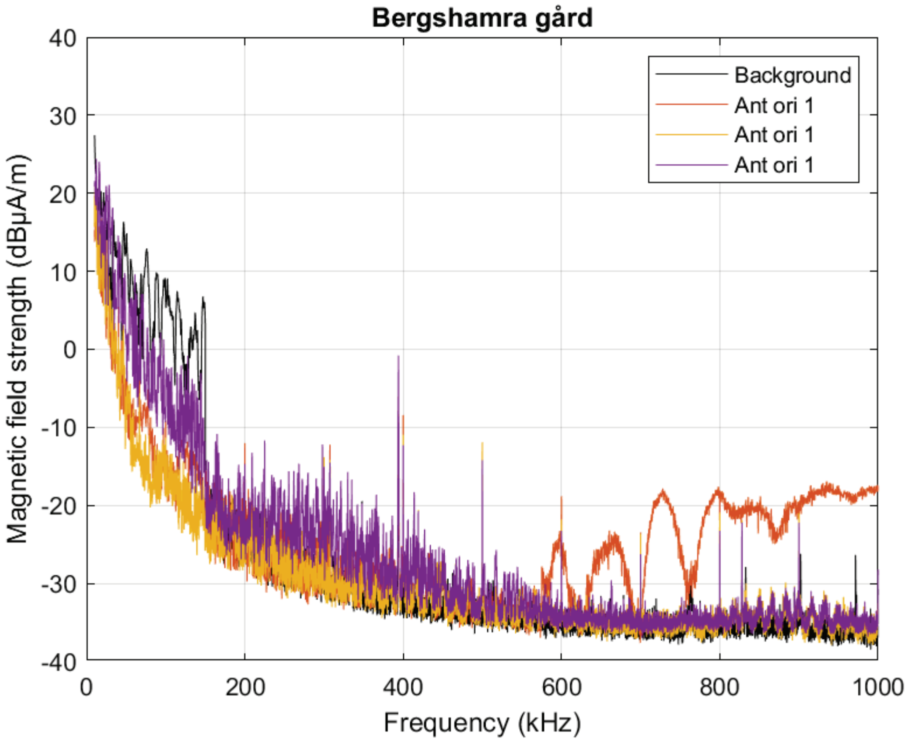

Figure 38. Radiated emission for frequency range 10 kHz to 1 MHz.

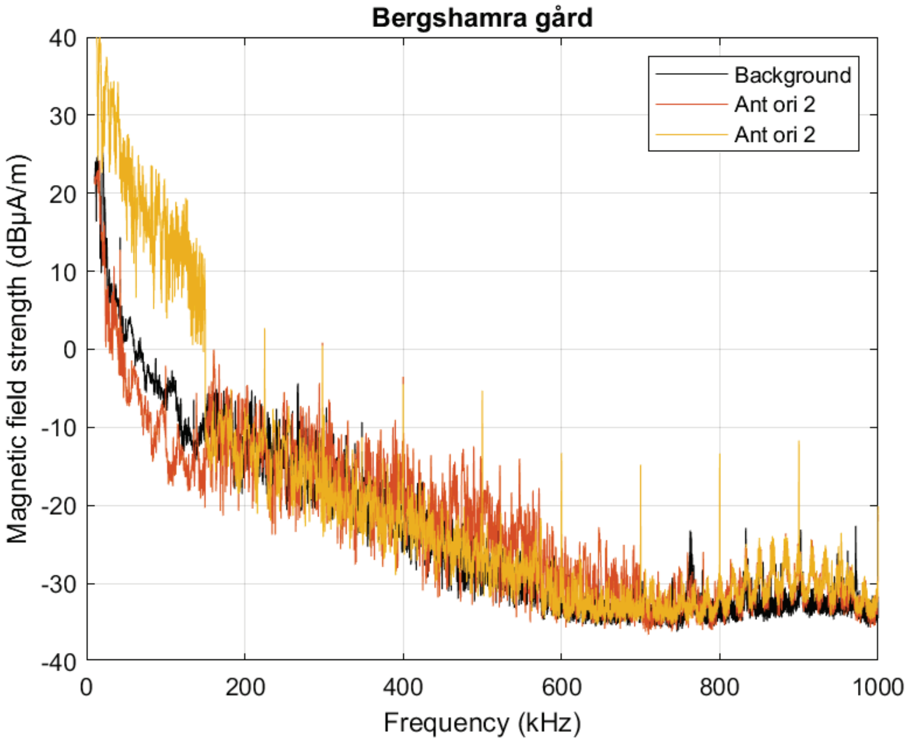

Figure 39. Radiated emission for frequency range 10 kHz to 1 MHz.

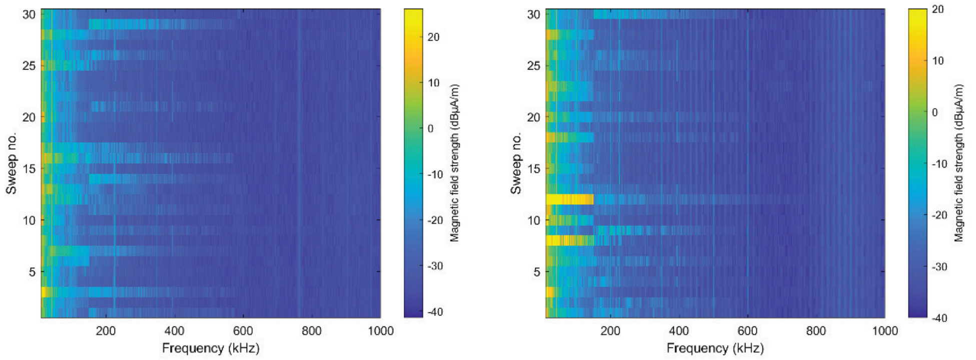

Figure 40. Spectrogram with inverter off (left) and on (rigth).

3.2.1.1 Conclusions for the frequency range 10 kHz–1 MHz

The measurement results show emission of 300, 400, 500 kHz and upwards, both for antenna orientation 1 and 2, which was also clear in the conducted measurements. However, no significant frequency component of 100 and 200 kHz is seen. Instead, there is a frequency component of about 225 kHz.

Especially between 800–1000 kHz, peaks with the frequency repetition of 16.6 kHz can also be seen as in the conducted measurements. These are probably also present for lower frequencies, even though it is a bit difficult to see it in Figure 38 and Figure 39.

With the inverter turned off, the narrowband components are not present at 100 kHz intervals. However, the noise level is approximately at the same level or some dB lower than with the inverter turned on.

The spectrograms in Figure 40 shows measurements with the inverter off to the left and with inverter on to the right. The measurements shows that the environment was quickly varying, but that the components from the solar installation were constant during the measurement.

3.2.2 Frequency range 1–30 MHz

This section presents results for radiated emission measurements in the frequency range 1 to 30 MHz.

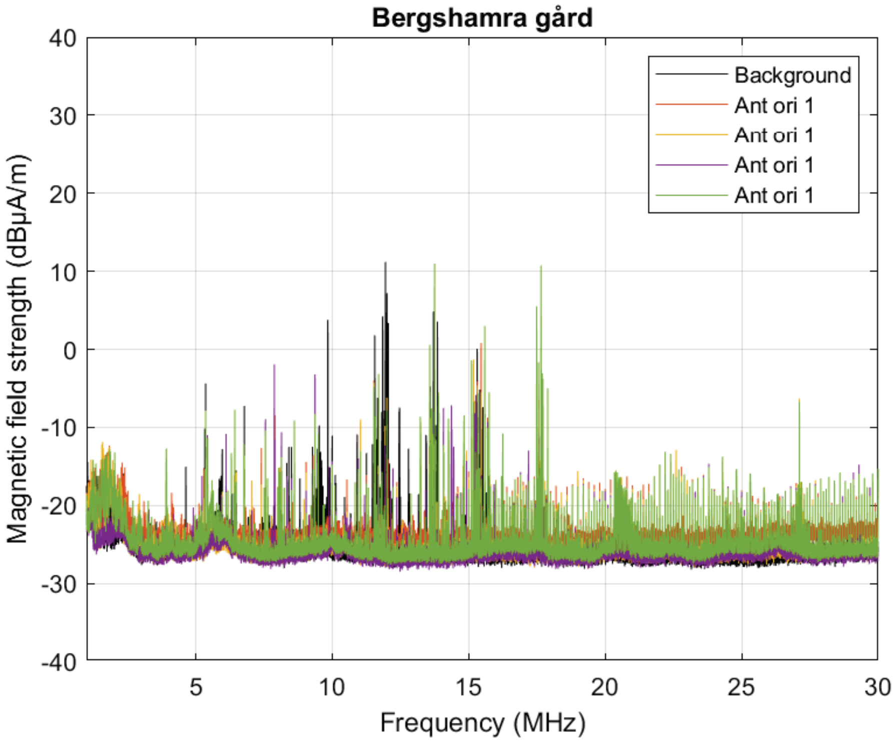

Figure 41. Radiated emission for frequency range 1 to 30 MHz.

