Performance test HFPD and PryCam Wing sensor

Prysmian Netherlands B.V.

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Contact person:	Jos van Rossum
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KEMA Nederland B.V.

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1 EXECUTIVE SUMMARY

Prysmian has requested DNV GL to:

- witness a "performance test" as described in the Prysmian procedure "IME16-20" [1]
- verify that Prysmian has performed the tests in accordance with the aforementioned procedure "IME16-20"
- confirm the measurement results
- draft a report describing the tests, test results and conclusions.

The relevant observations made during the measurements are summarized as follows:

1. The measurements have been performed according to the Prysmian test protocol IME-16-20 [1]
2. Both systems (HPFD and Pry-Cam Wing) are capable to measure signals in the frequency spectrum that is associated with partial discharge signals in cables. Successful measurements have been performed, using both systems, with signals generated by a PD-calibrator (pulses according to IEC60270) and using corona discharges. The signal to noise ratios for both systems are comparable for measurements performed at the location of a joint, for measurements performed at the cable termination the Pry-Cam Wing sensor performed better
3. Measurements have shown that the acquired signal level for the Pry-Cam Wing sensor is strongly dependent on the distance between the sensor and the cable. This is an indication that the Pry-Cam Wing sensor is detecting a signal that is travelling in or along the cable
4. Measurements performed on a "floating" Pry-Cam Wing sensor (not connected to a cable or accessory) have shown that in the test setup used there is a significant amount of signal injected in several other conductive paths in the surroundings of the test object, such as the earth mesh grid that is present underneath the test loop. Another propagation path in which signal is injected is the channel between the cable's (metallic) earth screen and earth. This an inevitable consequence due to the physical properties of a test loop as used
5. Measurements results have shown that both sensors are to a large extent susceptible to injected signals (either from the calibrator or corona) that are running in between the cable's (metallic) earth screen and earth
6. Since the tests were done on a test loop in a high voltage test laboratory, measurements and conclusions might be different if performed on operational HV connections (with different physical properties, surroundings, etc.) but this is outside the scope of this investigation.

2 INTRODUCTION

Prysmian has requested DNV GL to:

- witness a "performance test" as described in the Prysmian procedure "IME16-20" [1]
- verify that Prysmian has performed the tests in accordance with the aforementioned procedure "IME16-20"
- confirm the measurement results
- draft a report describing the tests, test results and conclusions.

The performance test has taken place on Thursday 25 February in the Prysmian laboratory in Delft, The Netherlands, in the presence of:

Prysmian:

- Jos van Rossum
- Bas Wegbrans
- Ignaat Eijpe
- Theo Hermans
- Roberto Candela
- Georgios Villas.

TenneT:

- Shima Mousavi Gargari
- Jan de Jong
- John Verduijn.

Ensol:

- Arjan Winters

DNV GL:

- Bernd van Maanen.

In section 3 of this report a brief description of test object, sensors and the test protocol is given. The test results are described in section 4. Forthcoming conclusions are discussed in section 5.

3 DESCRIPTION OF THE TEST

3.1 Test object

Prysmian has drafted a test protocol in the document "IME16-20" [1] for the execution of a "performance tests on Pry-Cam Wing and HFPD sensors".

The tests have been performed on a cable system consisting out of a cable loop of approximately 30 meters with two cross-bonding joints (type CFJX-420) and two outdoor terminations (type OTC-420). The cable is of the voltage class 220/380 kV with a 3000 mm^2 Milliken type Aluminum conductor. A schematic drawing of the loop is depicted in Figure 1 [1]. One photograph depicting the test loop (partly) is given in Figure 2.

DNV GL has not been involved in the design of the cable test loop or the procedure for the measurement.

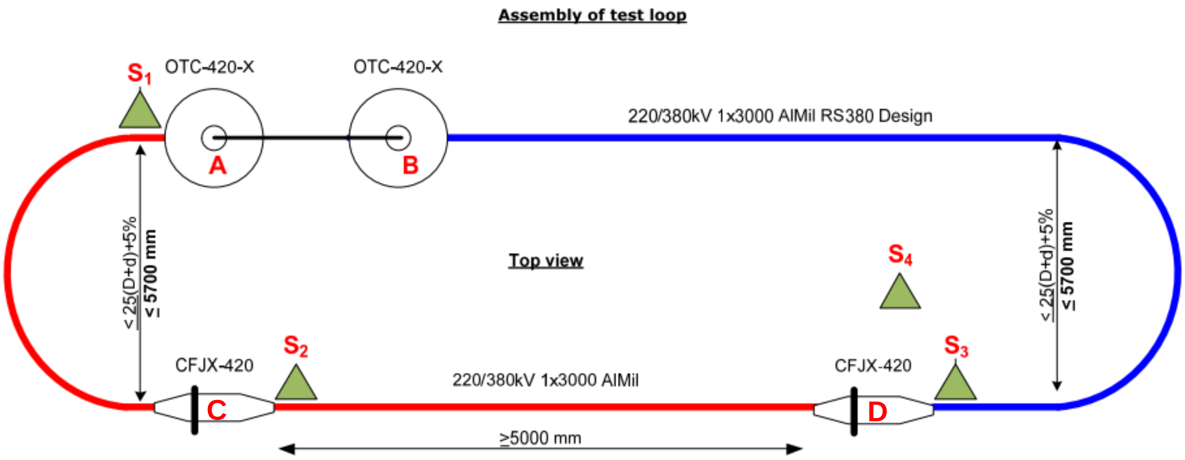

Figure 1 Assembly of the test loop.

Figure 2 Photo of the test loop.

3.2 Sensors

The following sensors are placed in the test loop, see Table 1.

Table 1 Sensors placed on/within the terminations and joints within the test loop

Position	HFPD sensor present	Pry-Cam Wing sensor present
Termination A	yes	yes
Termination B	yes	no
Joint C	yes	yes
Joint D	yes	yes

In Figure 1 the position of the Pry-Cam Wing sensors are indicated with the symbols S_1 – S_4. The Pry-Cam Wing and HFPD sensors are located close to each other (~50 cm or less) at each joint and termination, therefore these locations are assumed identical.

Note that sensor S_4 is located in a "floating" position, i.e. not directly to an accessory. The sensor is placed on an insulating (plastic) tube. The distance to the nearest cable joint us approximately 1,5 meter. The purpose of this position is to determine to what extent signals will be measured when the Pry-Cam Wing sensor is not mounted to a cable accessory.

Some examples of the sensors and how these are mounted on the accessories are depicted in Figure 3 and Figure 4.

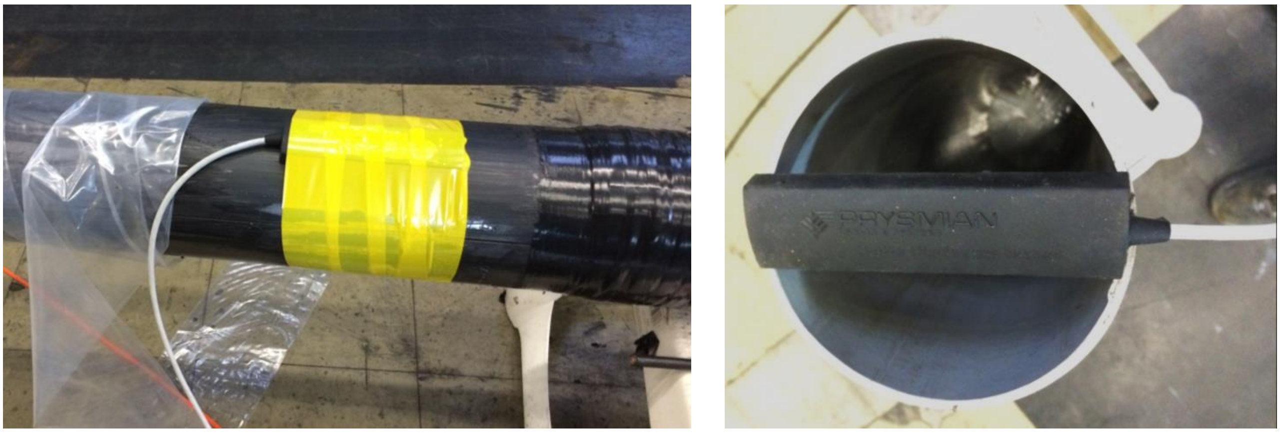

Figure 3 The Pry-Cam Wing sensors as mounted close to joint D (location S_3), photo to the left, and on a "floating" position (location S_4), photo to the right.

