OMICRON

Application Note

Testing Sampled Values publishers with DANEO 400

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Content

1 Safety instructions

This Application Note may only be used in conjunction with the relevant product manuals which contain all safety instructions. The user is fully responsible for any application that makes use of OMICRON products.

Instructions are always characterized by a ▶ symbol, even if they are included in a safety instruction.

DANGER

Death or severe injury caused by high voltage or current if the respective protective measures are not complied with.

- ▶ Carefully read and understand the content of this Application Note as well as the manuals of the systems involved before taking them into operation.
- ▶ Please contact OMICRON support if you have any questions or doubts regarding the safety or operating instructions.
- ▶ Follow each instruction listed in the manuals, especially the safety instructions, since this is the only way to avoid the danger that can occur when working on high voltage or high current systems.
- ▶ Only use the equipment involved according to its intended purpose to guarantee safe operation.
- ▶ Existing national safety standards for accident prevention and environmental protection may supplement the equipment's manual.

Only experienced and competent professionals that are trained for working in high voltage or high current environments may implement this Application Note. Additionally, the following qualifications are required:

- Authorized to work in environments of energy generation, transmission or distribution and familiar with the approved operating practices in such environments.
- Familiar with the five safety rules.
- Good knowledge of *DANEO 400.*

2 Introduction

This Appication Note shows how the *DANEO 400* is used to verify the correct operation of a Sampled Values publisher.

“Sampled Values” mean digitized current and voltage values from electrical power systems, coded and transmitted over Ethernet networks according to the IEC 61850 (IEC 61850-9-2 Ed 2.0, 2011), in particular to the “9-2LE” implementation guideline of the UCA IUG (UCA International Users Group, Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2), and IEC 61869-9.

References to corresponding test cases (Svp*nn*) from the test procedures for Sampled Values publishers from the UCA IUG testing subcommittee (UCA International Users Group, Testing Subcommittee: Test procedures for Sampled Values Publishers according to the "Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2". Version 1.0., 2010) are noted where applicable.

3 Test environment

The test environment as described in UCA International Users Group, Testing Subcommittee: Test procedures for Sampled Values Publishers according to the "Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2". Version 1.0., 2010 is shown in Figure 1.

It consists of:

> The device under test (DUT), which publishes the SV (in this case “9-2LE”) stream.
> A voltage and/or current signal source.
> A SV (“9-2LE”) analyzer.
> A time synchronization setup.

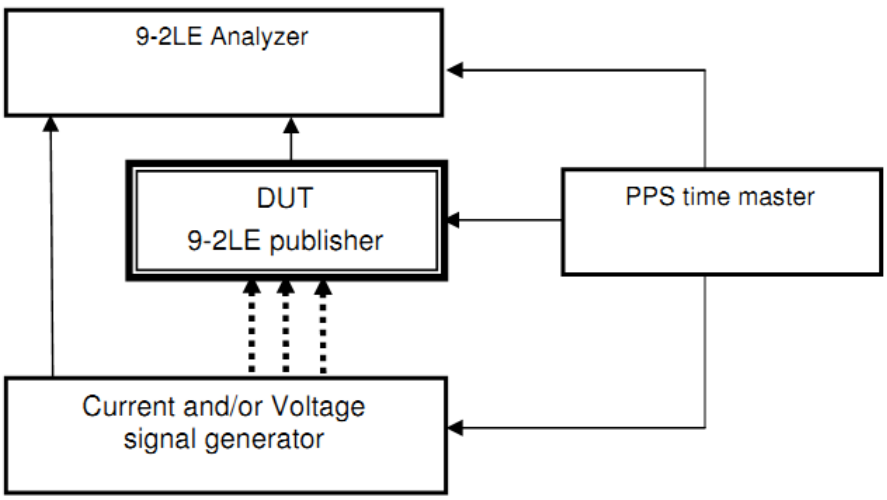

Figure 1: Generic test environment according to UCA International Users Group, Testing Subcommittee: Test procedures for Sampled Values Publishers according to the "Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2". Version 1.0., 2010

For this application note, the generic test environment from Figure 1 is translated into an even simpler test setup as shown in Figure 2, which consists of the following components:

> A CMC test set (in this case a *CMC 256plus*) with Ethernet interfaces (NET-1B or newer), which functions as a combined SV publisher and voltage/current signal source.
> A *DANEO 400*, which acts as a SV analyzer.
> An *OTMC 100*, which acts as a PTP grandmaster clock for the time synchronization of the CMC test set and the *DANEO 400*.

The DUT (typically a merging unit) is omitted, because the SVs are directly generated from the CMC test set.

The *DANEO 400* forwards the PTP traffic over the TAP ports to the CMC. This has the benefit that no PTP transparent switch is required.

The SV stream is transmitted over a direct connection from the CMC to the *DANEO 400*. This ensures that the timing statistics of the measurements are not influenced by any network switch.

All screenshots in this Application Note refer to this test environment, where the devices have been configured as outlined in the following chapters.

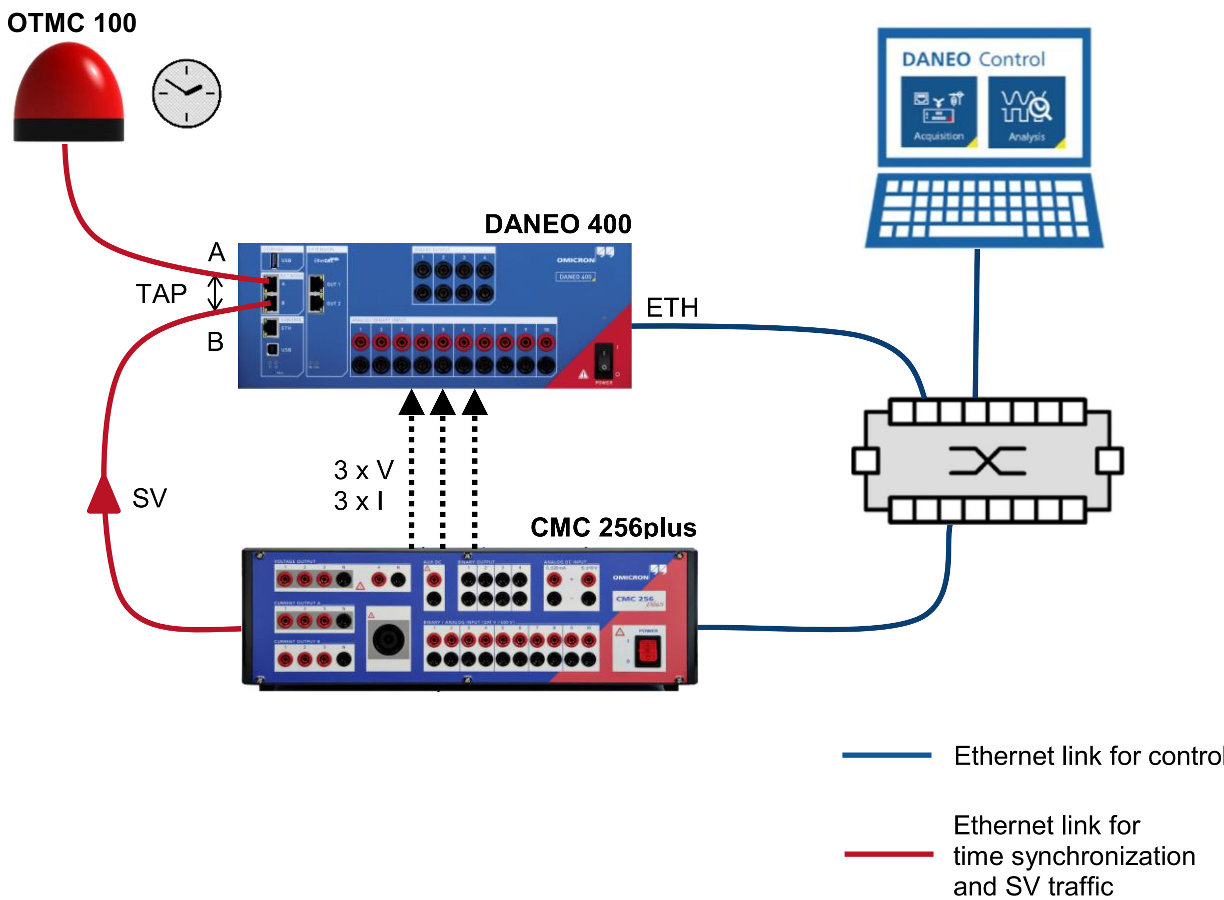

Figure 2: Test environment for this application note.

3.1 Configuring the OTMC 100

The *OTMC 100* provides the accurate time for the measurements in this application note (Figure 2). Since both the *DANEO 400* and the CMC test set support PTP (according to the power profile IEEE PC37.238), no PPS is required for this test setup. In case the DUT would require a PPS for time synchronization, the *TICRO 100* (an IEEE 1588/PTP time converter) could be used for such task.

The *OTMC 100* is powered from the *DANEO 400* with Power-over-Ethernet (PoE) and is configured to use the power profile (IEEE PC37.238). For further information on how to configure the power profile in the *OTMC 100*, see the user manual (OTMC 100 User Manual. OMICRON electronics GmbH, 2013).