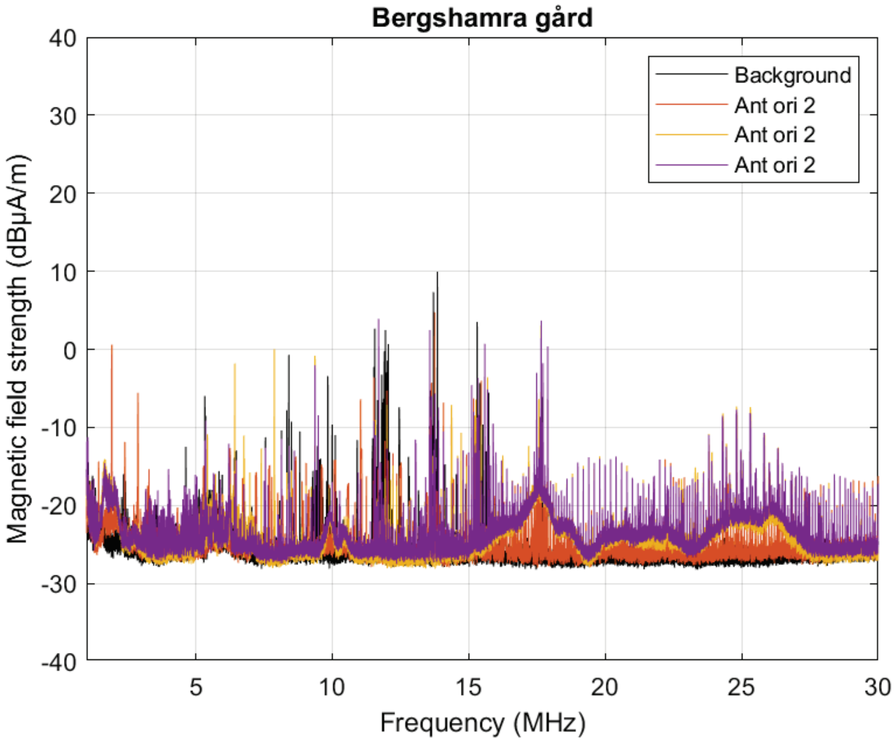

Figure 42. Radiated emission for frequency range 1 to 30 MHz.

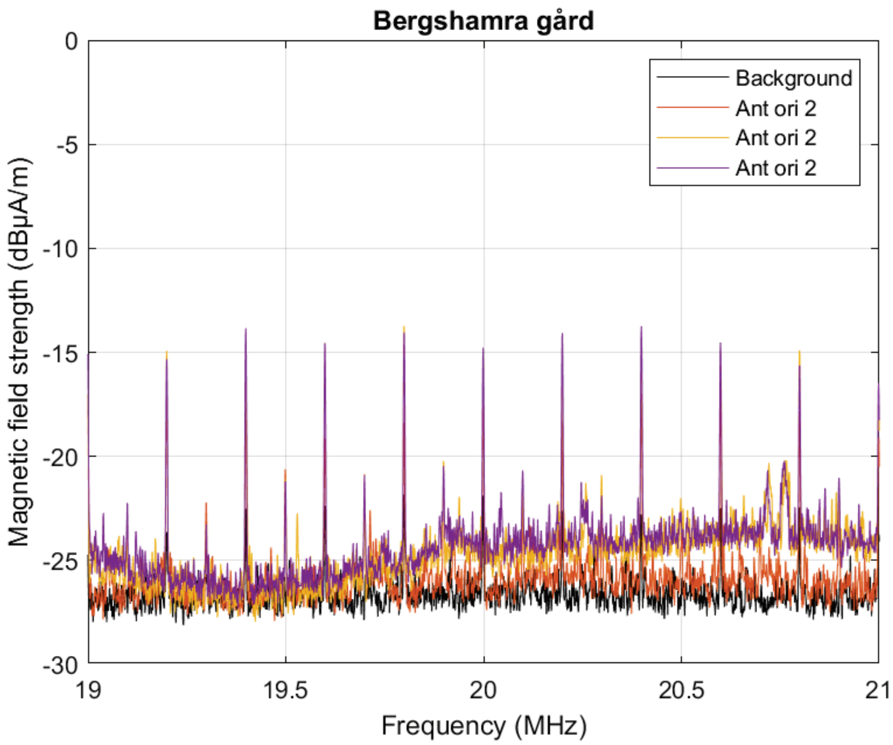

Figure 43. Magnification of frequencies around 20 MHz showing peaks with 200 kHz separation.

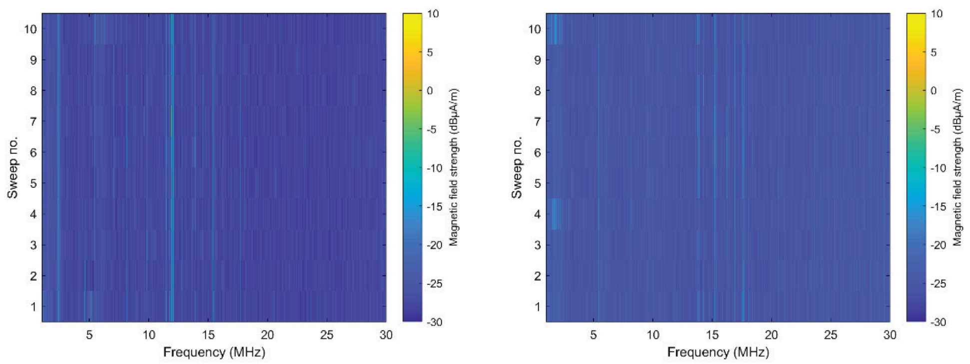

Figure 44. Spectrogram with inverter off (left) and on (right).

3.2.2.1 Conclusions for the frequency range 1–30 MHz

In the upper half of the frequency band in particular, components can be seen at 200 kHz intervals. These peaks are about 10 dB stronger than surrounding levels. The spectrograms in Figure 44 show that the peaks are present during all the measured sweeps, but are vaguely visible since they are narrowband.

For two of the measurements, there were also a general level increase between 15 and 27 MHz, that were particularly high around 17.5 MHz (see Figure 42).

3.2.3 Frequency range 30–200 MHz

This section presents results for radiated emission measurements in terms of the electrical field strength in the frequency range 30 to 200 MHz. The measurements are performed for vertical (VP) and horizontal (HP) polarisation, with, and without preamplifier connected to the antenna.

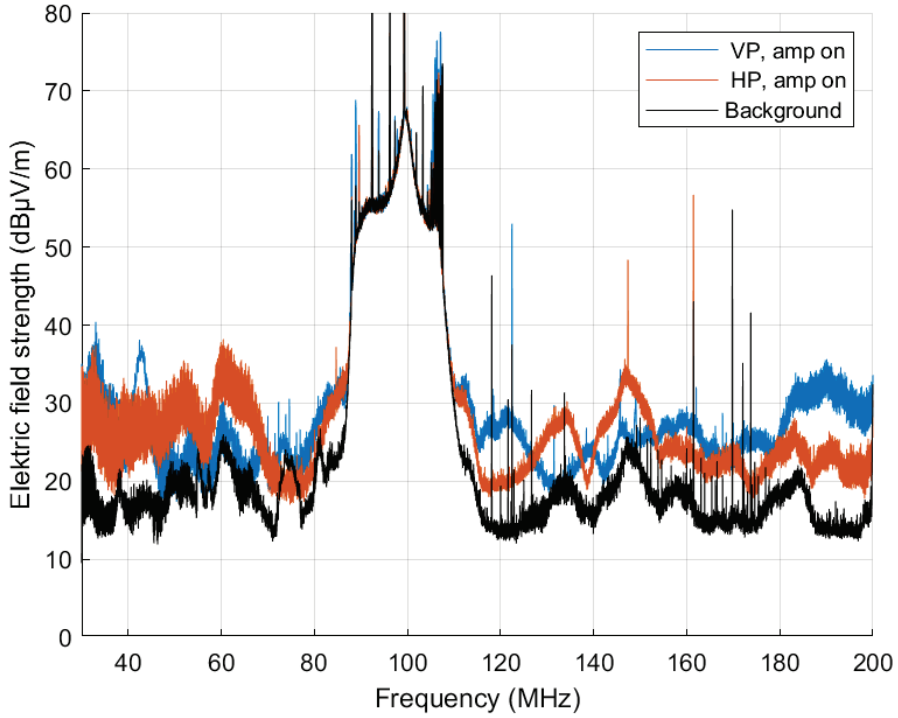

Figure 45. Radiated emission for frequency range 30 to 200 MHz.

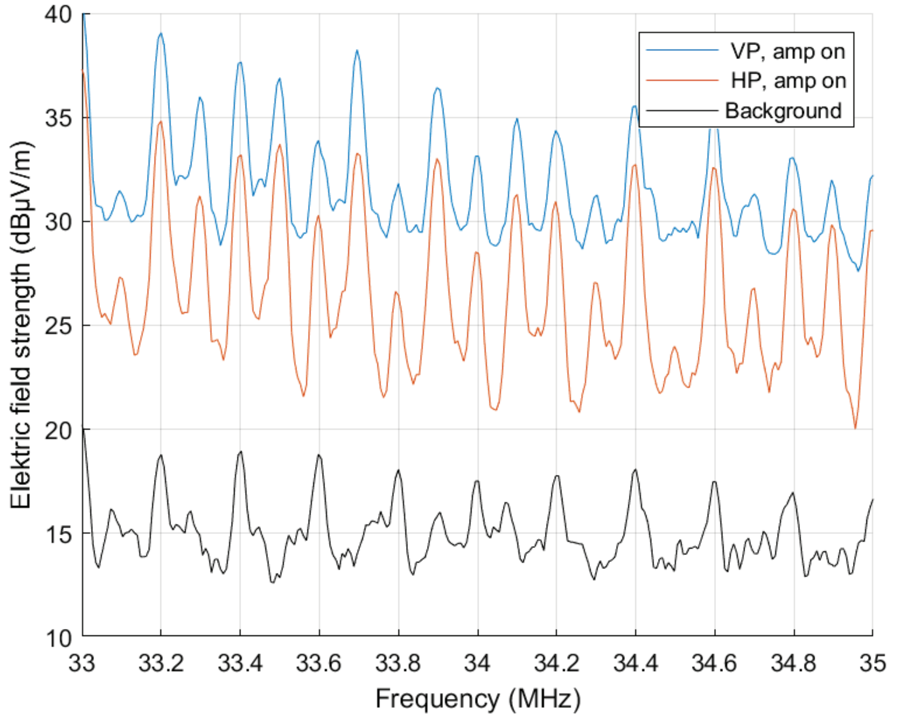

Figure 46. Magnification of frequencies around 34 MHz showing peaks with 100 kHz separation.