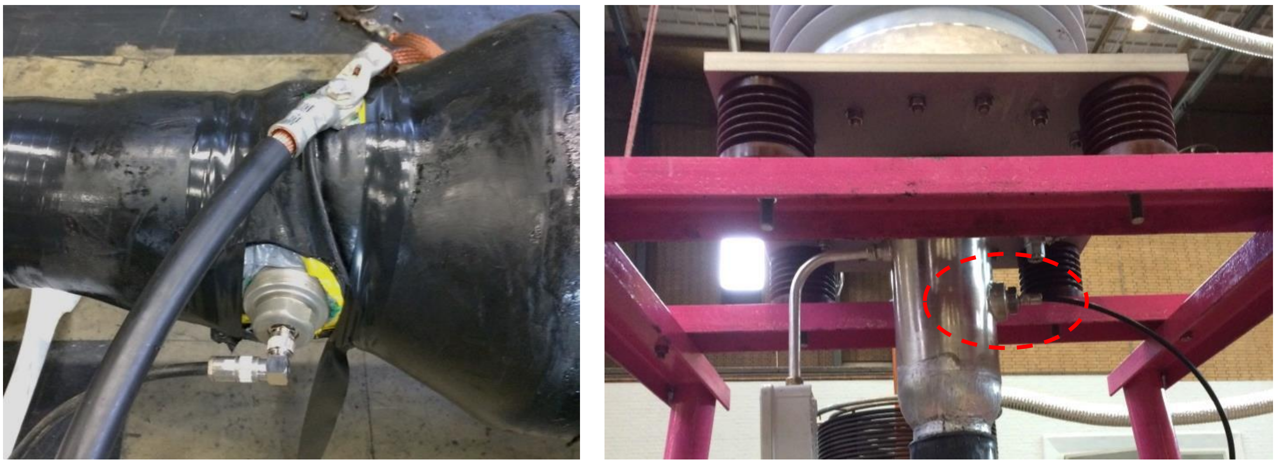

Figure 4 The HFPD sensor as mounted close to joint D (location S_3, photo left) and close to termination A (location S_1, photo right).

Both sensor types are connected to an Omicron MPD600 measurement system for analysis of the measured values. This also means that the interpretation of both sensors is done using the same software environment which is of benefit to the interpretation.

Injection of calibration pulses is done using an Omicron PD calibrator type CAL542, see Figure 5. This calibrator injects pulses with a rise-time less than 4 ns and is as such suitable for the high-frequency tests that are performed.

Figure 5 The PD-calibrator that was used for the tests.

3.3 Testprotocol

The test protocol drafted by Prysmian [1] for the “performance tests on Pry-Cam Wing and HFPD sensors” is depicted in Table 2.

Table 2 The test protocol drafted by Prysmian.

	1	2	3	4	5
	Test	Test method according to	Requirements	Results	Measuring Instrument(s) (see annex)
A.1	Response of both PD detection systems to standard calibration impulses (IEC60270) at the same center frequencies and bandwidth.	-	Calibrator set at 100pC	**Wing Sensor:** - SNR - Frequency response - Acquired pulse shape **HFPD Sensor:** - SNR - Frequency response - Acquired pulse shape	Omicron MPD600 measuring equipment
A.2	Response of both PD detection systems to introduced corona discharges at the same center frequencies and bandwidth.	-	Increase voltage to acquire measurable Corona.	**Wing Sensor:** - SNR - Frequency response - Acquired pulse shape **HFPD Sensor:** - SNR - Frequency response - Acquired pulse shape	Omicron MPD600 measuring equipment
A.3	Response of detection system to introduced corona discharges using the two Pry-Cam Wing sensors at locations S3 and S4 (on floor) at the same center frequencies and bandwidth.	-	Increase voltage to acquire measurable Corona.	**Wing Sensor S3:** - SNR - Frequency response - Acquired pulse shape **Wing Sensor S4:** - SNR - Frequency response - Acquired pulse shape	Omicron MPD600 measuring equipment

4 RESULTS

4.1 Test A.1

The response of both test systems to calibration pulses of 100 pC (pulses according to IEC60270) was tested by injecting pulses between the cable's earth screen and the cable conductor. An indicative drawing of the setup depicting how the calibrator is connected is given in Figure 6.

Figure 6 Indication of the connection of the calibrator for pulse injection.

4.1.1 Sensors S3, S4 and HFPD sensor near joint D

With the available measurement/acquisition system three individual measurement channels are available. For this test these channels are connected as follows:

- channel 1: Pry-Cam Wing sensor S3 (near joint D)
- channel 2: HFPD sensor near joint D
- channel 3: Pry-Cam Wing sensor S4 (floating near joint D).

Measurements have been performed over a broad frequency spectrum in order to obtain the frequency response of both systems. The following center frequencies have been used:

- 100 kHz
- 500 kHz
- 1 MHz
- 2 MHz
- 4 MHz
- 6 MHz
- 8 MHz
- 10 MHz
- 15 MHz
- 20 MHz.

For all measurements a bandwidth (centered around the center frequency) of 1.5 MHz has been used.

Injected pulses from the calibrator are used to calibrate each individual channel, provided that a signal from the calibrator can be detected. The calibration procedure has been performed at each center frequency. As such, the noise levels for the different sensors can be compared. The calibrator used injects 6 pulses each full period (50) Hz, thus 6 pulses per 20 ms. In Figure 7 the measurement results are depicted for a measurement with center frequency 100 kHz. Note that here no signal from the calibrator could be detected in channel 3. For this reason, this channel could therefore not be calibrated at this frequency.

Figure 8 depicts the same measurement, but now at a center frequency of 8 MHz. Here a signal is detected at channel 3 as well.

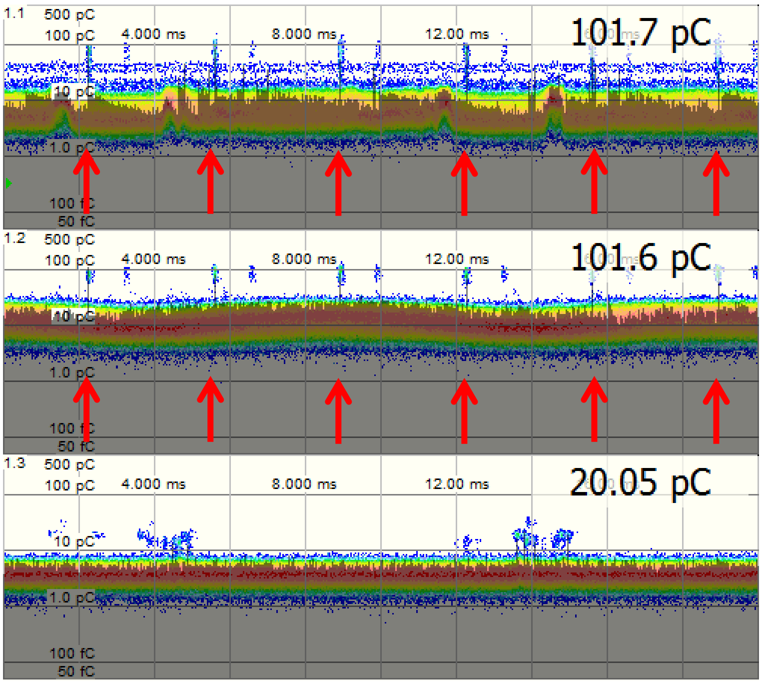

Figure 7 Measurement at a center frequency of 100 kHz. From top to bottom channel 1, 2 and 3.