3.2 Configuring the CMC test set

The CMC acts as the DUT and the voltage/current signal generator in this application note. Therefore, the CMC is set up to generate static sine signals at a nominal frequency of 50 Hz for 3 voltage and 3 current signals. The values are listed below:

- V1: 100 V ∠ 0 °
- V2: 100 V ∠ -120 °
- V3: 100 V ∠ 120 °
- I1: 2 A ∠ 0 °
- I2: 2 A ∠ -120 °
- I3: 2 A ∠ 120 °

Note:

The 100 V magnitude is an "even" value, which can be easily set, observed, and verified.

In real secondary systems, values such as $100\mathrm{V}/\sqrt{3}$ are typically found. See also 4.3.2.

Those sine signals are generated on the analog outputs and mapped, additionally, into one SV 9-2LE stream with a sampling rate of 4000 Hz (80 samples per cycle) with the following properties:

- Destination MAC address: 01:0C:CD:04:00:01
- Source MAC address: 00:50:C2:9B:BE:ED
- Application ID: 16384 (0x4000)
- SV ID: OMICRON_CMC_SV1
- Number of ASDU: 1
- VLAN ID: 0
- VLAN priority: 4
- Simulation/Test: False

The neutral values in the SV stream are calculated and are all zero (except some rounding noise) for balanced systems. For the correct timing of the SV stream, the CMC is time synchronized over PTP by means of the *OTMC 100* (Figure 2).

Further information on how to configure the *CMC 256plus* can be found in the CMC reference manual (CMC User Manual. OMICRON electronics GmbH, 2014).

3.3 Configuring the DANEO 400

DANEO 400 is used to verify the SV stream and the analog output signals from the CMC. This verification can either be done in the *DANEO Control* software or in the *DANEO 400* web interface. In this chapter the configuration screens are only shown for the DANEO Control software but they are similar in the web interface.

3.3.1 TAP mode

In the test setup of Figure 2, the *DANEO 400* passes on the PTP time to the CMC. Therefore, you should configure port A and B as a network TAP with 100 Mbit/s link speed (Figure 3). This feature of the *DANEO 400* makes it possible that no PTP transparent switch is required, because all traffic between port A and B can pass unimpeded.

Since there is only data link-layer traffic on port A and B, no IP address is required on those ports.

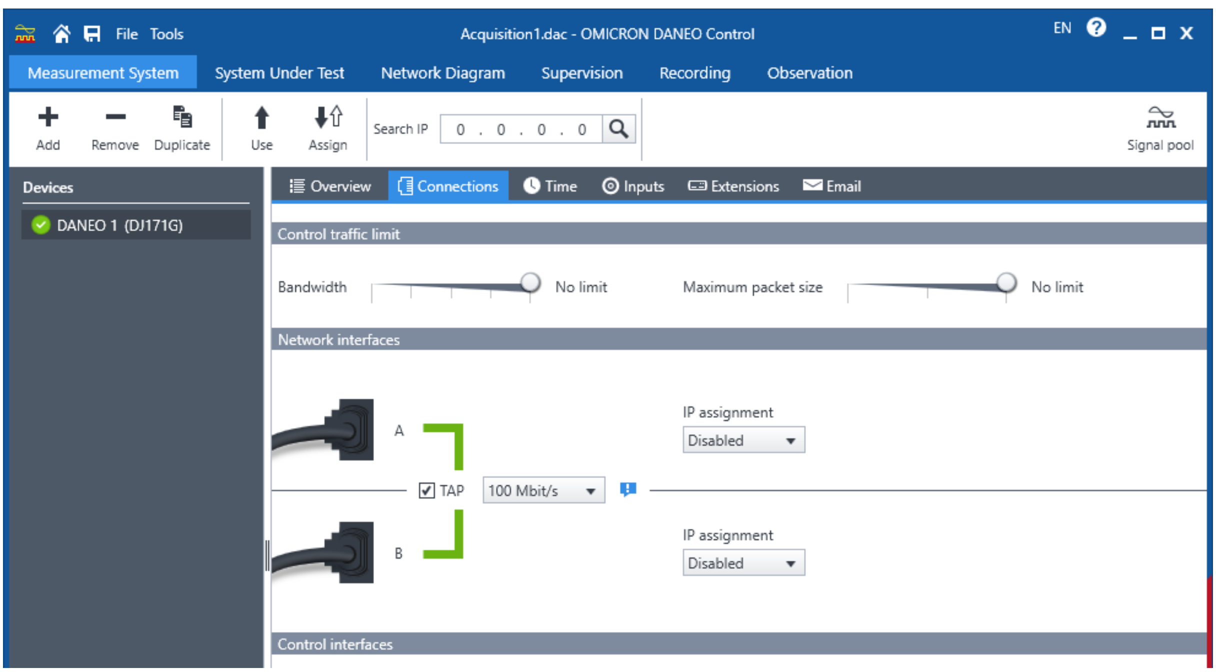

Figure 3: Activated TAP mode.

3.3.2 Time synchronization

PTP time synchronization has to be enabled on the *DANEO 400* for measuring the time characteristics of a 9-2LE publisher. Therefore, the PTP sniffer (Figure 4) is used to select the PTP source for time synchronization. After selecting the time source *DANEO 400* shows the status of the time synchronization (Figure 5). When the clock status icon is green the synchronization is established.

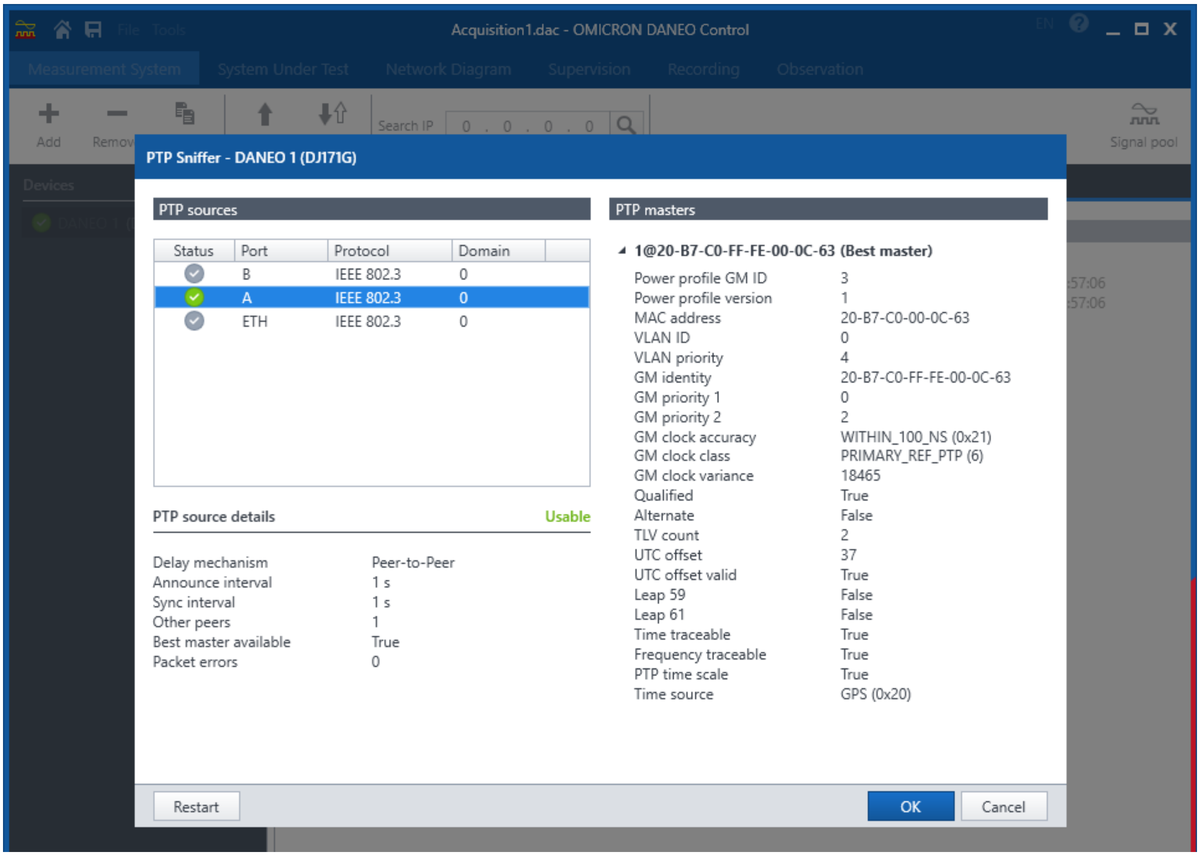

Figure 4: PTP sniffer: The *OTMC 100* is found on port A.