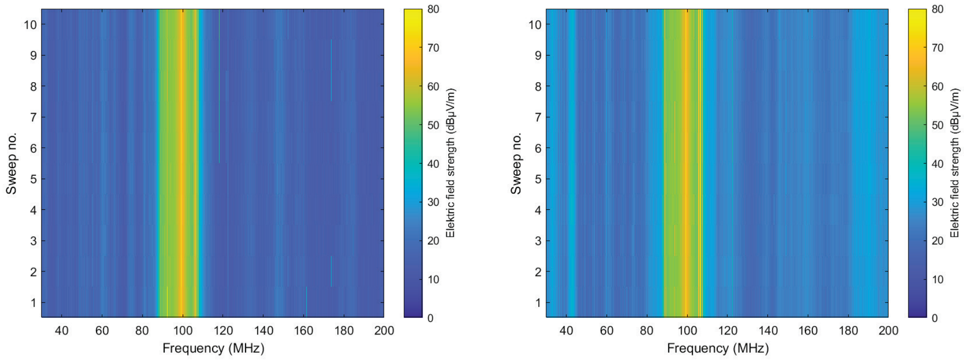

Figure 47. Spectrogram with inverter off to the left and with inverter on to the right.

3.2.3.1 Conclusions for the frequency range 30–200 MHz

A filter was used to filter out FM radio broadcasts for frequencies between 88 and 108 MHz. The environment varied between the measurements, but some conclusions can still be drawn.

Especially in the lowest and highest part of the frequency band, there are peaks at 100 kHz intervals and also a general increase in the emission level. The spectrograms in Figure 47 with inverter off (left) an on (right) shows that the levels are higher with the inverter on and also that the levels are relatively constant during the 10 measured sweeps.

3.2.4 Frequency range 200–1000 MHz

This section presents results for radiated emission measurements in terms of the electrical field strength in the frequency range 200 to 1000 MHz. The measurements are performed with the antenna in one orientation, with, and without preamplifier connected to the antenna.

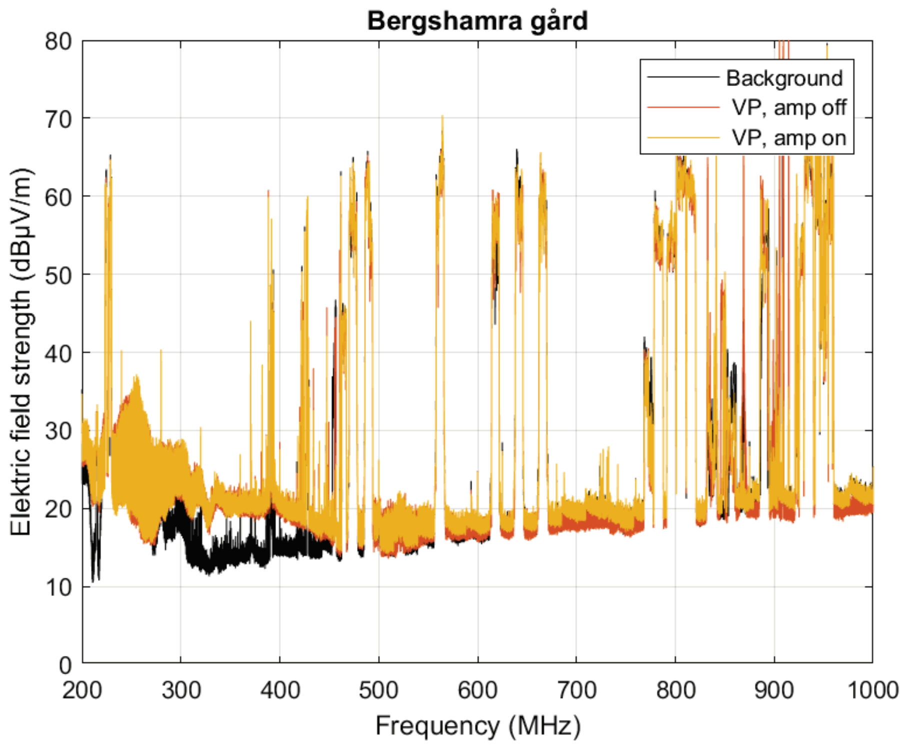

Figure 48. Radiated emission for frequency range 200 to 1000 MHz.

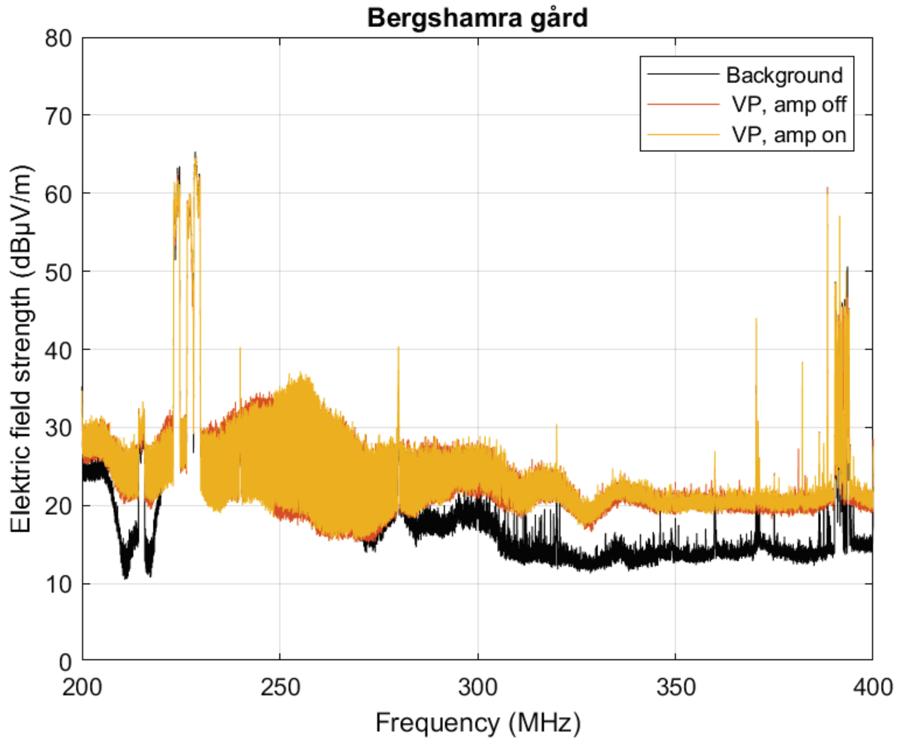

Figure 49. Magnification of the frequency range 200 to 400 MHz.

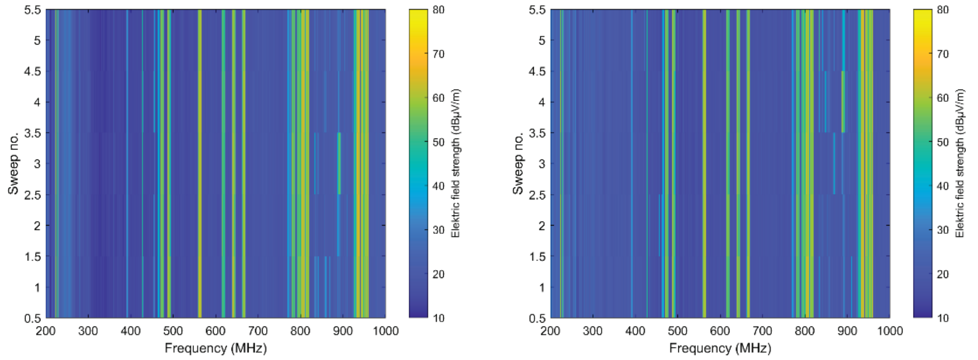

Figure 50. Spectrogram with inverter off to the left and with inverter on to the right.

3.2.4.1 Conclusions for the frequency range 200 –1000 GHz

In this frequency range, there are several frequency bands with strong radio transmitters, such as Rakel and cellular systems.

The measurements show elevated levels in the frequency range 200–450 MHz when the inverter is on. This increase is also visible when the measurements were performed at a greater distance (measuring antenna in a green open space south of BRF Bladet) and then the difference is about 10–15 dB, while the difference is greater when the measuring antenna is placed closer to the photovoltaic system.

3.3 Radiated emission measurements BRF Brunnsviken

The emission measurements at the BRF Brunnsviken are made with the measuring antenna at a relatively large distance to the solar panels. The measuring antenna is located at maximum 66 m (distance at the ground) from the solar panels and the panels are also placed high, on the roof of a four-storey building with attic, see Figure 51. Measurements were made at 66, 37 and 23 meter distance.

In addition to the marked PV installation on the right, there is also an installation in the house on the far left with solar panels directed to the left. During the measurements, the inverters at both PV installations have been turned off. When the inverters were turned off, the measurements were carried out at a distance of 66 m.