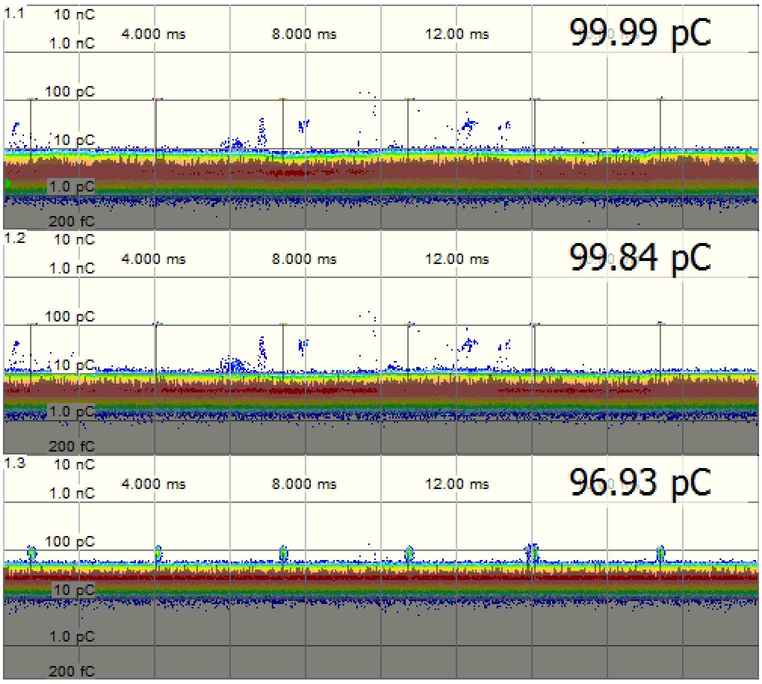

Figure 8 Measurement at a center frequency of 8 MHz. From top to bottom channel 1, 2 and 3.

The results of the measured (calibrated) noise levels are depicted in Table 3. When the results state "n.a." this means that there was no signal detected (signal below the noise level) from the calibrator. As such, for these cases no valid statement can be made regarding the noise level as there is no calibration possible. In some cases (indicated with *) a signal can just be seen above the noise level, helped by the fact that the calibrator injects a clear (expected) pulse pattern. In practice, for these cases, the signal and noise levels are basically equal.

Table 3 Measured noise levels after calibration at 100 pC.

Center frequency	noise level channel 1 (Pry-Cam Wing S3) [pC]	noise level channel 2 (HFPD near joint D) [pC]	noise level channel 3 (Pry-Cam Wing S4) [pC]
100 kHz	45	35	n.a.
500 kHz	n.a.	n.a.	n.a.
1 MHz	n.a.	n.a.	n.a.
2 MHz	100*	100*	n.a.
4 MHz	20	15	n.a.
6 MHz	12	15	n.a.
8 MHz	10	12	65
10 MHz	15	10	60
15 MHz	20	35	100*
20 MHz	15	30	80

*) the calibration signal is just detectable above the noise. However, the signal level is nearly equal to the noise level.

Based directly on Table 3, the calculated results for the Signal-to-Noise Ratios (SNR) are depicted in Table 4.

Table 4 Signal to noise ratio at the various center frequencies.

Center frequency	SNR channel 1 (Pry-Cam Wing S3) [dB]	SNR channel 2 (HFPD near joint D) [dB]	SNR channel 3 (Pry-Cam Wing S4) [dB]
100 kHz	7	9	n.a.
500 kHz	n.a.	n.a.	n.a.
1 MHz	n.a.	n.a.	n.a.
2 MHz	0*	0*	n.a.
4 MHz	14	16	n.a.
6 MHz	18	16	n.a.
8 MHz	20	18	4
10 MHz	16	20	4
15 MHz	14	9	0
20 MHz	16	10	2

*) the calibration signal is just detectable above the noise. However, the signal level is nearly equal to the noise level

The pulse shapes of the measured signals from the Pry-Cam Wing and HFPD sensors are compared, as depicted in Figure 9 for a center frequency of 4 MHz. Comparison of the waveforms is difficult, mainly due to the following practical limitations:

- The measurements are performed at a relatively small bandwidth of 1.5 MHz. Because of this, significant amounts of ringing are seen around the measured pulse (signal with a large bandwidth)
- Due to the relatively short length of the test object there are many reflections observed in the signal.

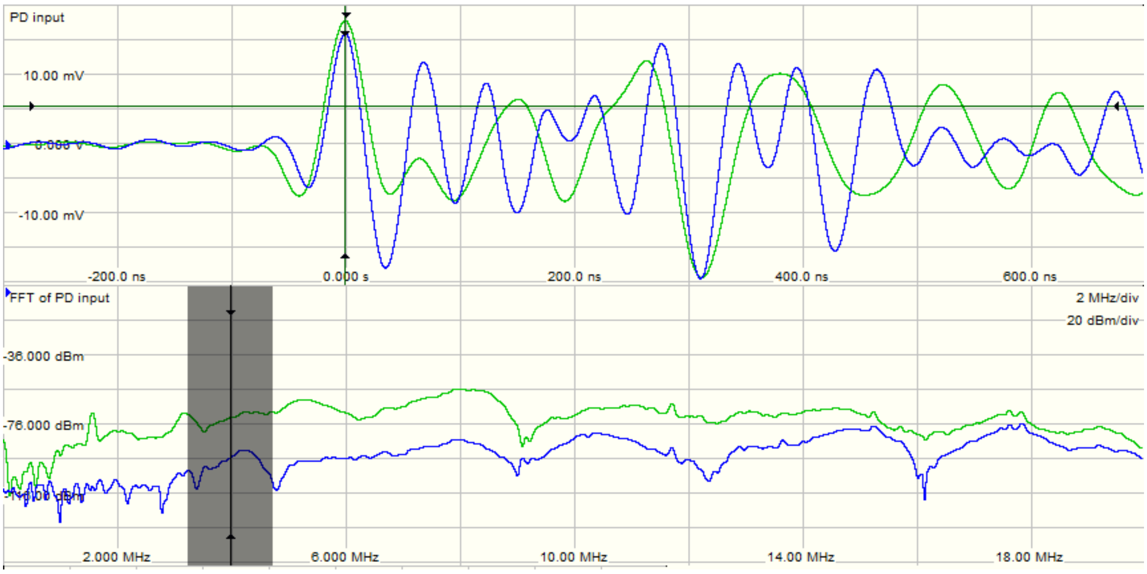

Figure 9 Example of a received pulse for channel 1 (green) and channel 2 (blue). The top graph shows the signal in time domain, the graph below indicated the associated frequency spectra.

