

IoT Power Consumption Measurement Application Note

Products:

- R&S®RT-ZVC02 / 04
- R&S®CMW500 / 290 / 270
- R&S®CMWrun
- R&S®HMC 8043

IoT devices have tight requirements for power consumption in order to achieve expected battery life times of multiple years without a connection to a power supply. In order to verify the power consumption and expected battery life time, voltage and current have to be measured accurately for different operating states of the device under test.

This application note explains battery life tests using RT-ZVC in combination with CMWrun and CMW500, including example applications.

The solution by Rohde & Schwarz enables precise voltage, current and consequently, power measurements. The RT-ZVC Multi-Channel Power Probe can be driven as part of a test plan combining signaling and power measurements for a detailed view of the power consumption in different signaling states as well as an estimation of overall lifetime given a certain battery capacity.

Note:

Visit our homepage for the most recent version of this application note (<http://www.rohde-schwarz.com/appnote/1MA281>).

IoT Power Consumption Measurement – 1MA281

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1 Introduction

The number of connected or "smart" devices that make up the Internet of Things (IoT) is rising day by day. More devices that are able to use wireless connectivity penetrate the market. Buzz words like wireless sensor networks, (home-) automation, control systems or other zip through journals, news and advertisement. Many of those wirelessly connected devices have to be deployable freely, without restriction due to a required connection to power supply. Combined with the ambition of battery lifetimes of multiple years, testing the power efficiency and the resulting battery lifetime of those devices becomes critical. New requirements for ultra-low power like in releases 12 and 13 of the 3GPP standardization define power save mode (PSM) and enhanced DRX (eDRX) to reduce power consumption.

With the solution presented in this application note, precise power measurements can be combined with connectivity and signaling test plans in a controlled network environment, resulting in a comprehensive picture of the device's under test power consumption given different operating modes.

The R&S®RT-ZVC Multi-Channel Power Probe is a dedicated accessory to achieve this goal. It enables you to conduct the high precision power measurements that help differentiate your design in respect to troublefree unattended operating time. In combination with the R&S®CMWrun testplan software and the R&S®CMW500 Radio Communication Tester this setup gives the user the ability to create controlled scenarios with real test conditions for the DUT. The R&S®CMW-KT051 option for R&S®CMWrun reads voltage and current from the R&S®RT-ZVC power probe with best-in-class precision and sampling rate.

This application note addresses all who develop, test or verify devices which are under tight power budget constraints or where the exact dynamic and long-term power consumption in different operating modes are a top priority device parameter. The application note introduces the R&S®RT-ZVC Multi-Channel Power Probe in combination with R&S®CMWrun and R&S®CMW500.

Chapter 2 introduces the required devices and their handling.

Chapter 3 explains the required preparation of the device under test to measure the power.

Chapter 4 describes how multi-threaded testplans can be set up in the CMWrun software. Multi-threaded testplans allow measuring the power drain simultaneously to a connectivity test plan using the CMW500.

Chapter 5 highlights example test plans with selected DUTs and the respective results.

The following abbreviations are used in this application note for Rohde & Schwarz products:

- The R&S®CMW500 Radio Communication Tester is referred to as CMW
- The R&S®CMWrun software is referred to as CMWrun
- The R&S®RT-ZVCxx Multi-Channel Power Probe is referred to as RT-ZVC

2 Used Hardware and Tools

The R&S®RT-ZVC02 and R&S®RT-ZVC04 Multi-Channel Power Probes are designed for measuring voltage, current and therefore power with high accuracy and fast sampling.



Figure 2-1: RT-ZVC04 Multi-Channel Power Probe

While the RT-ZVC02 offers two voltage and current channels, RT-ZVC04 offers four simultaneous voltage and current measurements. The high precision in each channel is achieved using 18 bit resolution analog to digital converters (ADC), sampling with 5 MSa/s. To retrieve a high precision power measurement, the measured voltage and current can be directly multiplied sample-wise in the device in real-time. The measured values can be averaged over 100, 1000 or 10000 samples before being transmitted over USB 3.0 to the host PC for further processing and logging.

When measuring a DUT, the RT-ZVC is able to handle voltages up to ± 15 Volts and 10 Ampere when using the internal shunt. The accuracy can be increased by selecting the correct range for the ADC when working with lower voltages and currents. The following voltage and current ranges are available:

- Voltage ranges: 1.88 V, 3.75 V, 7.5 V, 15 V
- Current ranges: 4.5 μ A, 45 μ A, 4.5 mA, 45 mA, 4.5 A, 10 A

It is also possible to use an external shunt, as explained in Chapter 3. In this case, the amperemeter channel functions as a high impedance voltmeter. This allows measuring higher currents without introducing too much additional resistance due to the connectors and cables.