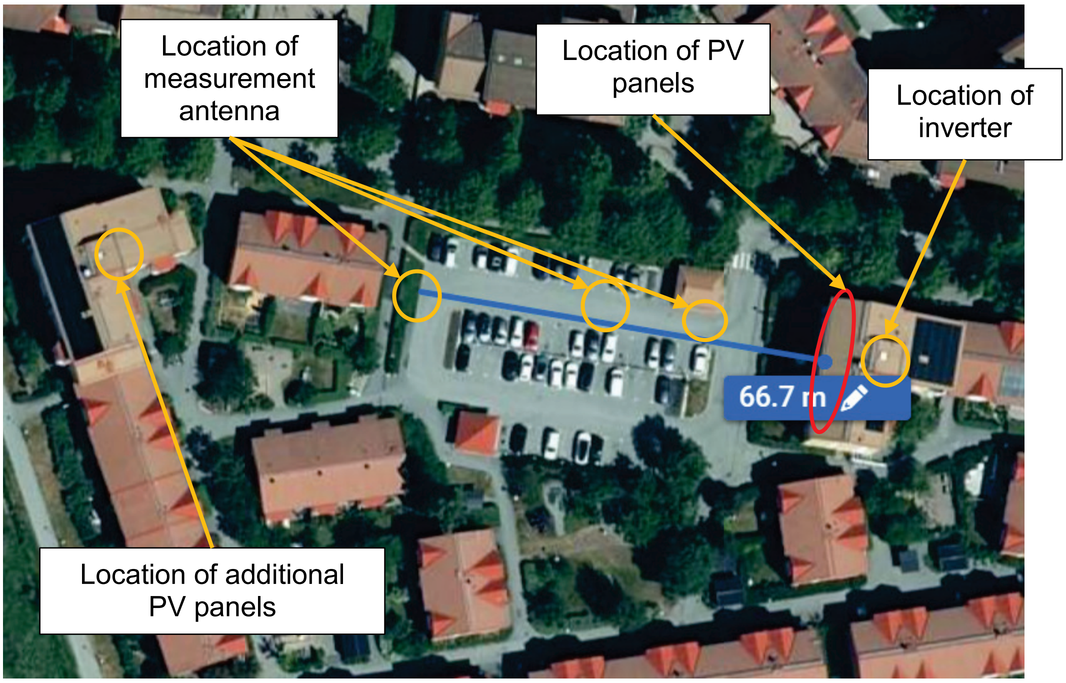

Figure 51. Map of measurements of radiated emissions for BRF Brunnsviken.

3.3.1 Frequency range 10 kHz–1 MHz

This section presents results for radiated emission measurements in the frequency range 10 kHz to 1 MHz. The figures show the measured magnetic field strength for the cases when the inverter is on and off measured at different distances from the PV installation.

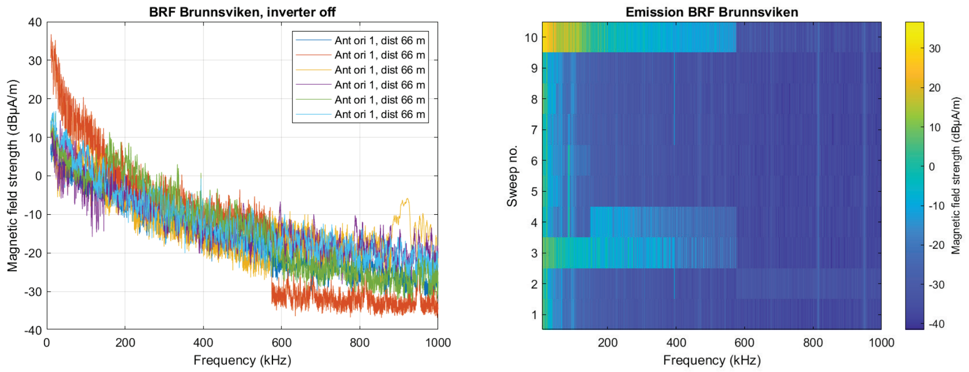

Figure 52. Radiated emissions in the frequency range 10 kHz to 1 MHz, with inverter off.

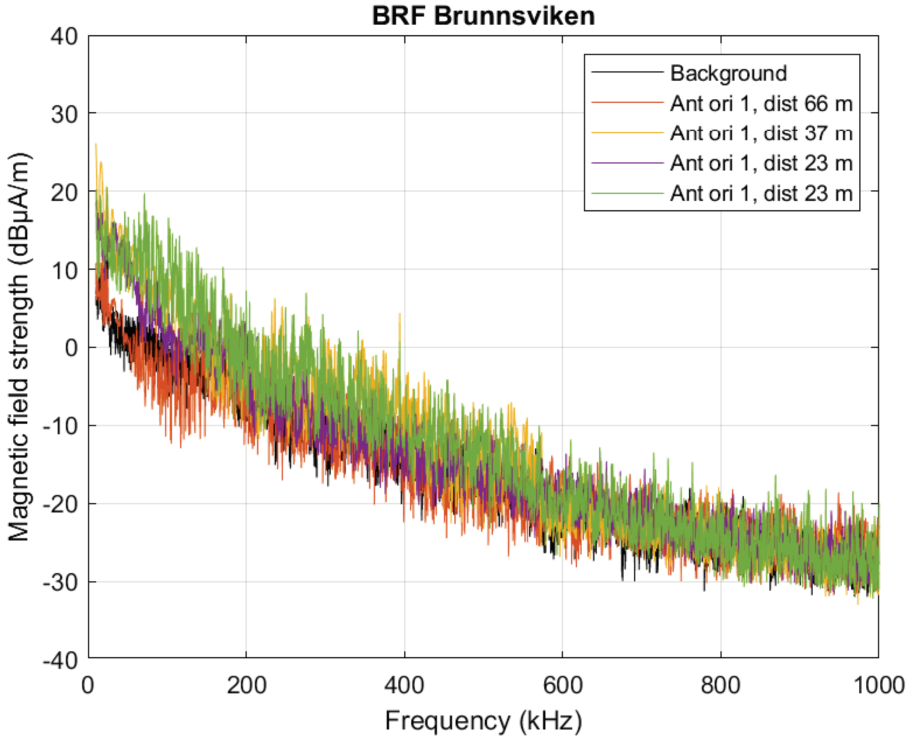

Figure 53. Radiated emissions in the frequency range 10 kHz to 1 MHz.

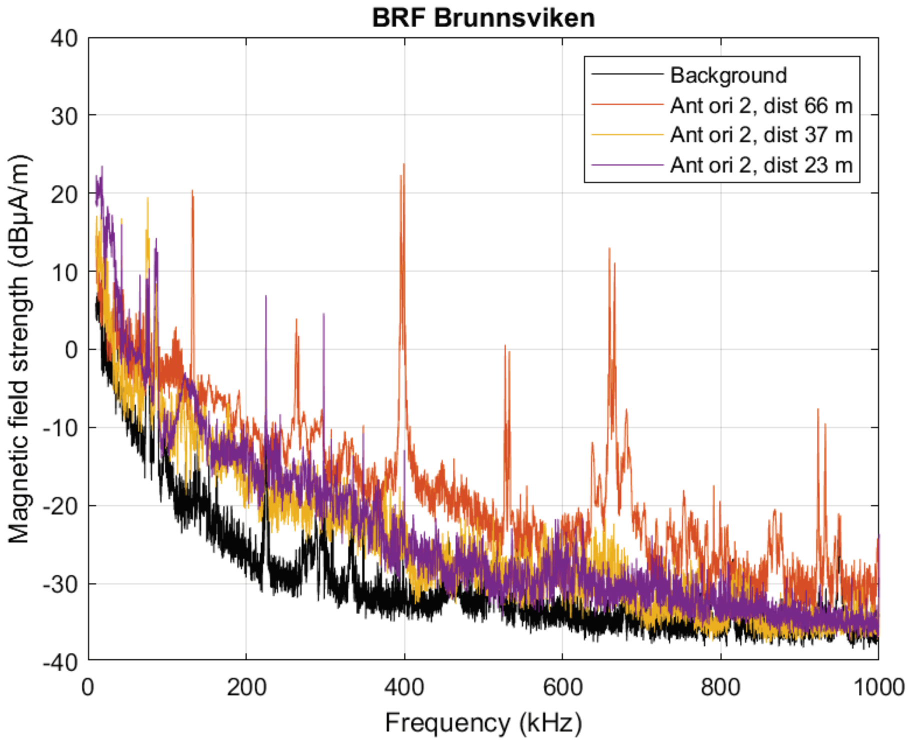

Figure 54. Radiated emissions in the frequency range 10 kHz to 1 MHz.

3.3.1.1 Conclusions for the frequency range 10 kHz–1 MHz

The measurement at 66 m distance with the antenna in orientation 2 shows very strong frequency components for the frequencies 132.5, 265, 398, 530, 663 and 928 kHz, which means that there are peaks with frequency separation of 132–133 kHz. These emissions consist of two peaks at adjacent frequencies similar to those found in the conducted measurements at frequencies of 58 or 73 kHz (see Figure 15).

The emission measured with the antenna in orientation 1 does not show a few strong frequency components but has relatively high levels throughout, see Figure 53. Even at the measurements with the inverter turned off, the levels were high in the entire frequency band. The spectrogram in Figure 52 shows that there are temporary strong disturbances detected by the antenna in orientation 1 even when the inverter is turned off.

Figure 54 shows measured emission at a distance of 66 m for antenna orientation 2, for the inverter turned off (background) and turned on. It is clear that the emission levels increase when the inverter is turned on. At the same time, Figure 54 shows that the emission levels does not increase for shorter measurement distances. The reason for this is probably that the roof of the house obscures the direct component between the solar panels and the measuring antenna when the measuring antenna is moved closer to the house. Another possible explanation is that intermittent dominant disturbances were captured when measuring at the longer measurement distance.

3.3.2 Frequency range 1–30 MHz

This section presents results for radiated emission measurements in the frequency range 1 to 30 MHz.