The following relevant observations were made during the measurements:

1 The signal level measured at channel 3 (floating sensor near joint D) shows a strong dependency of the distance between the sensor and the floor. When the sensor is moved closer to the floor, the signal level increases significantly. Note that the distance to the cable is kept nearly constant in this procedure. Prysmian stated that in the laboratory floor (underneath the test loop) a meshed earth grid is present. Presumably it is this meshed grid that picks up a part of the injected signal from the calibrator. Thus, the Pry-Cam Wing it (also) susceptible to the signal that runs in this earth mesh.

2 The signal level in channel 2 is strongly dependent on the distance between the sensor and the cable. When the sensor is moved away from the cable by a couple of centimeters, the signal level drops significantly. This is an indication that the Pry-Cam Wing sensor is detecting a signal that is travelling in or along the cable.

With regards to the second observation the following remark is made. It is unclear whether the signal that is travelling along the cable is present in between the cable conductor and earth screen (as is the case for a naturally occurring partial discharge pulse), that it is present between the cable's earth screen and earth or a combination of these two. Note that in a laboratory setup as this, there exists a viable propagation path for high frequency (PD) pulses between the cable's earth screen and earth. Due to the physical dimensions of a laboratory setup as this, it is very difficult to inject pulses (using a calibrator) in only one of the propagation channels. This is also the reason why similar signals are present in the earth mesh grid (observation 1)

A repeated measurement has been performed where the PD-calibrator is connected between the cable's earth screen and earth. In Figure 10 the connections of the PD-calibrator are shown. The results for the Pry-Cam Wing sensor (S3) are depicted in Figure 11 and for the HFPD sensor near joint D in Figure 12.

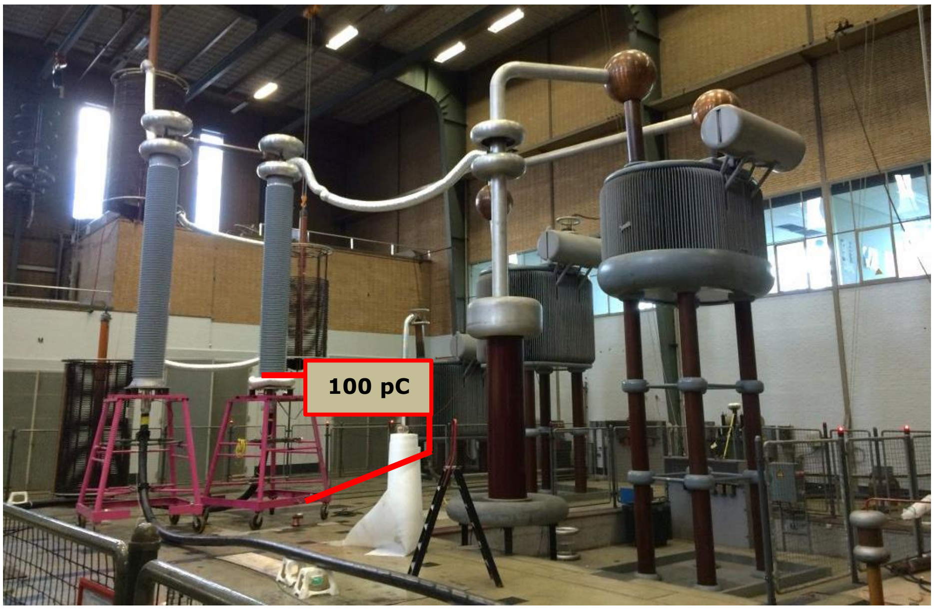

Figure 10 Indication of the way the PD-calibrator has been connected.

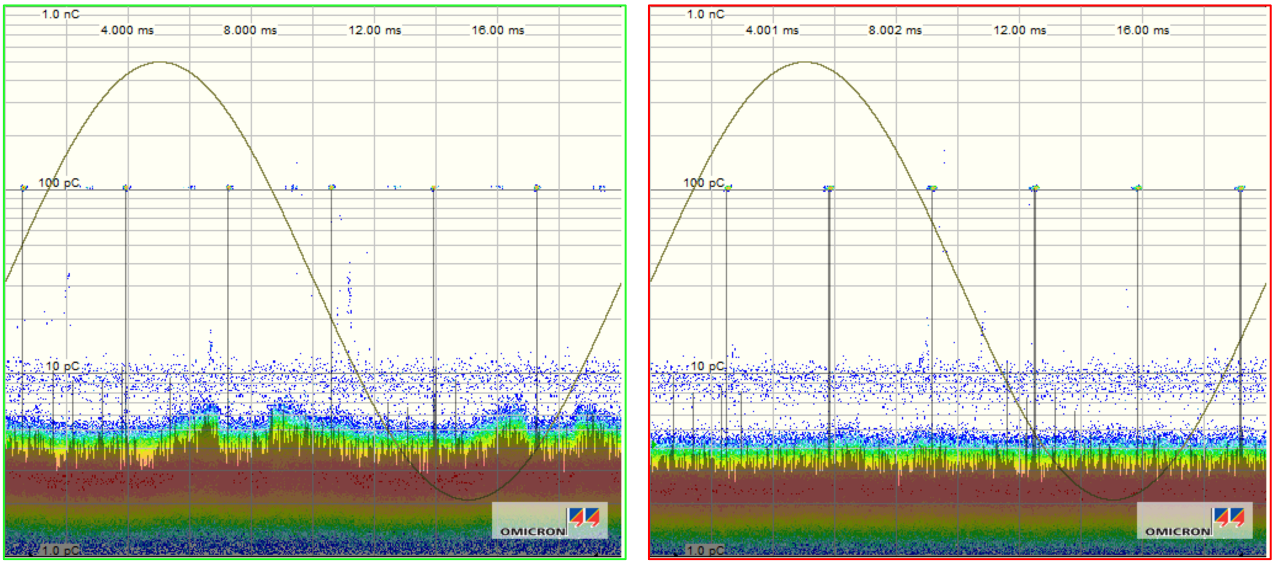

Figure 11 Measurement results for channel 1 (Pry-Cam Wing, location S3) with center frequency 6 MHz for signals injected conductor and earth screen (left figure) and for signals injected between the earth screen and earth (right figure)

The following is noted:

- The "divider factor" (factor that is set during the calibration process) is for both measurements with the Pry-Cam Wing sensor nearly equal (4,98 vs. 4,96)
- The "divider factor" is for both measurements with the HFPD sensor significantly different (129 vs. 202).

The significance of this is that the calibration results for the Pry Cam Wing are practically equal for both the injection between the conductor and screen (like a "real" PD) and for injection between the earth screen and earth. This is an indication that the Pry-Cam Wing sensor is (also) to a significant extent susceptible to signals that are propagating between the screen and earth.

For the HFPD sensor the calibration results are significantly different for injection in the different channels. It is however clear that also this sensor is susceptible to signals that propagate between the earth screen and earth, which can also be explained directly from the working principle for this sensor.