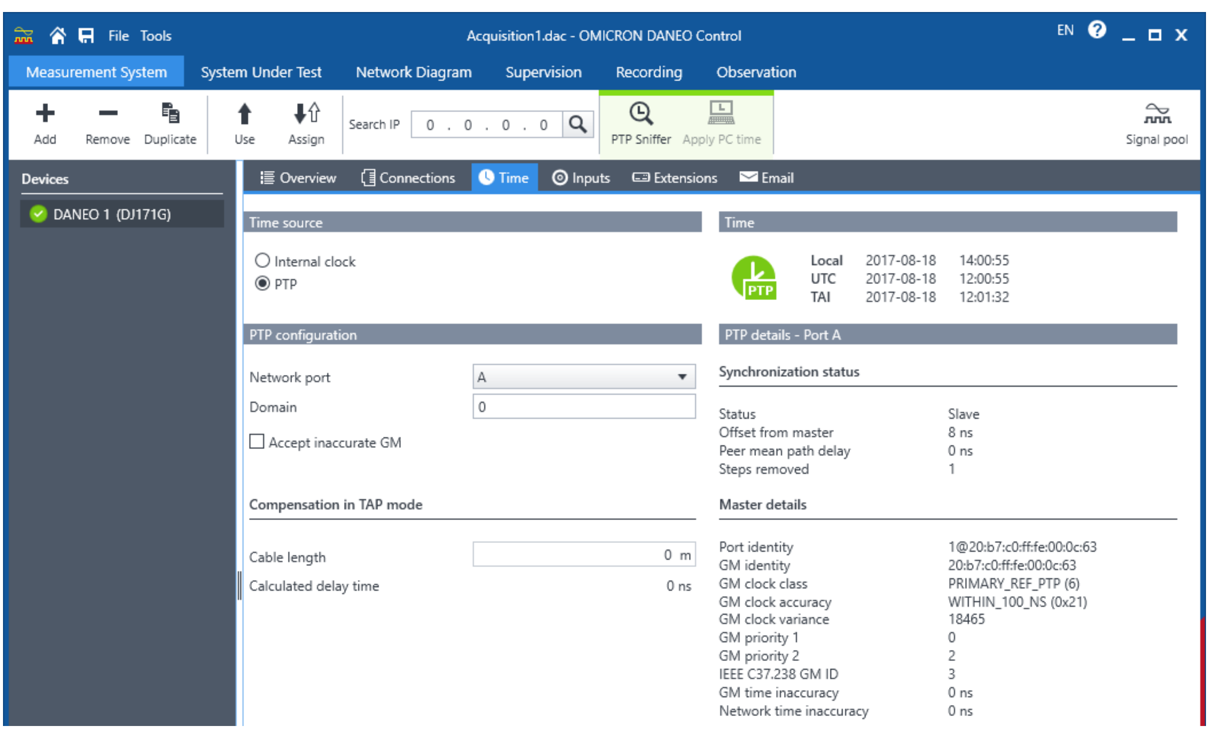

Figure 5: PTP status: Synchronization is established.

3.3.3 Measurement configuration

Measured values must be mapped in the *DANEO Control* software for measuring magnitude and phase of signals in the SV stream from the CMC. Therefore, go to the **System Under Test** view and on the toolbar, click **Find orphans** (Figure 6). Once the SV stream appears in **Orphans**, the dialog can be closed.

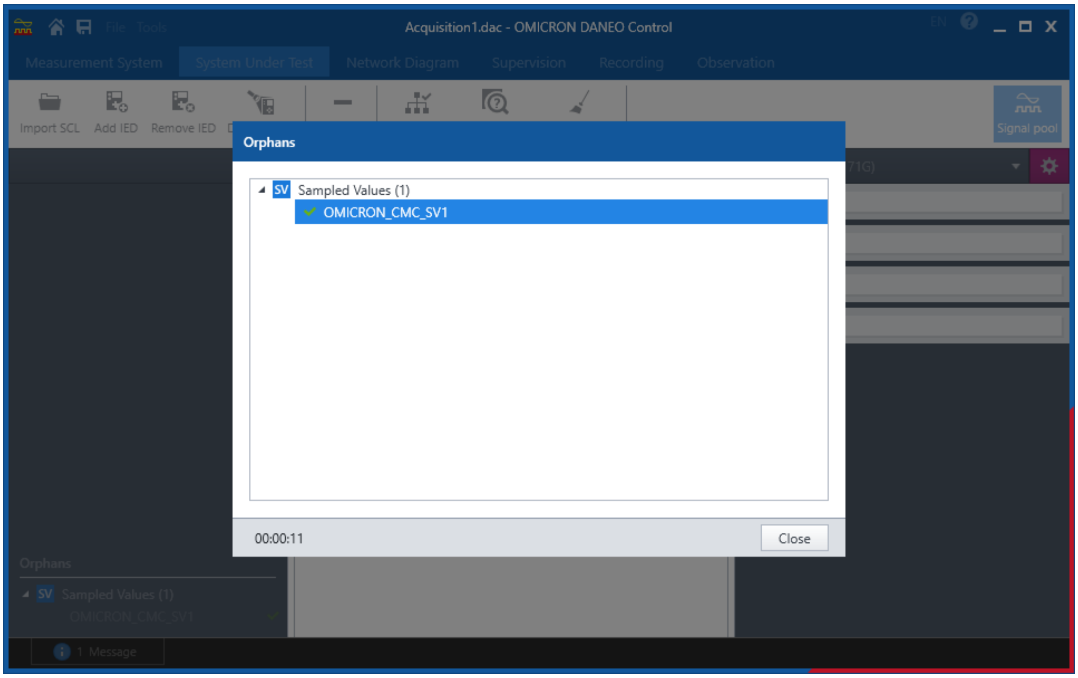

Figure 6: The SV stream from the CMC is detected as orphan.

Afterwards, the SV stream appears in the **Navigation** pane, in the **Orphans** list. Select the SV stream and click **Add to IED** in the toolbar or the context menu.

Click the port column in the **DataSet** section of the SV stream, then click **Map** in the toolbar. A new current system and a new voltage system are added to the signal pool (Figure 7).

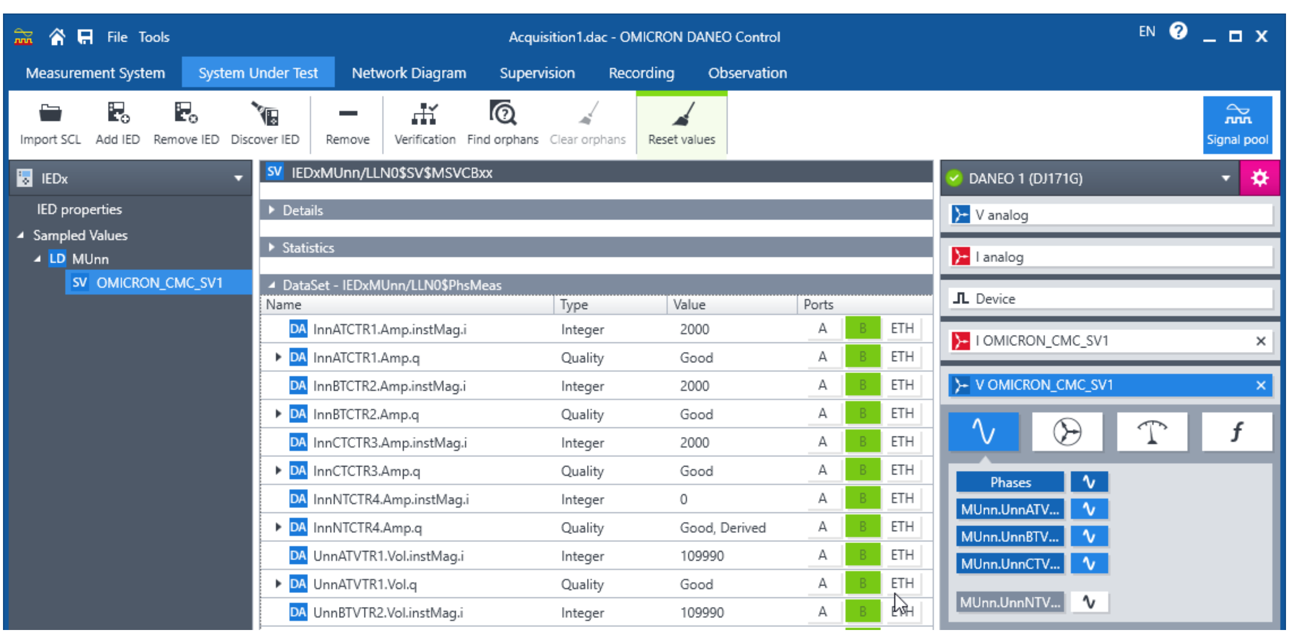

Figure 7: Mapped SV stream from the CMC received on port B in the signal pool.

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Configuration with SCL file

The configuration method shown above uses an arbitrary SV stream (in this case the one published from the CMC), which is sniffed from the network and creates an “ad hoc” configuration based on the sniffed data. Protocol data units are checked for “well formedness” according to the specification, but all other parameters are accepted as found.

In a real installation, the system is engineered and corresponding SCL files, which contain the configuration of the IEDs, are created. Such a file is either an ICD file for a single IED (in this case a merging unit) or a SCD file for the whole substation that contains the data for all configured IEDs. These SCL files can be used to configure the OMICRON tools. Primarily, such a file can be used in the **Sampled Values Configuration** module of the OMICRON **Test Universe** software to set up the CMC to publish Sampled Values exactly with the parameters specified in the SCL file. Secondly, the same file can be loaded into the System under Test in the *DANEO Control* software. The preparation and mapping can be done even offline, only based on the information from the SCL file.

Verification of configuration

When the System Verification is then started, the detected SV streams on the network are first compared against the loaded definitions from the SCL file.

> If everything is correctly set up and all parameters match, a green "OK" icon is displayed.

> If some parameters do not match, a warning icon is displayed and the differences are shown in detail for debugging the problem (Figure 8).

By using this method, based on the information from the SCL files, the correct configuration of the SV stream is verified.