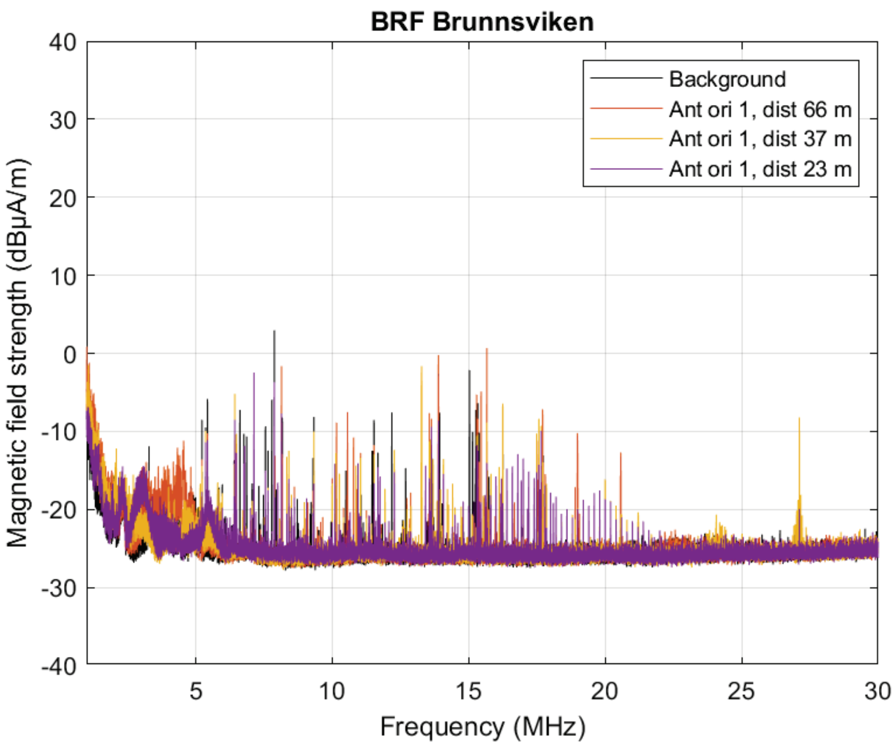

Figure 55. Radiated emissions in the frequency range 1 to 30 MHz.

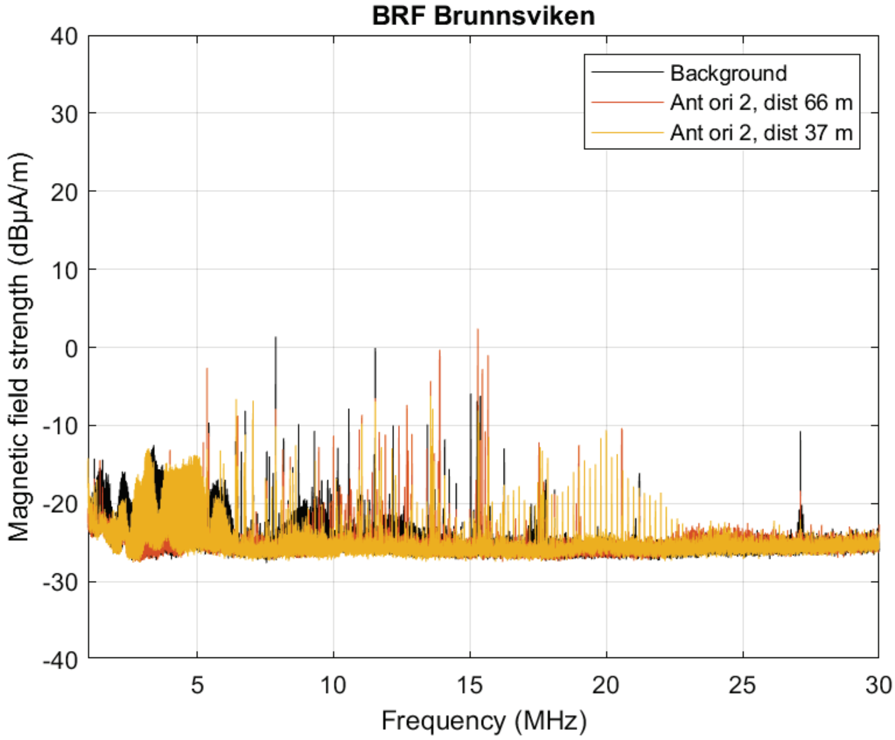

Figure 56. Radiated emissions in the frequency range 1 to 30 MHz.

3.3.2.1 Conclusions for the frequency range 1–30 MHz

The measurements show peaks at 16 kHz intervals for low frequencies, below approximately 7 MHz, which are present at the measurement with the inverter turned off at 66 m and with the inverter turned on at 37 m with the antenna in orientation 2. Even with the antenna in orientation 1, there were emissions on these frequencies, but not with the same clear periodicity.

For frequencies between 15 and 23 MHz, peaks with 200 kHz intervals are visible in results for both antenna orientations. For antenna orientation 1, these peaks are visible at distances 37 and 23 m and with antenna orientation 2 at 37 m. These peaks have different amplitudes but are at most 10–15 dB stronger. This kind of emission was commonly recognized in the conducted measurements.

3.3.3 Frequency range 30–200 MHz

This section presents results for radiated emission measurements in terms of the electrical field strength in the frequency range 30 to 200 MHz. As in the previous measurements, they are performed with the two defined antenna orientations and with, and without preamplifier connected to the antenna.

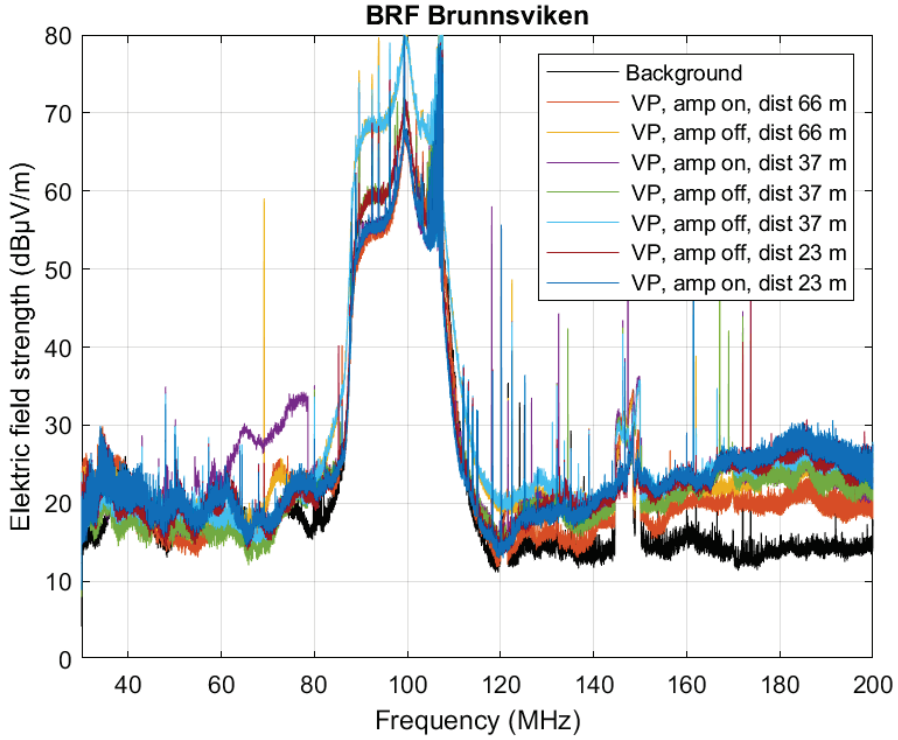

Figure 57. Radiated emissions in the frequency range 30 to 200 MHz with vertical polarisation.

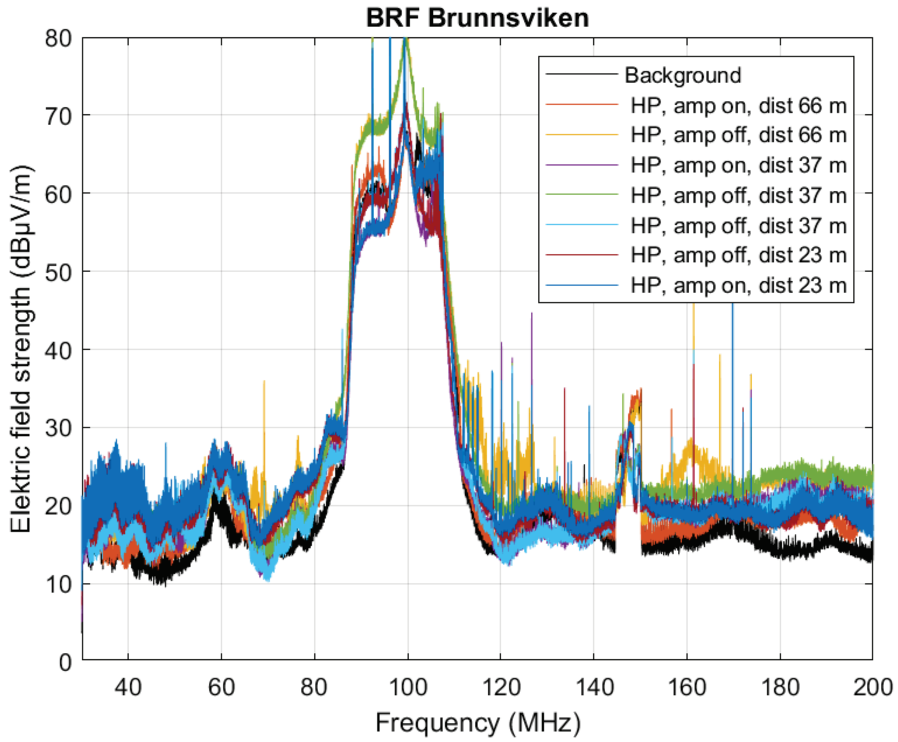

Figure 58. Radiated emissions in the frequency range 30 to 200 MHz for horizontal polarization.