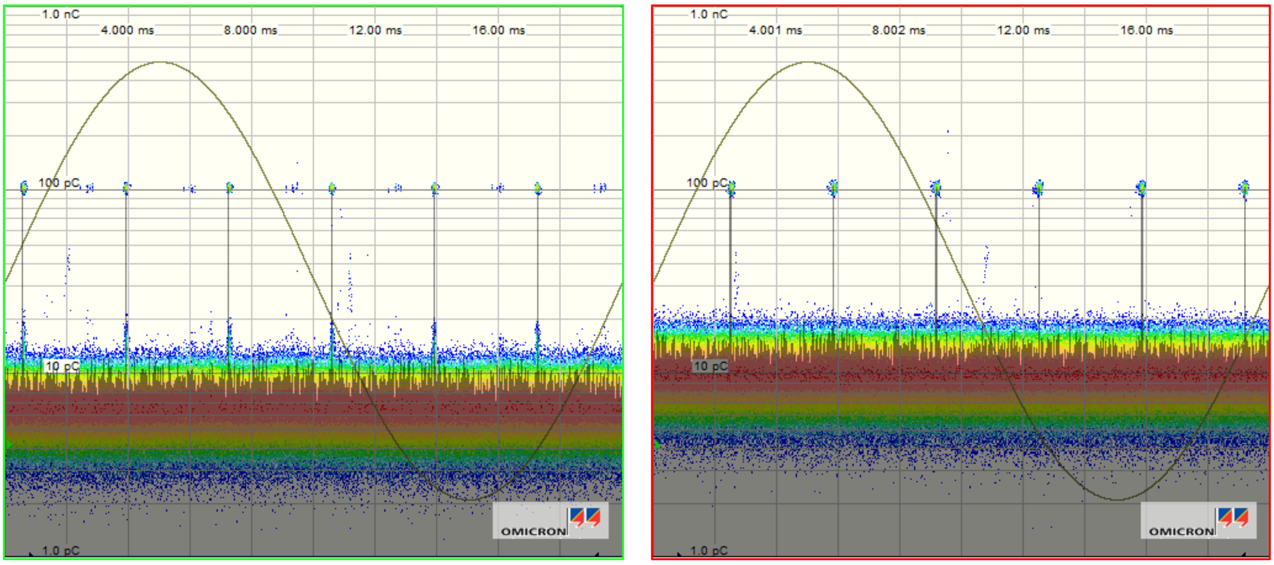

Figure 12 Measurement results for channel 2 (HFPD near joint D) with center frequency 6 MHz for signals injected conductor and earth screen (left figure) and for signals injected between the earth screen and earth (right figure)

4.1.2 Sensors S1, S4 and HFPD sensor near termination A

For this test these channels are connected as follows:

- channel 1: Pry-Cam Wing sensor S1 (near termination A)
- channel 2: HFPD sensor near termination A
- channel 3: Pry-Cam Wing sensor S4 (floating near joint D).

Measurements have been performed over a broad frequency spectrum in order to obtain the frequency response of both systems. The following center frequencies have been used:

- 100 kHz
- 500 kHz
- 1 MHz
- 2 MHz
- 4 MHz
- 6 MHz
- 8 MHz
- 10 MHz
- 15 MHz
- 20 MHz.

For all measurements a bandwidth (centered around the center frequency) of 1.5 MHz has been used.

Injected pulses from the calibrator are used to calibrate each individual channel, provided that a signal from the calibrator can be detected. The calibration procedure has been performed at each center frequency. As such, the noise levels for the different sensors can be compared. The calibrator used injects 6 pulses each full period (50) Hz, thus 6 pulses per 20 ms.

The results of the measured (calibrated) noise levels are depicted in. When the results state "n.a." this means that there was no signal detected (signal below the noise level) from the calibrator. As such, for these cases no valid statement can be made regarding the noise level as there is no calibration possible.

Table 5 Measured noise levels after calibration at 100 pC.

Center frequency	noise level channel 1 (Pry-Cam Wing S1) [pC]	noise level channel 2 (HFPD near termination A) [pC]	noise level channel 3 (Pry-Cam Wing S4) [pC]
1 MHz	55	n.a.	70
2 MHz	40	80	35
4 MHz	20	25	12
6 MHz	15	50	20
8 MHz	50	80	75
10 MHz	35	50	70
15 MHz	90	n.a.	n.a.
20 MHz	n.a.	n.a.	n.a.

Based directly on Table 5, the calculated results for the Signal-to-Noise Ratios (SNR) are depicted in Table 6.

Table 6 Signal to noise ratio at the various center frequencies.

Center frequency	SNR channel 1 (Pry-Cam Wing S1) [dB]	SNR channel 2 (HFPD near termination A) [dB]	SNR channel 3 (Pry-Cam Wing S4) [dB]
1 MHz	5	n.a.	3
2 MHz	8	2	9
4 MHz	14	12	18
6 MHz	16	6	14
8 MHz	6	2	2
10 MHz	9	6	3
15 MHz	1	n.a.	n.a.
20 MHz	n.a.	n.a.	n.a.

Remarkable from this measurement is that a relatively large amount of the injected signal is measured at the floating sensor Pry-Cam Wing sensor on location S4 (channel 3)

4.2 Test A.2 and A.3

Corona discharges have been introduced in the cable test loop by means of a spark-gap construction which can be used to create low intensity discharges in a controlled manner.

The measurements have been performed on the following positions:

1. S3, S4 (Pry-Cam Wing) and a HFPD-sensor near joint D.
2. S1, S4 (Pry-Cam Wing) and a HFPD sensor near termination A.

Measurements have been performed on center frequencies for which a valid calibration results is available as discussed in section 4.1. The calibration factors determined during these calibration sessions have been entered for the corona measurements as a best estimate for comparison of the acquired signals between the different sensors. All corona measurements were performed with a bandwidth of 1.5 MHz.

Note that not for all center frequencies a valid calibration could be acquired. For these cases the charge levels displayed by the system is not calibrated and are therefore not valid. This has been indicated in the relevant figures by a red box covering the values.

4.2.1 S3, S4 (Pry-Cam Wing) and HFPD-sensor near joint D.

The results are depicted graphically in Figure 13 up to and including Figure 18. The measurement channels are connected as follows:

- channel 1: Pry-Cam Wing sensor S3 (near joint D)
- channel 2: HFPD sensor near joint D
- channel 3: Pry-Cam Wing sensor S4 (floating near joint D).

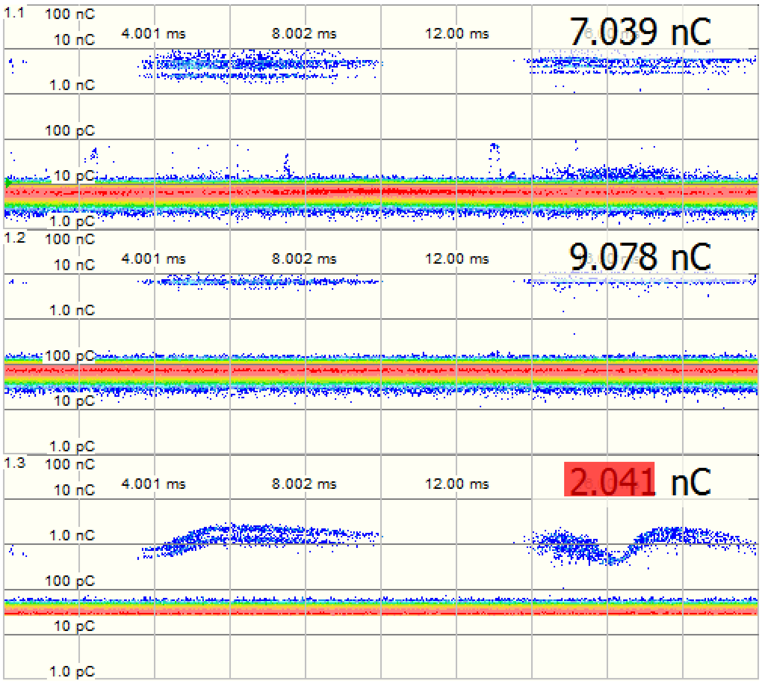

Figure 13 Results for the corona measurements at center frequency 4 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