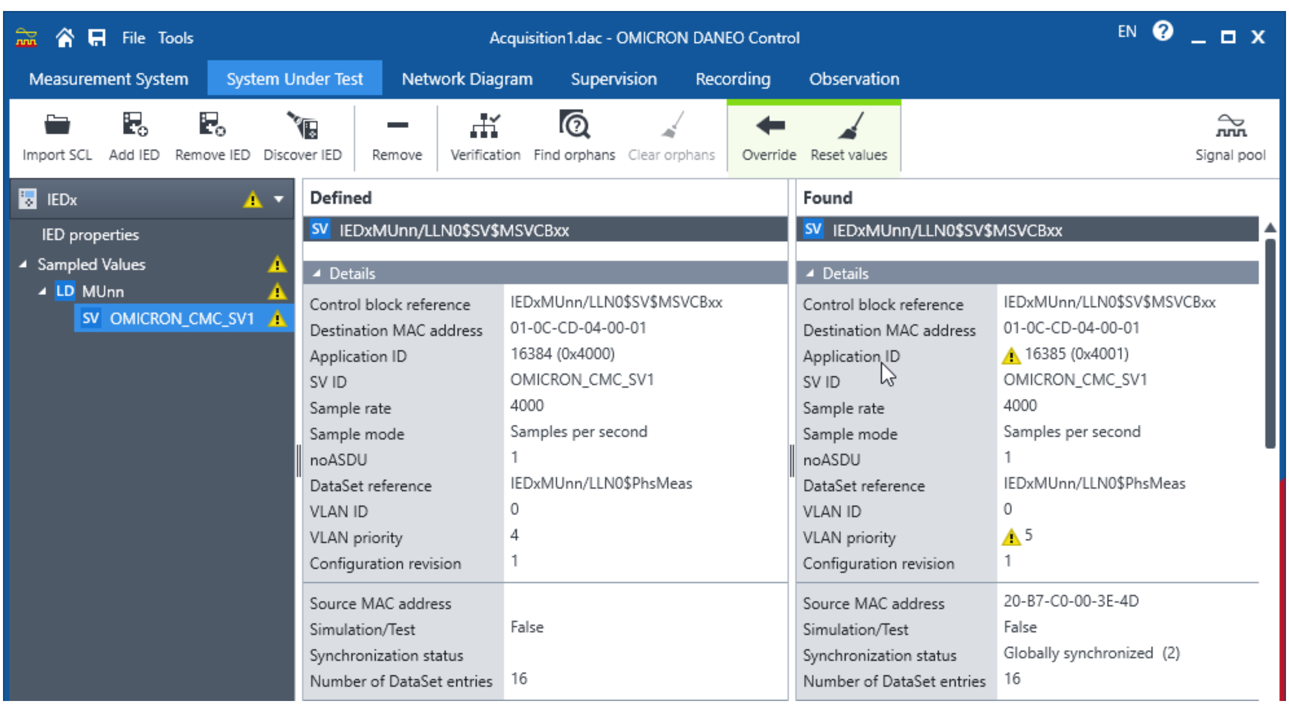

Figure 8: Example of a verification difference (application ID and VLAN priority mismatch).

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4 Testing

4.1 General

With the following three *DANEO 400* features most tests defined in (UCA International Users Group, Testing Subcommittee: Test procedures for Sampled Values Publishers according to the "Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2". Version 1.0., 2010) can be covered with minimal effort:

> Observation
> Measurement
> Recording

- Observation
- Measurement
- Recording

The use of these features is extensively described in this chapter. Each use description contains a reference to the corresponding test IDs in (UCA International Users Group, Testing Subcommittee: Test procedures for Sampled Values Publishers according to the "Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2". Version 1.0., 2010).

4.1.1 Protocol support

The *DANEO 400* is able to capture and analyze SV streams with the following properties:

- Ethertype: 0x88BA
- Number of ASDUs: between 1 and 8
- Sampling rate: between 600 and 15360 Hz
- Dataset: PhsMeas1 specified by 9-2LE (8 channels with 8 quality fields). However, more channels are allowed, but cannot be mapped as signals in the signal pool at the moment.

DANEO 400 is able to subscribe to streams with an arbitrary combination of those properties and not just the ones defined by the implementation guideline (UCA International Users Group, Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2). Consequently, the *DANEO 400* can handle SV variants according to the upcoming standard IEC 61869-9 (IEC 61869-9 Ed. 1.0, 2014).

4.1.2 Accuracy

The *DANEO 400* is able to time stamp every received Ethernet packet in hardware with a time stamping resolution of 10 ns. The time stamping on all three Ethernet ports within one *DANEO 400* refers to a common clock, so calculating relative timings from time stamps recorded within one *DANEO 400* works perfectly without synchronizing to an external clock.
For absolute time measurements, the *DANEO 400* can be synchronized over PTP with a precision better than 500 ns.

4.2 Observation

The live observation is possible in the *DANEO Control* software and in the *DANEO 400* web interface. By using the live observation, most of the SV stream characteristics can be verified immediately.

4.2.1 Observation in the *DANEO Control* software

Go to the **System Under Test** view and select the previously configured SV stream in the **Navigation** pane. Then, expand the **Statistics** table to show the SV observation details (Figure 9).

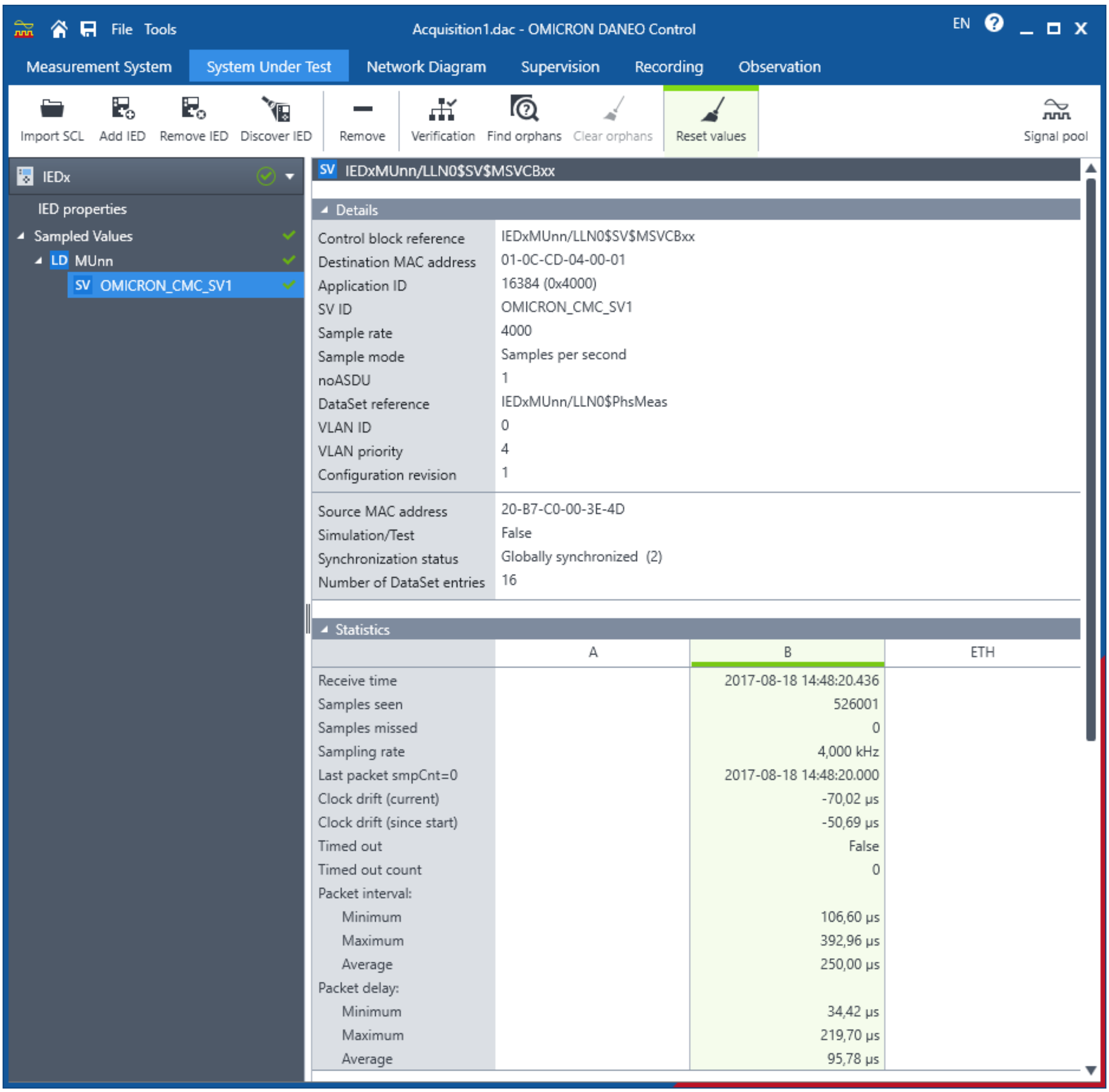

Figure 9: The stream from the CMC is observed on port B (*DANEO Control* software).

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4.2.2 Observation in *DANEO 400* web interface

Go to **Observation** > **Sampled Values** page and click **Start**. A list of sniffed SV streams from all network ports appears in **Sniffed Sampled Values**. By selecting a sniffed SV stream, the observed stream details appear in **Observed SV details** (Figure 10).

Note that during observation new streams do not appear in **Sniffed Sampled Values** (the sniffing is paused).