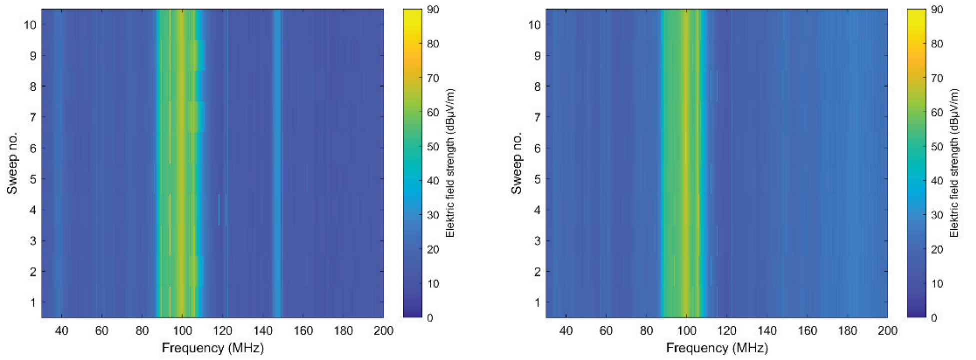

Figure 59. Spectrograms for vertical polarization with inverter off and on.

3.3.3.1 Conclusions for the frequency range 30–200 MHz

The measurements show higher levels when the inverter was turned on in principle in the entire frequency band. This is especially visible for vertical polarization and frequencies above 150 MHz. Throughout the band, there are narrowband peaks at 200 kHz intervals when the inverter is on, which has been recognized earlier.

3.4 Radiated emission measurements BRF Bladet

The measurements of radiated emission were conducted with the measurement antenna placed between the different photovoltaic installations. The distances are relatively long and the approximate distances are:

- 145 m to BRF Bergshamra gård or somewhat shorter to their second installation.
- 184 m and 266 m to the two installations at BRF Brunnsviken.
- 45 to 158 m to the installations at BRF Bladet.

The solar panels for BRF Bladet were placed very high, on the roof of a ten-storey building with attic. This means that there is almost no line of sight between the panels on the roof and the measuring antenna.

At the start of these measurements, all inverters were turned off and then inverters were turned on in the following order:

- Inverters in the two houses to the right in BRF Bladet
- All other inverters in BRF Bladet
- Inverters in BRF Brunnsviken
- Inverters in BRF Bergshamra gård.

Hence, after the inverters in BRF Bergshamra gård were turned on, all inverters were on.

Figure 60. Map of measurements at BRF Bladet. The shortest distance to a solar installation is about 45 m.

3.4.1 Frequency range 10 kHz–1 MHz

This section presents results for radiated emission measurements in the frequency range 10 kHz to 1 MHz. The figures show the measured magnetic field strength for the case when all of the sites' inverters were off and then successively were turned on.

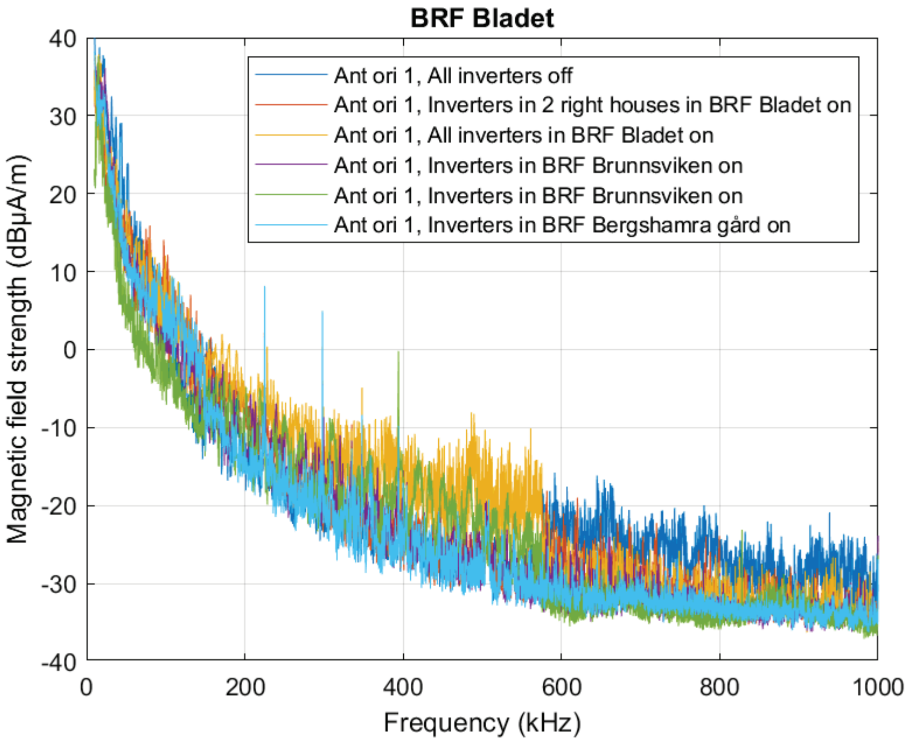

Figure 61. Radiated emissions in the frequency range 10 to 1000 kHz.

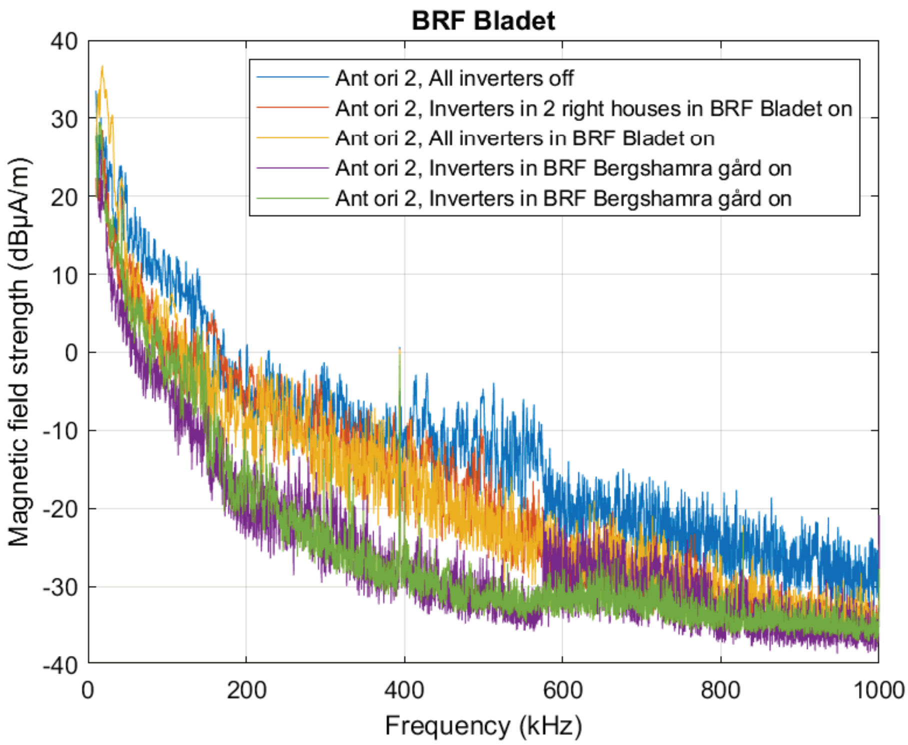

Figure 62. Radiated emissions in the frequency range 10 to 1000 kHz.

3.4.1.1 Conclusions for the frequency range 10–1000 kHz

At this measuring position, we see no direct difference between the cases when the inverters were turned on or off. For antenna orientation 2, the interference levels were even higher when the inverters were turned off. The reason is probably that there exist other dominate interference in the surroundings during this measurement.

3.4.2 Frequency range 1–30 MHz

This section presents results for radiated emission measurements in the frequency range 1 to 30 MHz.

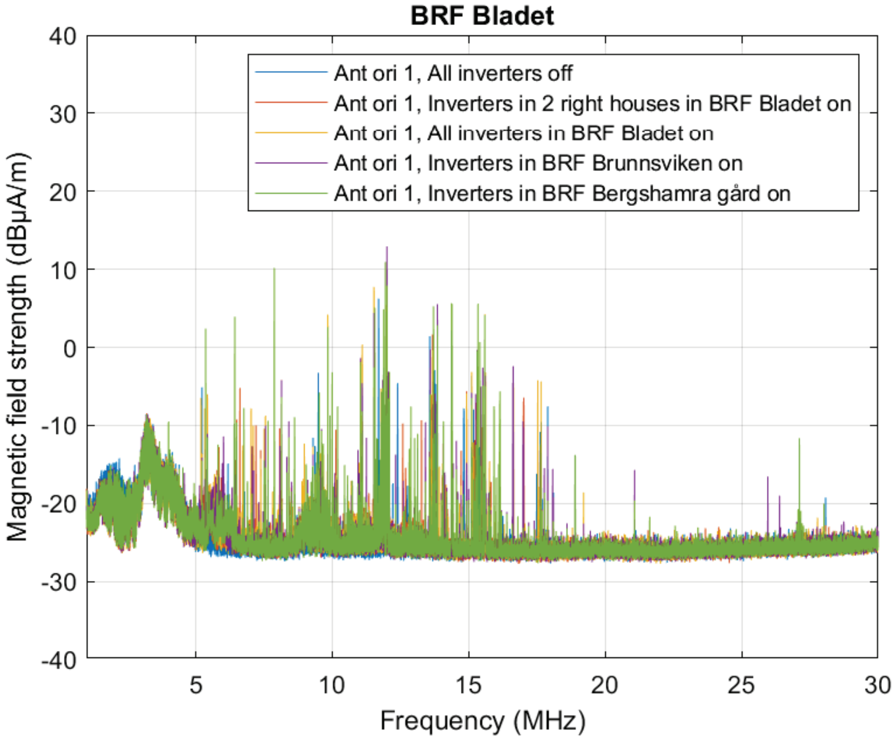

Figure 63. Radiated emissions in the frequency range 1 to 30 MHz.