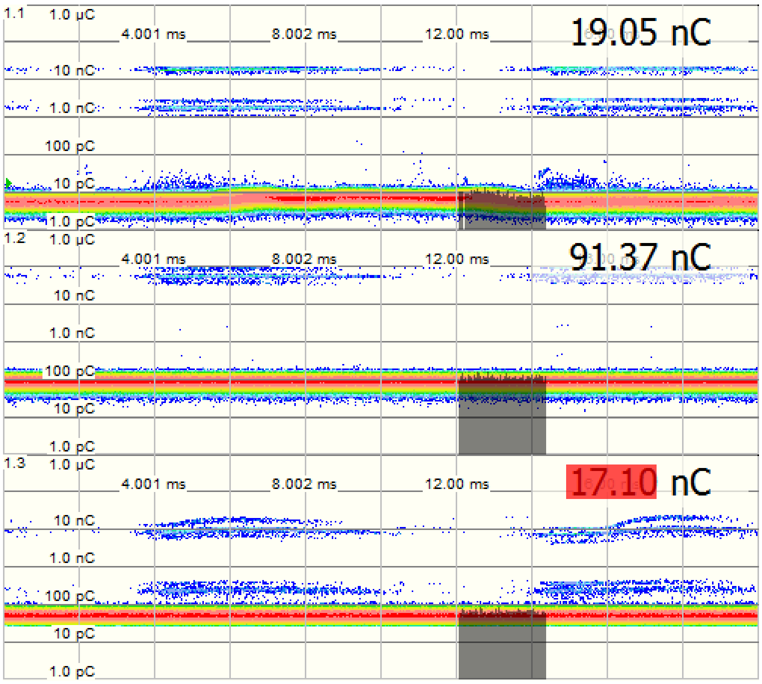

Figure 14 Results for the corona measurements at center frequency 6 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

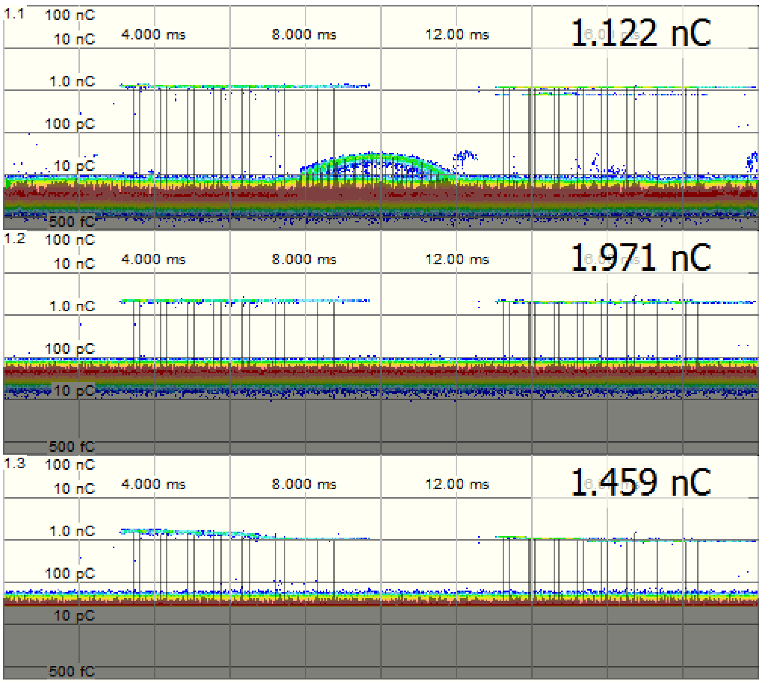

Figure 15 Results for the corona measurements at center frequency 8 MHz. From top to bottom channel 1, channel 2 and channel 3.

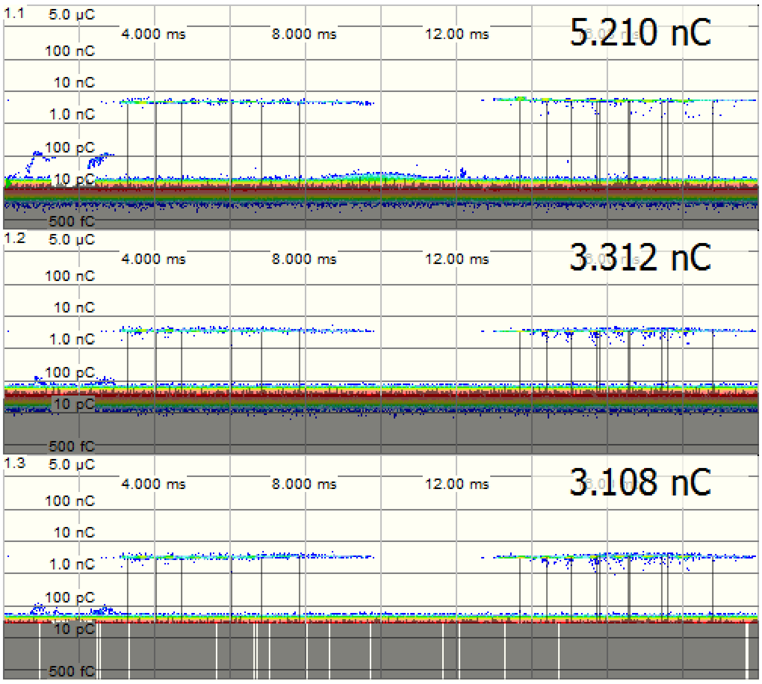

Figure 16 Results for the corona measurements at center frequency 10 MHz. From top to bottom channel 1, channel 2 and channel 3.

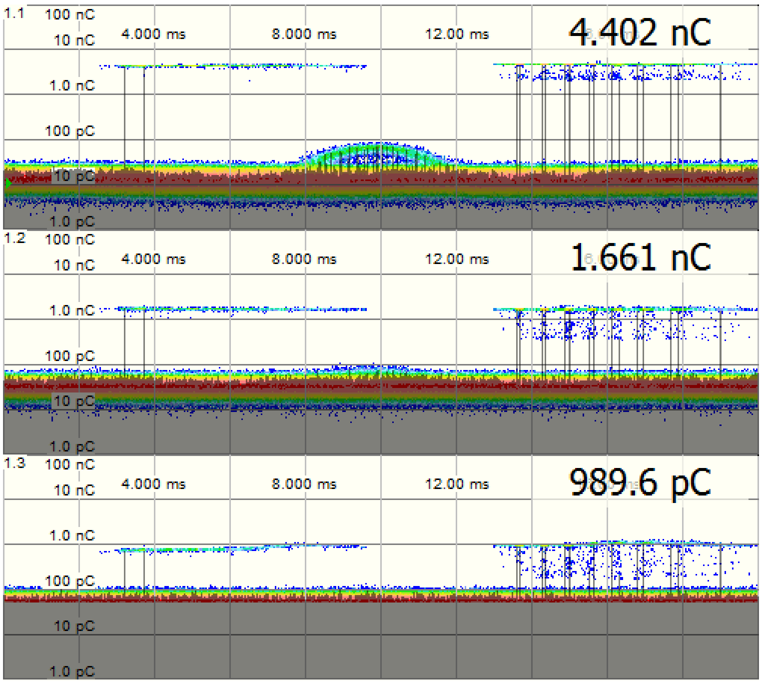

Figure 17 Results for the corona measurements at center frequency 15 MHz. From top to bottom channel 1, channel 2 and channel 3.