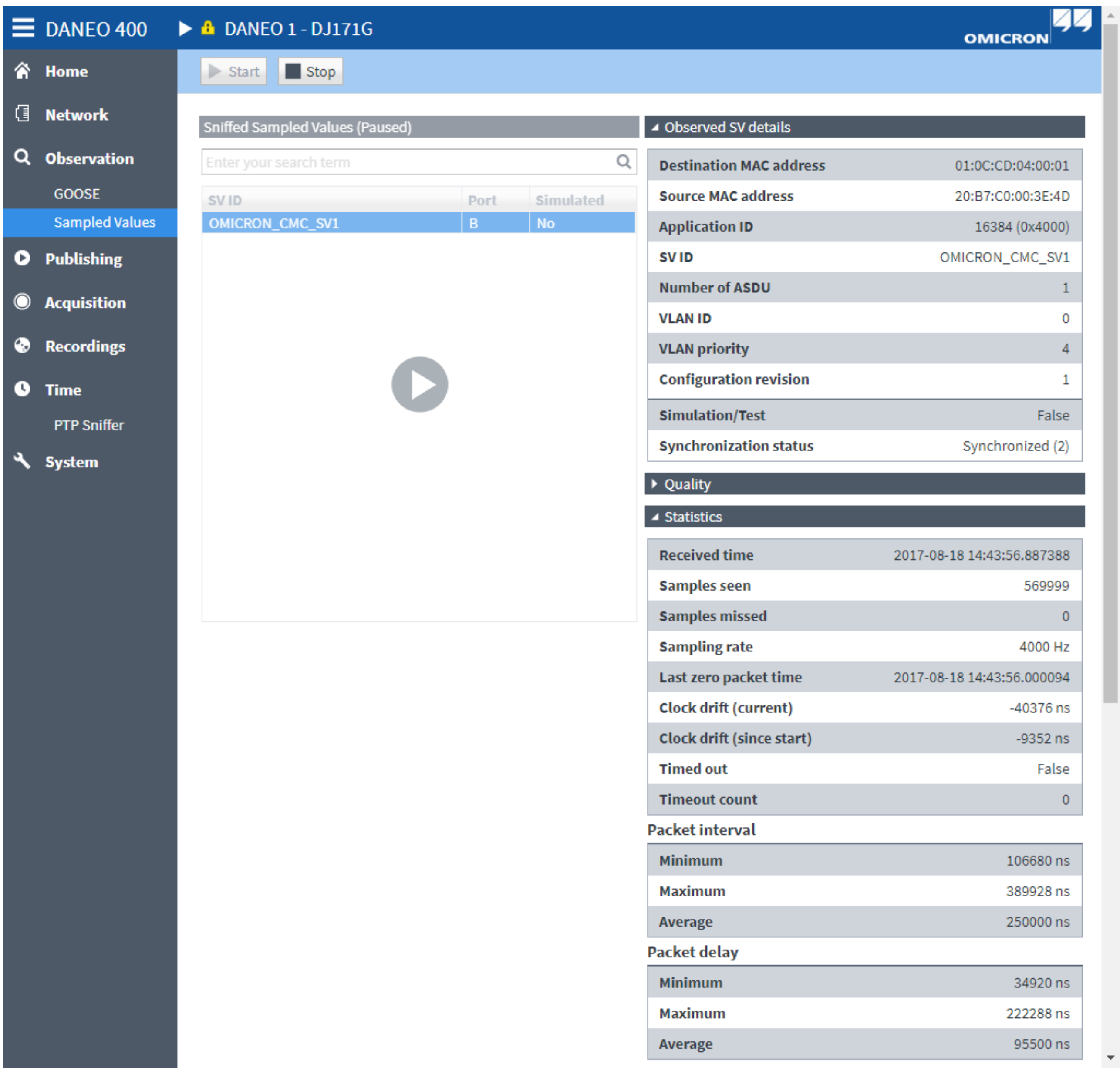

Figure 10: The stream from the CMC is observed on port B (*DANEO 400* web interface).

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4.2.3 Verification of the delay time (Svp1)

The delay time is the period between the theoretical time instant of sampling the analog value from the primary process until the Ethernet packet (contains the corresponding sampled value) is published from the DUT.

DANEO 400 measures the packet delay for every received SV frame to calculate the packet delay statistics (minimum, maximum, average). This can be used to verify that the delay time is within the limit of 3 ms. Note that this only works if the SV publisher is synchronized to the same time source as the *DANEO 400*.

Packet delay

Minimum	34512 ns
Maximum	227056 ns
Average	98435 ns

Figure 11: Packet delay statistics of the CMC.

In Figure 11, the measurement was running for about one minute. It shows the maximum measured delay of the CMC, which was ~ 230 µs, frankly within the allowed tolerance of 3 ms. Since the *DANEO 400* is taking every received frame into account (not just the frame with smpCnt = 0), meaningful statistics are already available after a few seconds. This is possible because *DANEO 400* calculates the expected packet arrival time for each packet based on sampling rate and sample counter.

4.2.4 Verification of the packet interval (Svp8, Svp9)

The packet interval is the time between two Ethernet packets of a SV stream.

The *DANEO 400* uses the time of the arrival of two SV packets to calculate the packet interval statistics (minimum, maximum, average). This information can be used to diagnose if the SV publisher is sending the packets with the correct frequency. The correct packet frequency depends on the number of ASDU and the sampling rate (sampling rate / noASDU).

Packet interval

Minimum	104920 ns
Maximum	390240 ns
Average	250000 ns

Figure 12: Packet interval statistics of the CMC.

In Figure 12, the average interval between two consecutive packets after measuring for about one minute was 250 µs. This value arose due to the fact the CMC was using one ASDU and a sampling rate of 4000 Hz. Note that the *DANEO 400* is taking every received SV packet into account, so meaningful statistics are already available after a few seconds.

4.2.5 Packet format on link layer (Svp3, Svp6)

The sampled values frame parser of the *DANEO 400* is parsing according to the 9-2LE implementation guideline (UCA International Users Group, Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2). Any parsing error due to an invalid packet layout is shown in the live statistics with a special error flag.

Possible errors that can be detected:

> Unexpected fields are encountered (e.g. refresh time and sample rate should not be there).
> Missing fields are detected (e.g. application ID is missing, reserved 1 or 2 is missing…).
> Data set has less than 4 currents / 4 voltages with the corresponding quality fields.
> Encoding errors (e.g. invalid tags or lengths).
> Invalid values (e.g. number of ASDU is less than 1 or greater than 8).

4.2.6 Stream information (Svp4, Svp5, Svp14, Svp16)

If the parsing of frames is successful, all properties appear as parsed from the SV stream.

Observed SV details

Destination MAC address	01:0C:CD:04:00:01
Source MAC address	20:B7:C0:00:3E:4D
Application ID	16384 (0x4000)
SV ID	OMICRON_CMC_SV1
Number of ASDU	1
VLAN ID	0
VLAN priority	4
Configuration revision	1
Simulation/Test	False
Synchronization status	Synchronized (2)

Figure 13: Observed SV application layer properties.

This can be used to verify that the observed application layer values are identical to the published ones. In this example, the observed values using *DANEO 400* are identical to the ones published by the CMC (see chapter 3.2).

Note that the simulation flag and the synchronization status are updated whenever they change on the wire. The verification of the correct values of the 9-2LE publisher can be done easily this way:

> Synchronization status: e.g. by disconnecting the PTP master or by forcing a value with the CMC.
> Simulation/test flag: e.g. by changing it on the CMC.

Furthermore, the *DANEO 400* also accepts SV streams without a VLAN tag. In this case, VLAN ID and VLAN priority fields are not shown.

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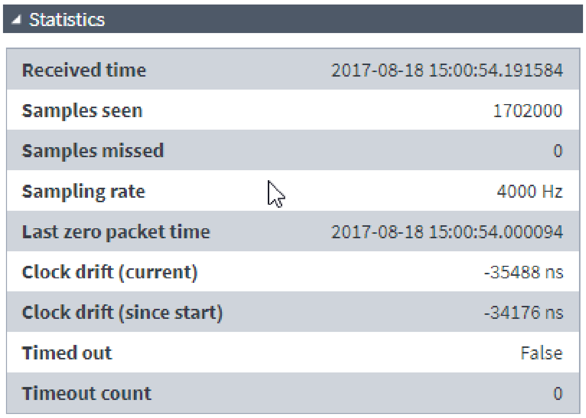
4.2.7 Sample sequence and timing (Svp8, Svp9, Svp10)

The *DANEO 400* evaluates the smpCnt field of every received packet for its statistics (Figure 14). This helps you verifying that the SV publisher is correctly incrementing and resetting the smpCnt.



Statistics

Received time	2017-08-18 15:00:54.191584
Samples seen	1702000
Samples missed	0
Sampling rate	4000 Hz
Last zero packet time	2017-08-18 15:00:54.000094
Clock drift (current)	-35488 ns
Clock drift (since start)	-34176 ns
Timed out	False
Timeout count	0

Figure 14: Sample sequence and timing statistics.

You can find out the following problems by easily checking the statistics:

> The detected sampling rate does not match the configured sampling rate at the publisher:
The *DANEO 400* detects the sampling rate by observing the reset to zero (e.g., last seen 3999, new seen 0, hence the sampling rate is 4000). If this number is not correct, packets are either missing or the publisher does not reset the count.

> "Samples missed" is not 0:
The *DANEO 400* counts the minimum number of missing ASDUs. The *DANEO 400* will recognize if the smpCnt is not incremented correctly at each received ASDU. This could either happen if SV packets are dropped somewhere in the network or the SV publisher does not behave correctly.