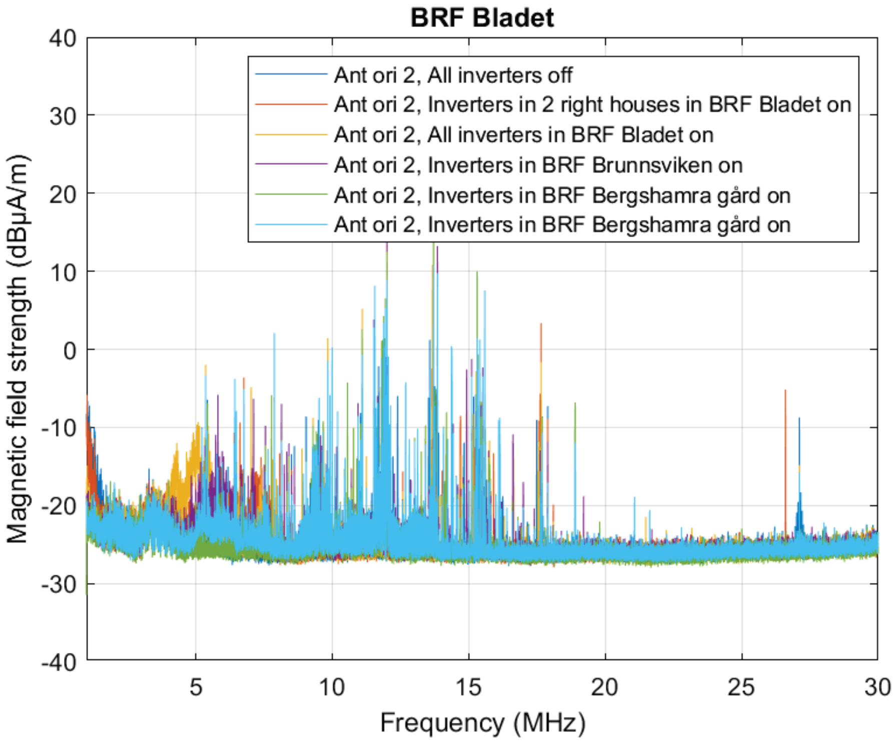

Figure 64. Radiated emissions in the frequency range 1 to 30 MHz.

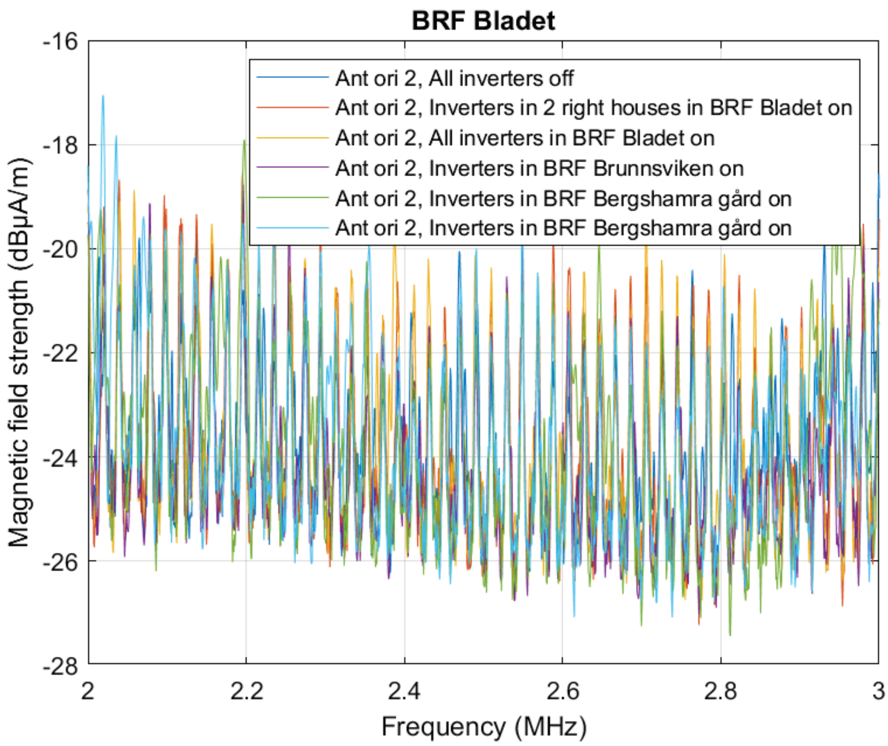

Figure 65. Magnification of 2–3 MHz, showing components with 16.6 kHz repetition.

3.4.2.1 Conclusions for the frequency range 1–30 MHz

In this frequency range, it is difficult to see any clear differences for the different cases, but in general, higher levels were measured when inverters were turned on. For frequencies below approximately 7 MHz, emissions are measured in all cases and peaks with 16.7 kHz intervals are clearly visible.

3.4.3 Frequency range 30–200 MHz

This section presents results for radiated emission measurements in terms of the electrical field strength in the frequency range 30 to 200 MHz.

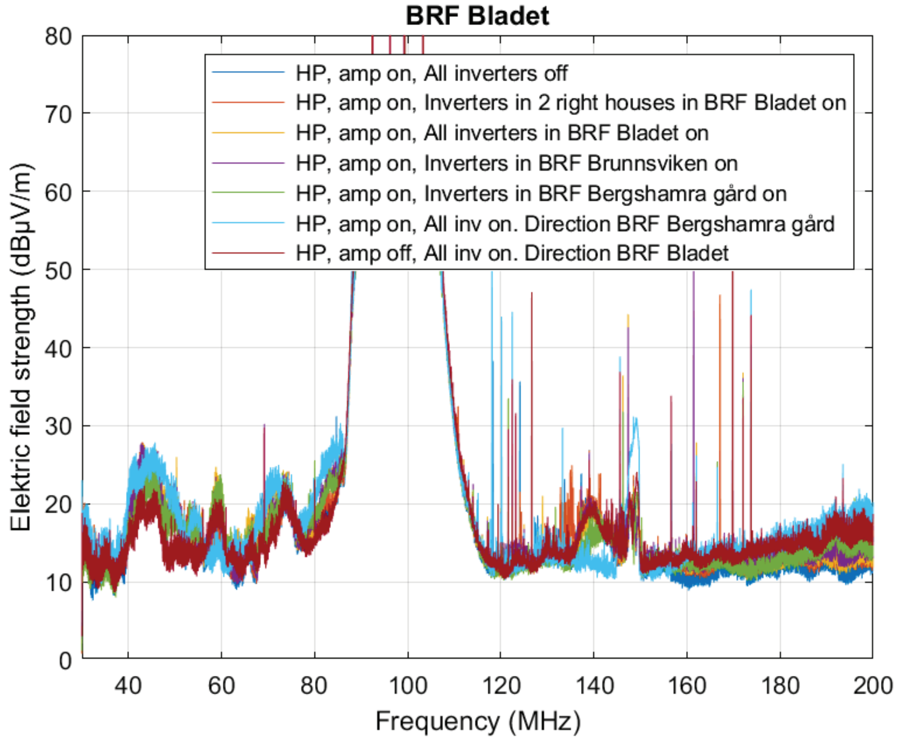

Figure 66. Radiated emissions in the frequency range 30 to 200 MHz for horisontal polarization.

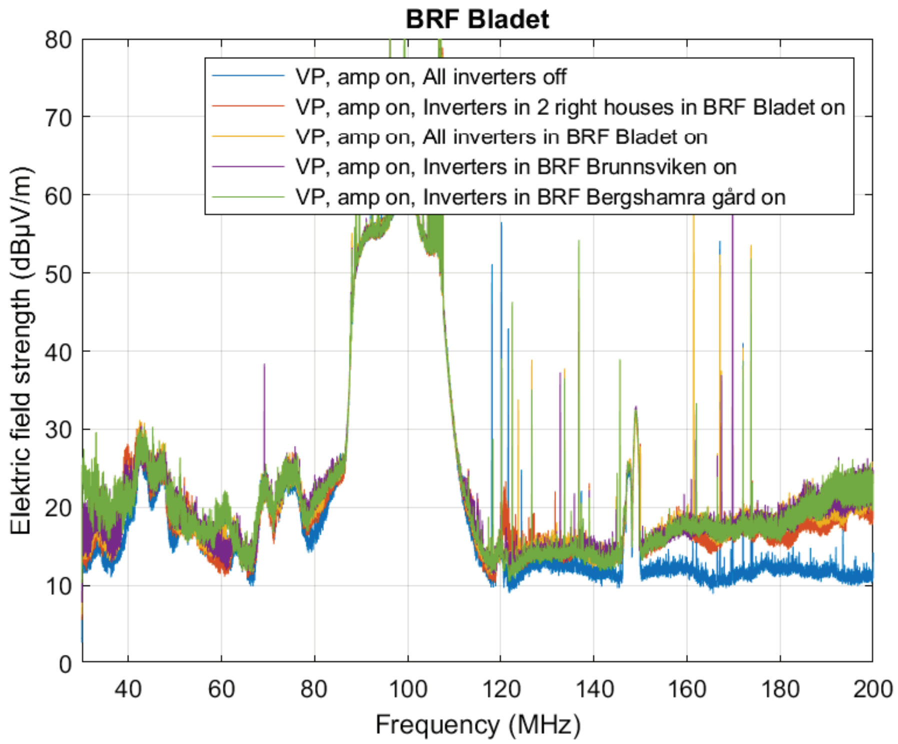

Figure 67. Radiated emissions in the frequency range 30 to 200 MHz for vertical polarization.