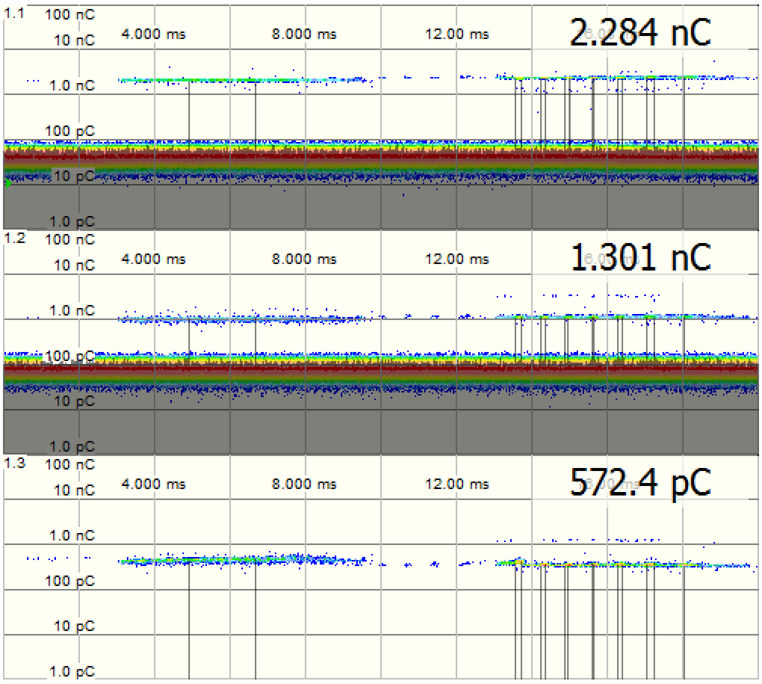

Figure 18 Results for the corona measurements at center frequency 20 MHz. From top to bottom channel 1, channel 2 and channel 3.

The results have been summarized in Table 7.

Table 7 Acquired signal levels for the corona measurements.

Center frequency	channel 1 (Pry-Cam Wing S3) [nC]	channel 2 (HFPD near joint D) [nC]	channel 3 (Pry-Cam Wing S4) [nC]
4 MHz	7.0	9.1	n.a.
6 MHz	19.1	91.4	n.a.
8 MHz	1.1	2.0	1.5
10 MHz	5.2	3.3	3.1
15 MHz	4.4	1.7	1.0
20 MHz	2.3	1.3	0.6

A significant amount of signal is picked up by the “floating” Pry-Cam Wing sensor. The dependency of the acquired signal level and the distance between the floating sensor and the ground was found again. It is quite likely that the explanation for this phenomenon is the same as for calibration procedure described in section 4.1.

The pulse shapes of the measured signals from the Pry-Cam Wing and HFPD sensors are compared, as depicted in Figure 9 for a center frequency of 4 MHz. Comparison of the waveforms is difficult, mainly due to the following practical limitations:

- The measurements are performed at a relatively small bandwidth of 1.5 MHz. Because of this, significant amounts of ringing are seen around the measured pulse (signal with a large bandwidth)
- Due to the relatively short length of the test object there are many reflections observed in the signal.

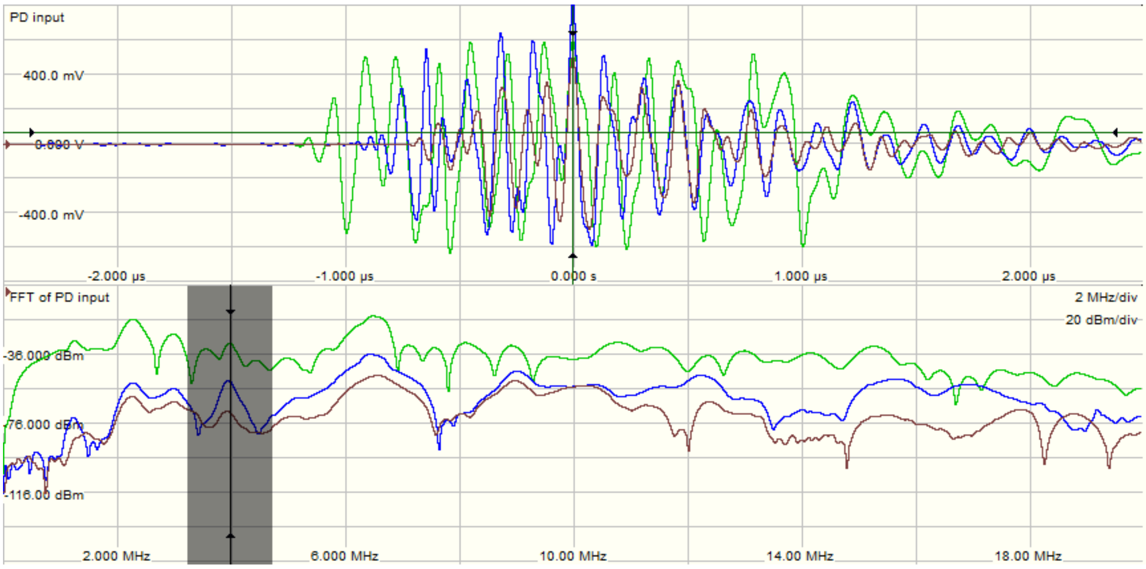

Figure 19 Example of a received corona discharge pulse for channel 1 (green), channel 2 (blue) and channel 3 (brown). The top graph shows the signal in time domain, the graph below indicated the associated frequency spectra.

4.2.2 S1, S4 (Pry-Cam Wing) and the HFPD-sensor near termination A.

For this measurement, sensor S4 has been relocated to a position underneath the connection between the high voltage transformer and termination B. Similar to its previous position, the sensor is in a floating position, at around 1 meter from the ground floor.

The results are depicted graphically in Figure 20 up to and including Figure 23. The measurement channels are connected as follows:

- channel 1: Pry-Cam Wing sensor S1 (near termination A)
- channel 2: HFPD sensor near termination A
- channel 3: Pry-Cam Wing sensor S4 (floating).

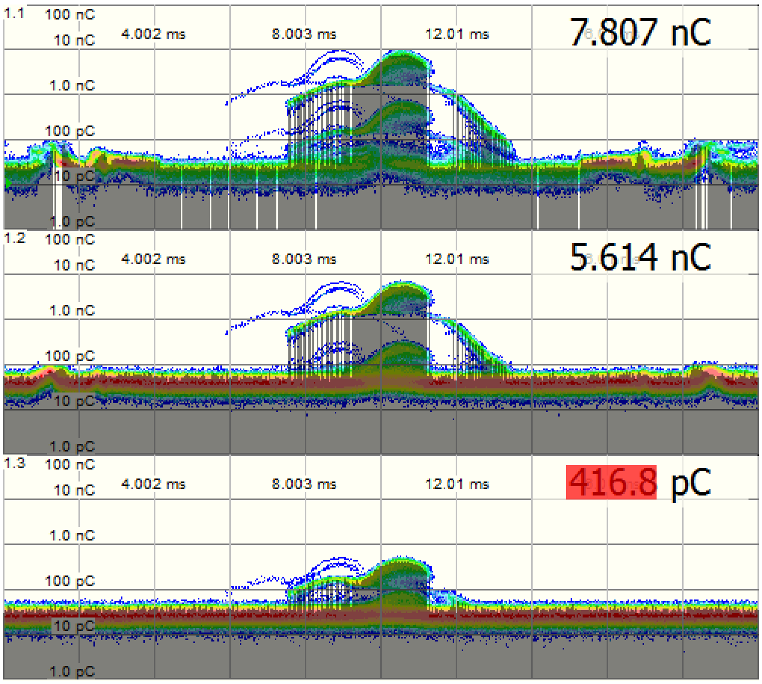

Figure 20 Results for the corona measurement at a center frequency of 2 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