> The fraction of seconds' part of "Last zero packet time" is not close to 0:
The *DANEO 400* is showing the time stamp of the last received SV packet with smpCnt = 0. According to 4.2.3, the value has to be lesser than 3 ms. This allows to verify that the SV publisher sends this frame at the beginning of each new second. Note that this value is only meaningful if the SV publisher and the *DANEO 400* are synchronized to the same time source.

> "Samples seen" is not incremented, "Timed out" is true, "Timeout count" is not zero:
The *DANEO 400* continuously observes the presence of the SV stream and counts the received packets. If the SV publisher stops sending SV packets, the counter does not increment any more. Also the "Timed out" field would then be true. Since the UI is only refreshed every second, short timeouts would not be visible. Therefore, an additional value "Timeout count" is calculated, which indicates how often the SV stream has been interrupted for more than 3 ms (which is equal to the maximum permitted time delay of an SV packet).

> "Clock drift (current)" and "Clock drift (since start)" are not close to 0:
The *DANEO 400* evaluates if its clock and the one of the SV publisher are synchronous or drifting away from each other. This evaluations is done by calculating the time duration between the last two received samples with smpCnt = 0, which should be exactly one second. Any deviation from the expected interval of one second is shown as "Clock drift (current)". This field indicates how much the clock of the DUT deviated in the past second, whereas the "Clock drift (since start)" is the accumulated clock drift since starting the observation. In case the "Clock drift (since start)" field does not remain close to 0 (and is therefore constantly increasing), the SV publisher is either not synchronized to the same time source as the *DANEO 400* or the SV publisher has a timing issue.

4.3 Measurement

The *DANEO 400* is a hybrid measurement system, capable of measuring analog input signals from physical inputs and digital inputs (SV streams) simultaneously. With this feature it is possible to verify if the SV stream generated by the DUT matches with the physical analog values and if the voltage/current scaling parameters are applied correctly.

4.3.1 Comparing measurements (Svp11, Svp12, Svp13)

Go to the **Observation** view in the *DANEO Control* software. For each phase system, drag the **Phasors** and **Instantaneous Values** from the **Signal pool** to observation sheets.

The live values of the physical voltages / currents generated by the CMC (see chapter 3.2 for the configured phasor values) appear in **V analog** and **I analog** system. The measured values from the SV stream are shown in **V OMICRON_CMC_SV1** and **I OMICRON_CMC_SV1** system. In this example, they contain the same values as the physical signals, so the 9-2LE stream contains the correctly scaled values.

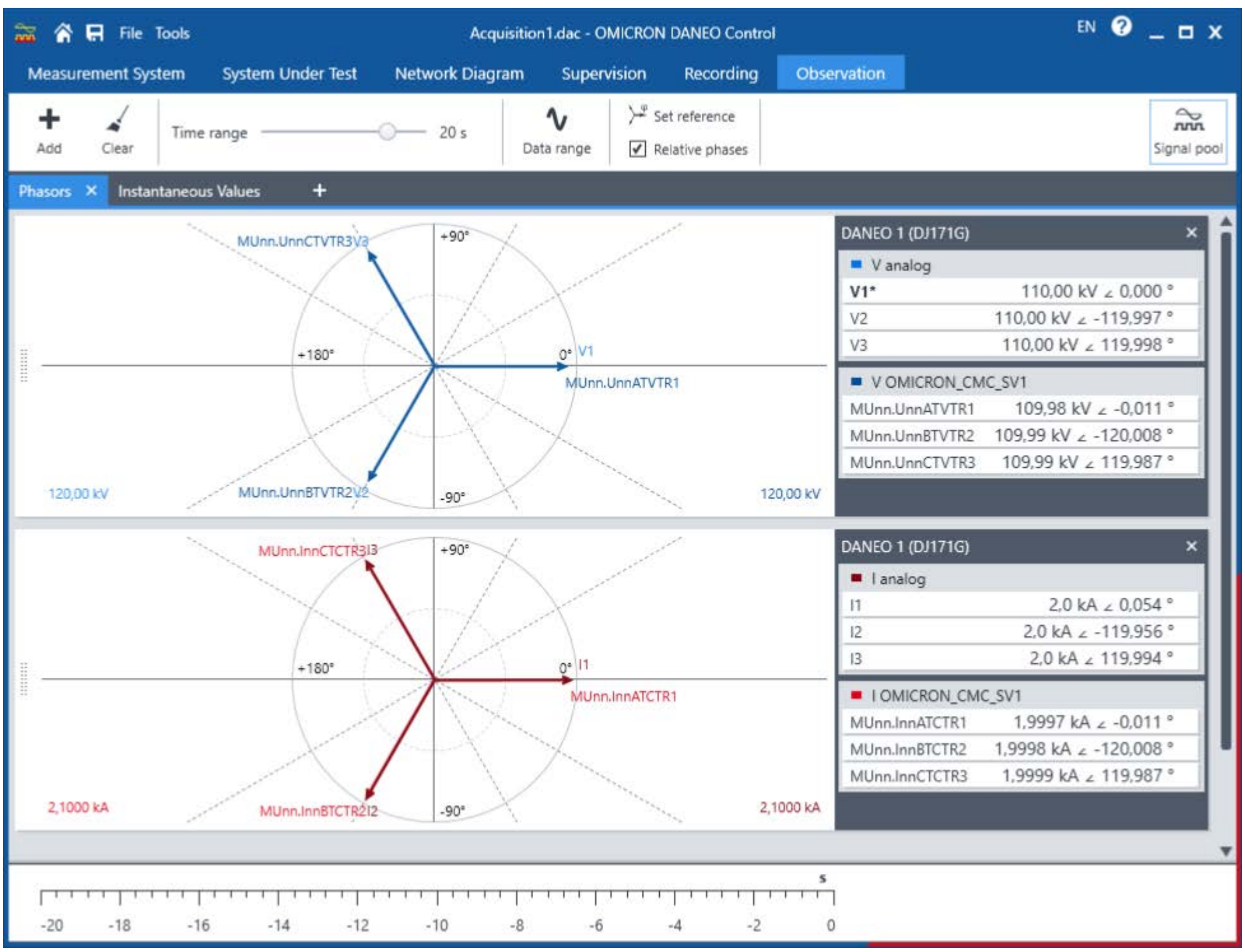


Figure 15: Measured phasors of physical and virtual analog signals generated by the CMC.

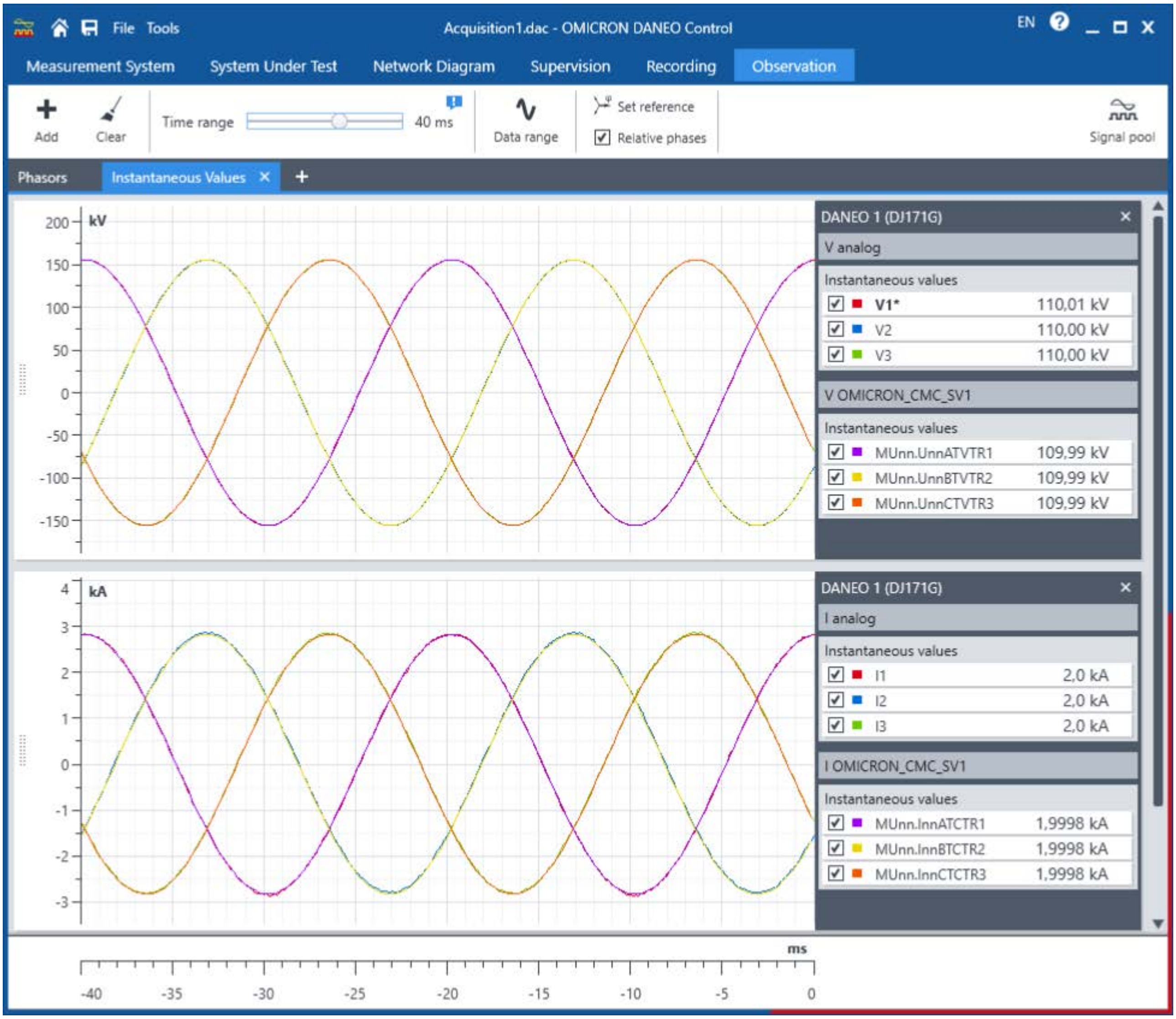


Figure 16: Measured instantaneous Values of physical and virtual analog signals generated by the CMC.