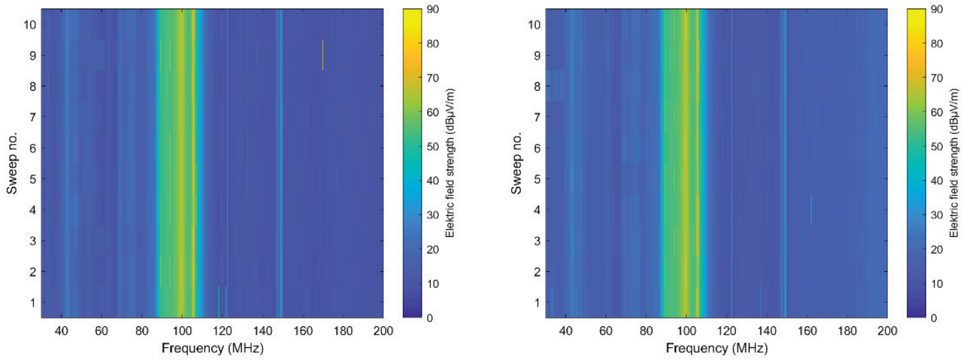

Figure 68. Spectrogram for vertical polarisation with all inverters off and on.

3.4.3.1 Conclusions for the frequency range 20–200 MHz

The measurements show higher levels when inverters are turned on. For vertical polarisation, the increase is between 5 and 10 dB for the frequency range 30–40 MHz and between 7–15 dB for 140 –200 MHz. For horizontal polarization, the difference is slightly lower.

3.4.4 Frequency range 200–1000 MHz

This section presents results for radiated emission measurements in terms of the electrical field strength in the frequency range 200 to 1000 MHz.

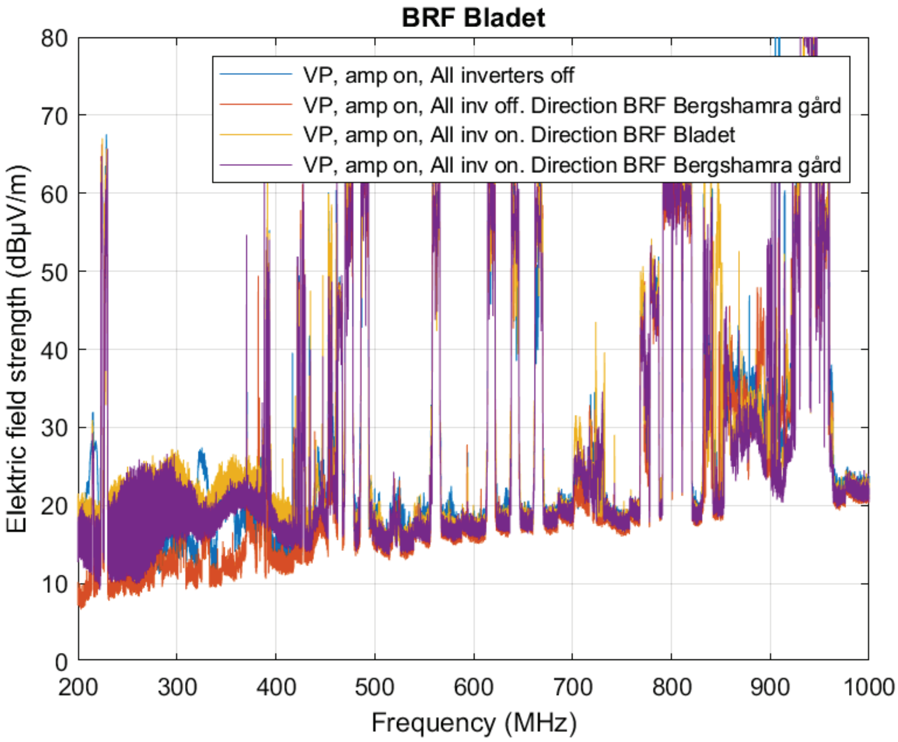

Figure 69. Radiated emissions in the frequency range 200 MHz to 1 GHz for vertical polarisation

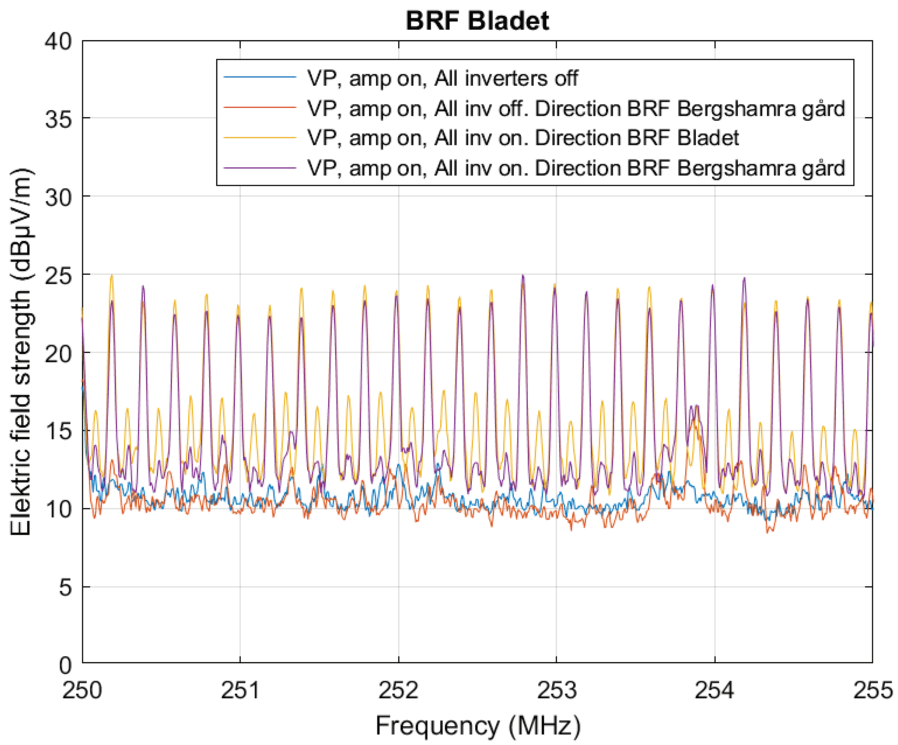

Figure 70. Magnification of frequencies 250–255 MHz showing peaks with 200 kHz separation.

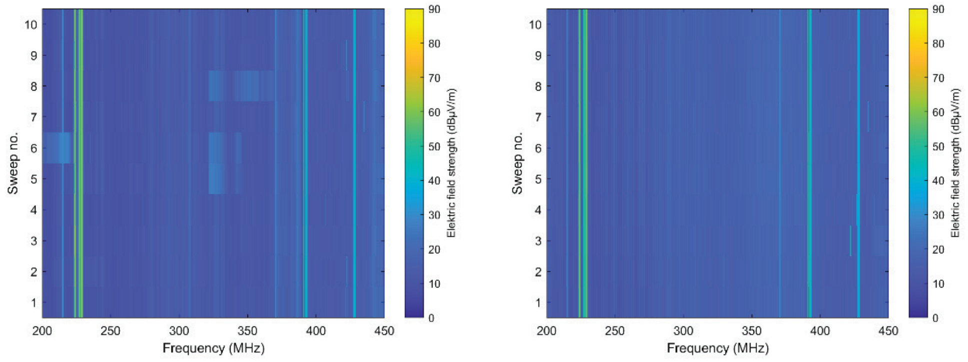

Figure 71. Spectrogram for 200–450 MHz with all inverters off and on.

3.4.4.1 Conclusions for the frequency range 200–1000 MHz

The measurements show higher levels in the frequency range 200–450 MHz when all inverters are turned on. The difference is about 5–15 dB.

The 200 kHz-peaks are still very clear in the magnification of the frequency band 250 to 255 MHz.

4 Conclusions

When measuring in an environment with other signals, it is difficult to determine which signals come from the measuring object and which come from other sources in the environment. This is further complicated by the fact that the environment is not constant and signals can be short lived and only present during some measurements. In all frequency bands there are also radio transmitters that can be strong. This is especially pronounced for FM radio and mobile communication.

In order to get an idea of which emissions that are generated in a photovoltaic system, conducted measurements were first performed on inverters at two different sites. At the measurements with the inverters turned on, there were repetitive peaks at 16.7 and 100 and 200 kHz intervals, which were relatively constant over time. In addition, there were strong peaks at 53 or 78 kHz and multiples thereof that were intermittent. When the inverters were turned off, the peaks with 16.7 and 100 and 200 kHz disappeared during the measurements in the lowest frequency band, however, the strong intermittent signals remained together with other emissions. It is clear that signals are still being generated even though the inverter is turned off. The cause is that optimizers are not totally turned off when the inverter is off.

The fact that the photovoltaic systems generates emissions even when the inverter is turned off makes it more difficult to compare cases with inverters on and off to determine whether the measured emission originates from the photovoltaic system. In the surroundings, there are probably also more photovoltaic systems that can also affect the measurements.

In the measurements of radiated emissions, the surrounding environment varied, especially in the lowest frequency bands. Peaks with the same frequency intervals are also visible in the emission measurements as the peaks in the conducted measurements. For the frequency band 1–30 MHz, for example, signals with 16.6 kHz intervals are present, while in the higher frequency bands it is primarily peaks with 200 kHz intervals that are visible. These emissions are present at least for frequencies up to 450 MHz.

In addition to the narrowband peaks, there is also a general increase in the background noise in certain frequency ranges.

5 References

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