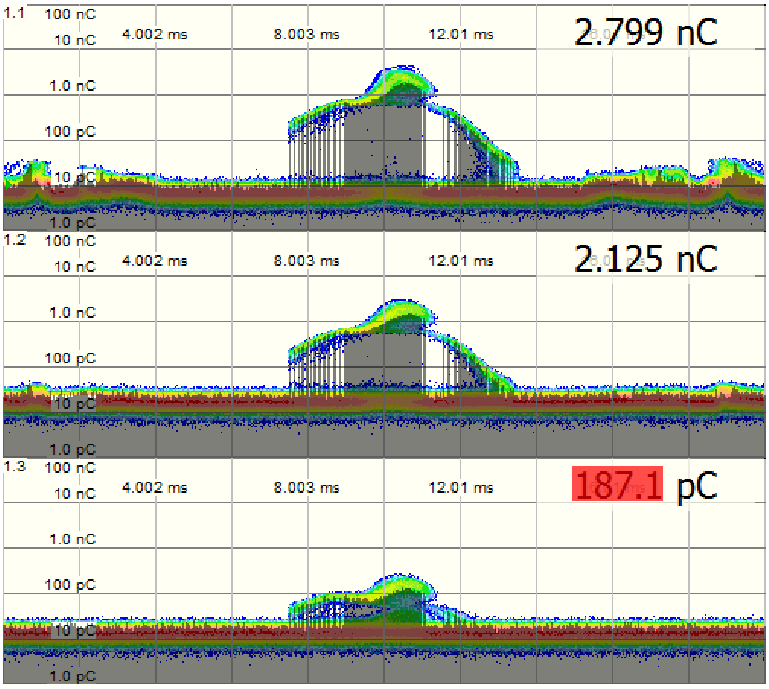

Figure 21 Results for the corona measurement at a center frequency of 4 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

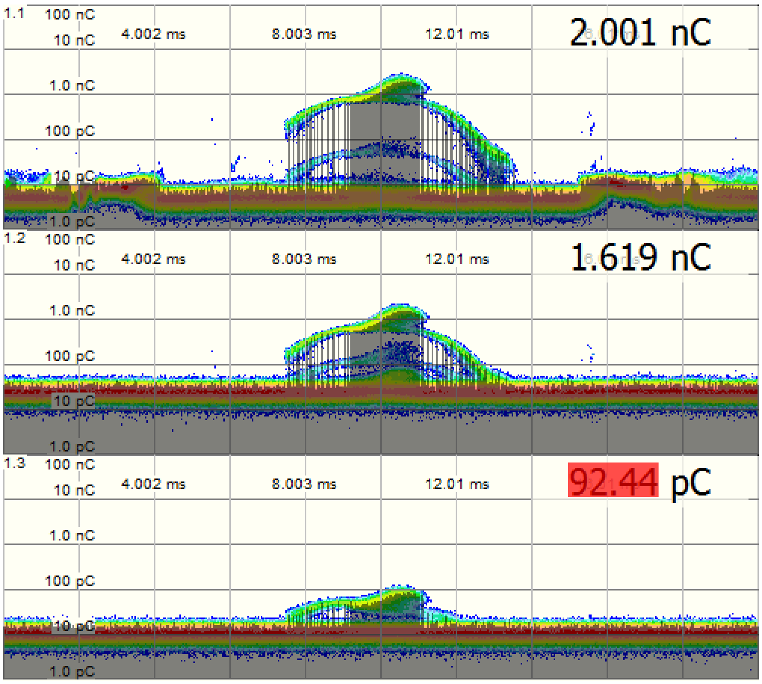

Figure 22 Results for the corona measurement at a center frequency of 6 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

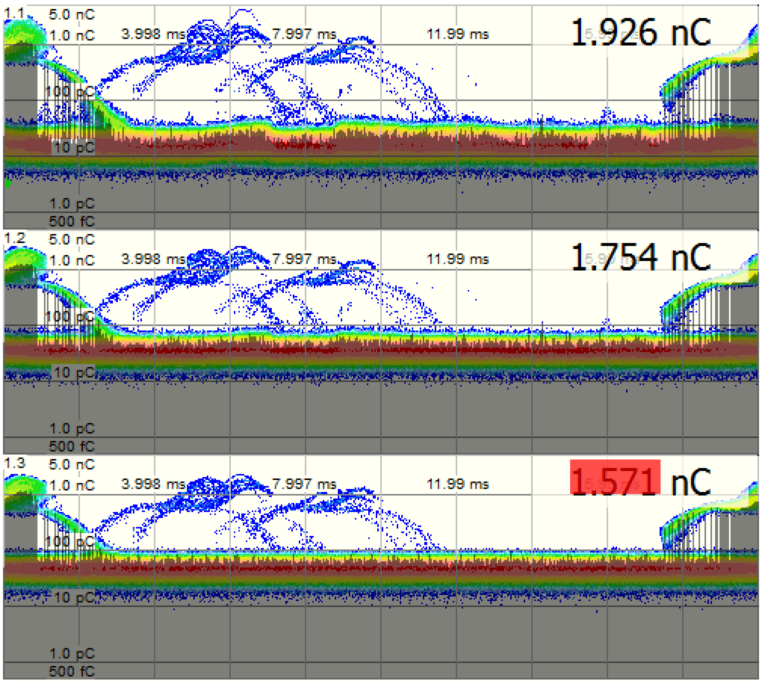

Figure 23 Results for the corona measurement at a center frequency of 8 MHz. From top to bottom channel 1, channel 2 and channel 3 (not calibrated, indicated by the red box).

The results have been summarized in Table 8.

Table 8 Acquired signal levels for the corona measurements.

Center frequency	channel 1 (Pry-Cam Wing S1) [nC]	channel 2 (HFPD near termination A) [nC]	channel 3 (Pry-Cam Wing S4) [nC]
2 MHz	7.8	5.6	n.a.
4 MHz	2.8	2.1	n.a.
6 MHz	2.0	1.6	n.a.
8 MHz	1.9	1.8	n.a.

5 CONCLUSIONS

The relevant observations and conclusions made during the measurements are summarized as follows:

1. The measurements have been performed according to the Prysmian test protocol IME-16-20 [1]
2. Both systems (HPFD and Pry-Cam Wing) are capable to measure signals in the frequency spectrum that is associated with partial discharge signals in cables. Successful measurements have been performed, using both systems, with signals generated by a PD-calibrator (pulses according to IEC60270) and using corona discharges. The signal to noise ratios for both systems are comparable for measurements performed at the location of a joint, for measurements performed at the cable termination the Pry-Cam Wing sensor performed better
3. Measurements have shown that the acquired signal level for the Pry-Cam Wing sensor is strongly dependent on the distance between the sensor and the cable. This is an indication that the Pry-Cam Wing sensor is detecting a signal that is travelling in or along the cable
4. Measurements performed on a "floating" Pry-Cam Wing sensor (not connected to a cable or accessory) have shown that in the test setup used there is a significant amount of signal injected in several other conductive paths in the surroundings of the test object, such as the earth mesh grid that is present underneath the test loop. Another propagation path in which signal is injected is the channel between the cable's (metallic) earth screen and earth. This an inevitable consequence due to the physical properties of a test loop as used
5. Measurements results have shown that both sensors are to a large extent susceptible to injected signals (either from the calibrator or corona) that are running in between the cable's (metallic) earth screen and earth
6. Since the tests were done on a test loop in a high voltage test laboratory, measurements and conclusions might be different if performed on operational HV connections (with different physical properties, surroundings, etc.) but this is outside the scope of this investigation.

6 REFERENCES

1 Prysmian. Performance tests on Pry-Cam Wing Wing and HFPD sensors. Document nr. IME-16-20, dated 17-02-2016.

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