4.3.2 Use of primary and secondary values

By definition, values conveyed by Sampled Values are primary values. For example, when merging units with non-conventional sensors, there are no secondary values accessible at all. Then, of course, ratios and scaling factors need to be considered.

The ratios for the signal generation in the CMC are located in the device settings of the test object in the OMICRON *Test Universe* software. These ratios also determine the scaling of the Sampled Values. The test modules also support the direct use of primary values in the user interface. By using this feature, the settings in the test modules correspond to the generated Sampled Values.

The concept of *DANEO 400* is also to use primary values. This is also for the general case, where secondary values do not exist, which can be increasingly expected with Sampled Values applications. The corresponding scaling factors need to be calculated according to the instructions in the user manual (DANEO 400 User Manual. OMICRON electronics GmbH, 2014) and set in the **Inputs** configuration of the *DANEO Control* software.

4.4 Recording

4.4.1 Recording in the *DANEO Control* software

The SV traffic can be recorded in PCAP format for an Ethernet packet-level analysis. Therefore, go to **Recording** and click **Traffic**. From **Network ports**, select the appropriate Ethernet port (here the traffic from the CMC is received on port B), and on the toolbar, click **Record**.

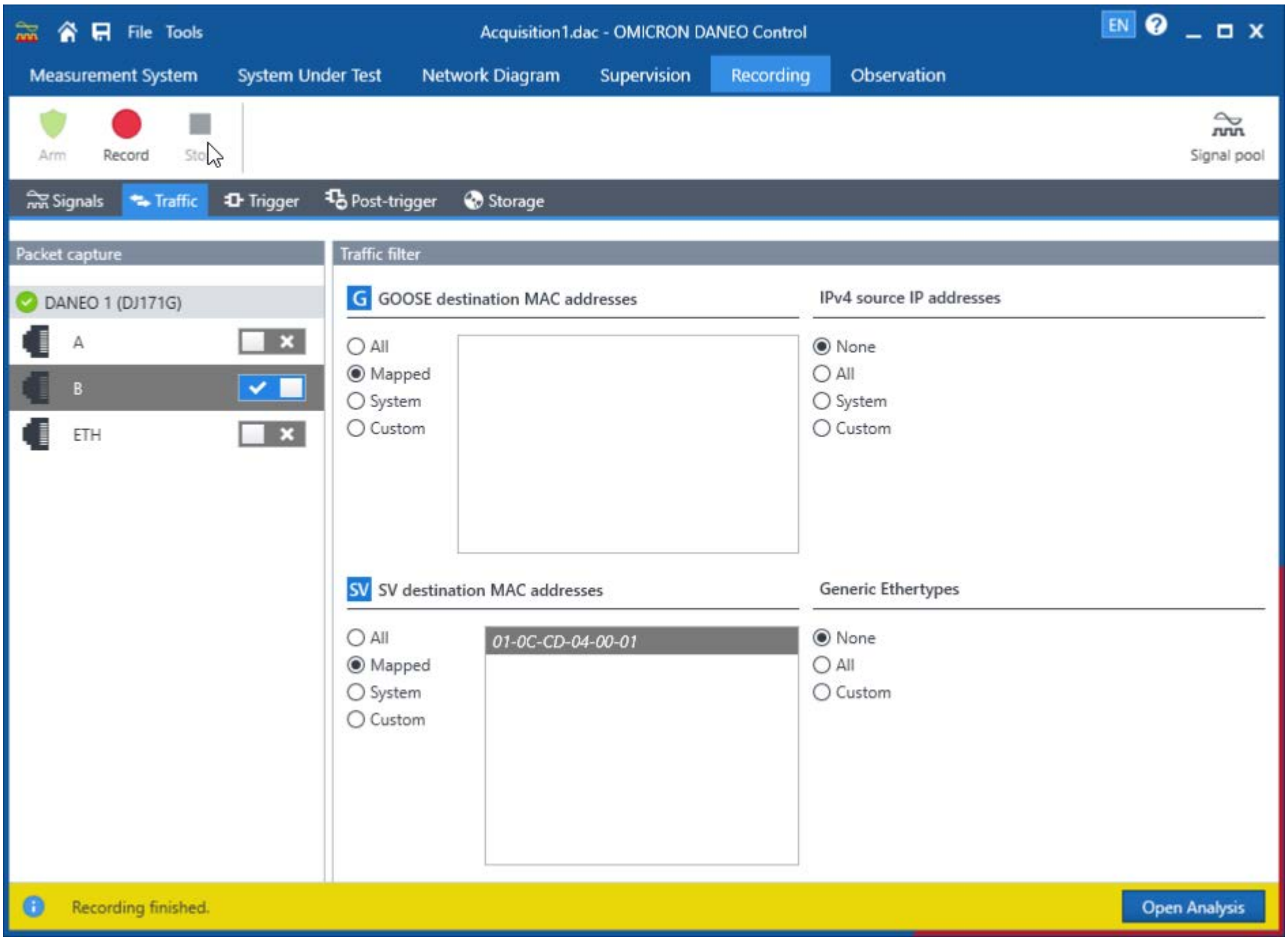


Figure 17: Recording the SV traffic of the CMC on port B.

Since there are thousands of packets published per second, a large number of packets is captured in a short time. Clicking **Stop** quickly after starting the recording captures enough packets for most evaluations. The software offers you to open the finished recording in the analysis. If you accept, the **Analysis** window appears (Figure 18).

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4.4.2 PCAP export

The analysis, when opened directly after the recording has finished, is automatically added to **Selected recordings**, where its details appear (Figure 18). This recording lasted for about 5 seconds with a total size of 3 MB. It contains the complete captured SV traffic of the CMC from port B.

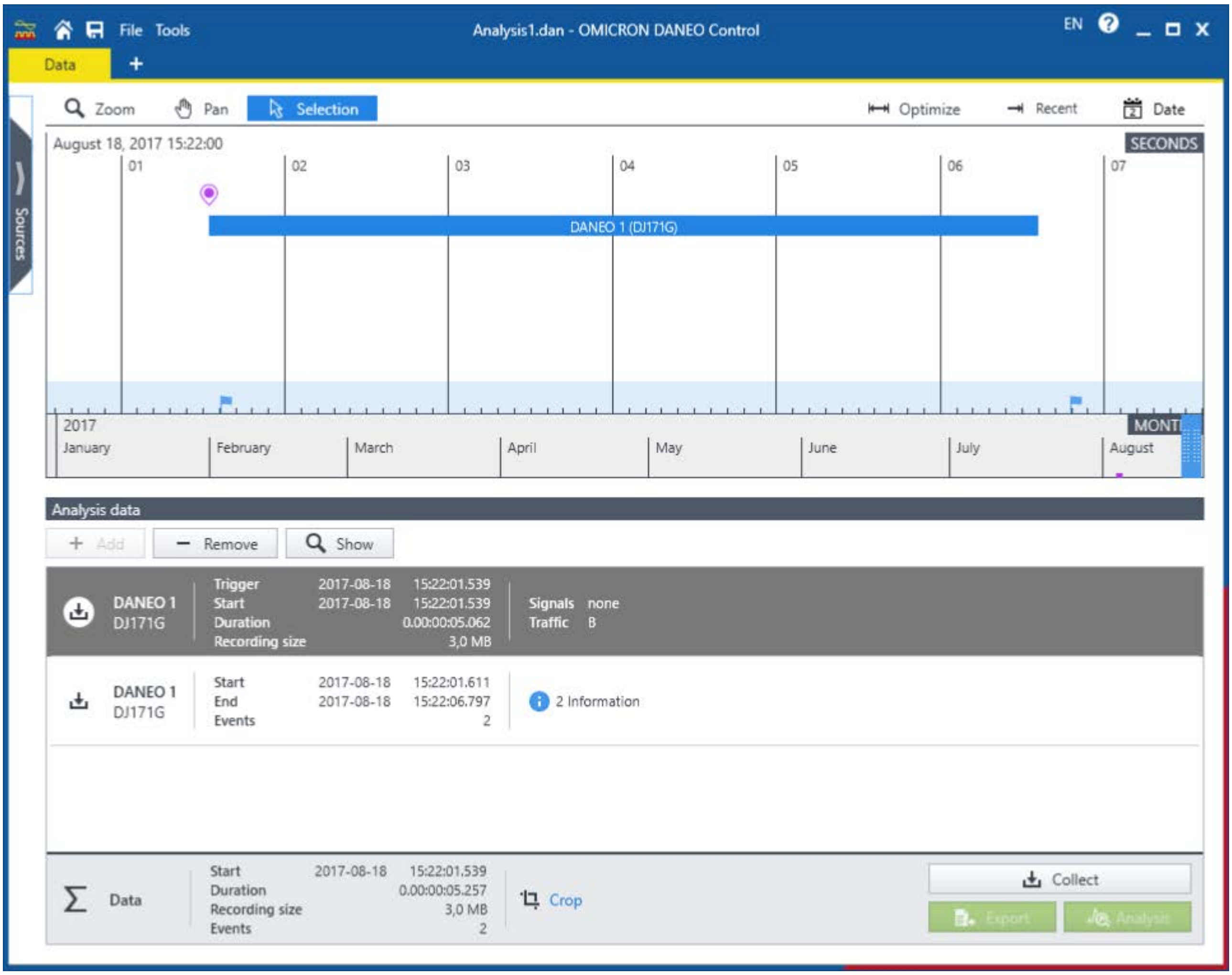

Figure 18: The **Analysis** shows SV recording details.

Now click **Collect** to download the data from the *DANEO 400*, then click **Export**. A new dialog appears to select the data to export (Figure 19).

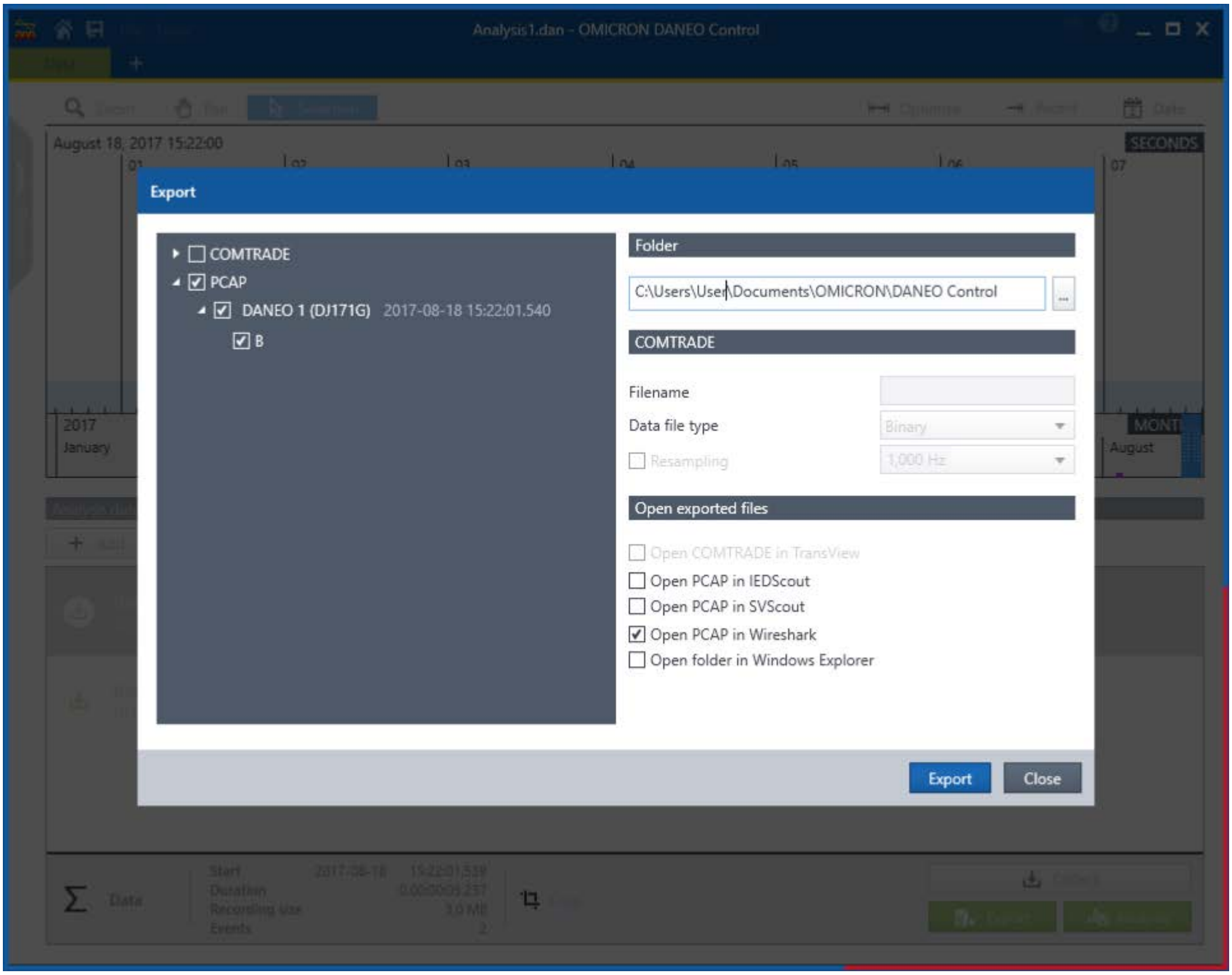

Figure 19: Export dialog where the PCAP export is selected for port B, which should be directly opened in Wireshark.

4.4.3 Analysis in Wireshark (Svp3, Svp4, Svp5, Svp8, Svp9, Svp10, Svp14, Svp15, Svp16)

Figure 20 shows the time synchronized PCAP recording of *DANEO 400* in Wireshark. In this example, a packet with smpCnt = 0 has been selected where the time was 15:22:39.000041904. This result shows that the CMC test set is time synchronized to the same PTP clock as *DANEO 400*, because the frame with smpCnt = 0 was seen ~ 42 µs after the top of the second.

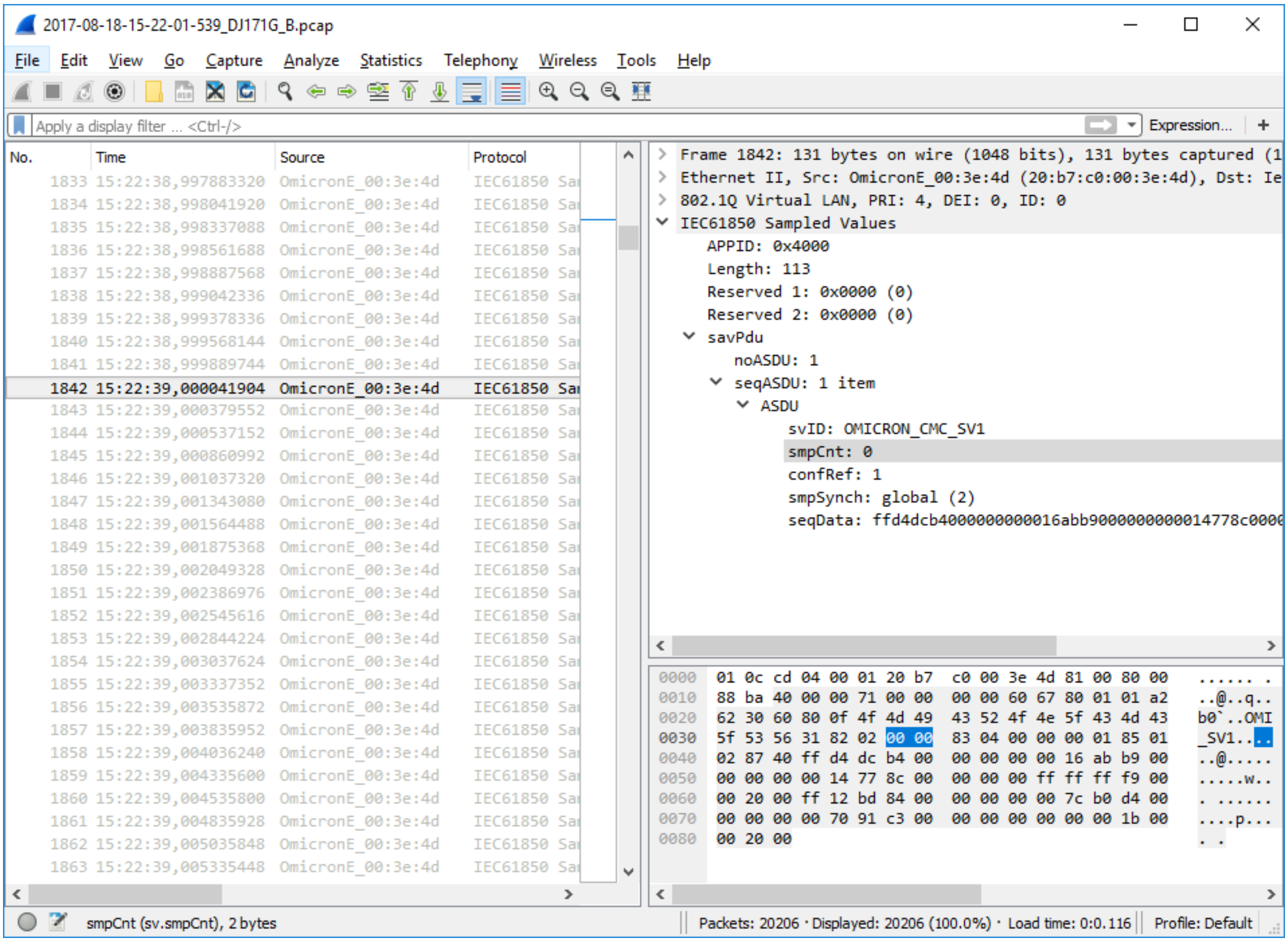

Figure 20: Sampled Values stream from the CMC captured with the *DANEO 400* in Wireshark.

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