When using the RT-ZVC in combination with CMWrun and CMW500, the setup enables the user to embed the power consumption measurement into an emulated network scenario in which the DUT communicates with the CMW500, while CMWrun controls both the RT-ZVC and the CMW500 directly.

Figure 2-2 shows an example setup for probing an LTE DUT with the RT-ZVC and CMW500, controlled by CMWrun.

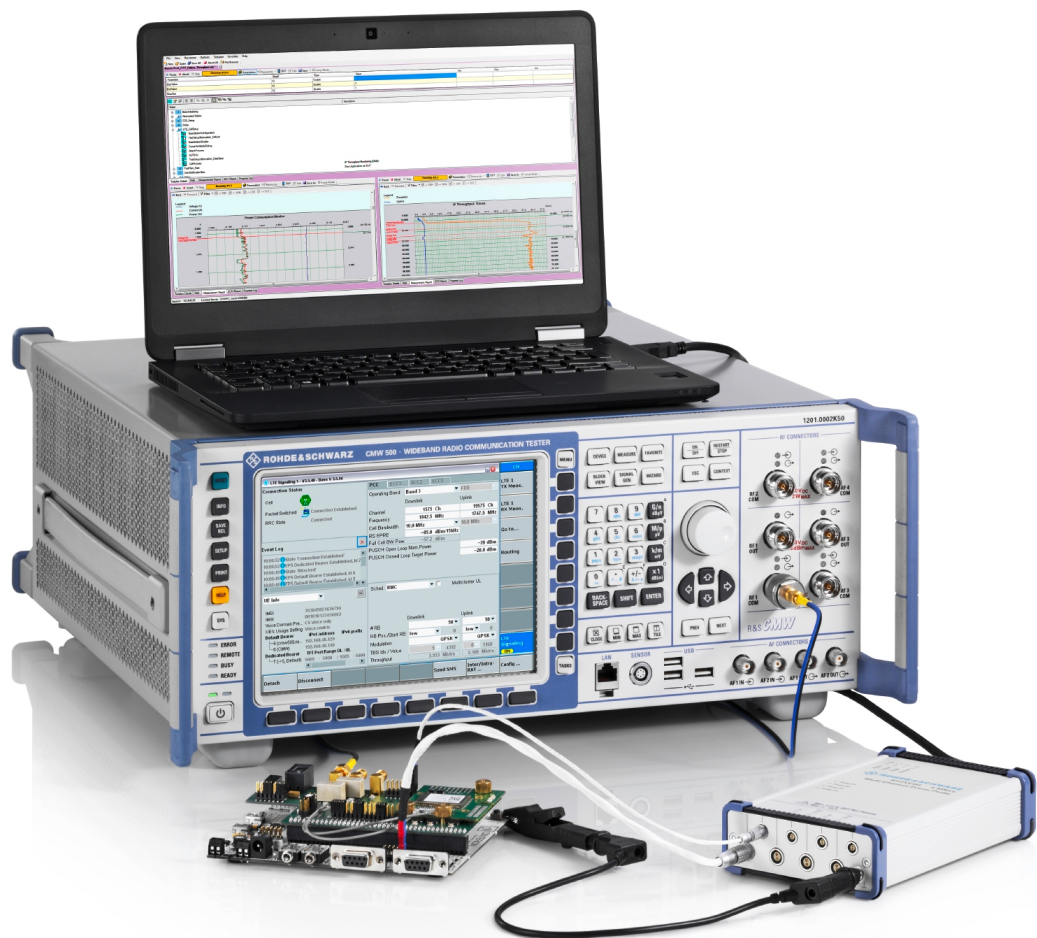


Figure 2-2: Setup with RT-ZVC, CMW500 and CMWrun for probing an LTE DUT

The CMWrun software is a remote control test sequencer for the CMW500, used in R&D, quality assurance, production and service. Based on DLL files, which provide tests and drivers for devices and test scenarios, CMWrun can easily be expanded to different use cases. For more information on CMWrun, applications and order information, please refer to the CMWrun product page, https://www.rohde-schwarz.com/product/cmwrn-productstartpage_63493-199809.html.

Version 1.8.8 or newer of CMWrun has to be installed to use the RT-ZVC with CMWrun on a PC. During installation, the "R&S RT-ZVC USB 3.0 driver" has to be selected for installation, as shown in [Figure 2-3](#).



The required option/driver is not selected by default. Please make sure to select the "R&S RT-ZVC USB 3.0 Drivers" option, which can be found under "R&S CMW-KT051 General Purpose" in the "R&S CMWrun Software Options Setup".

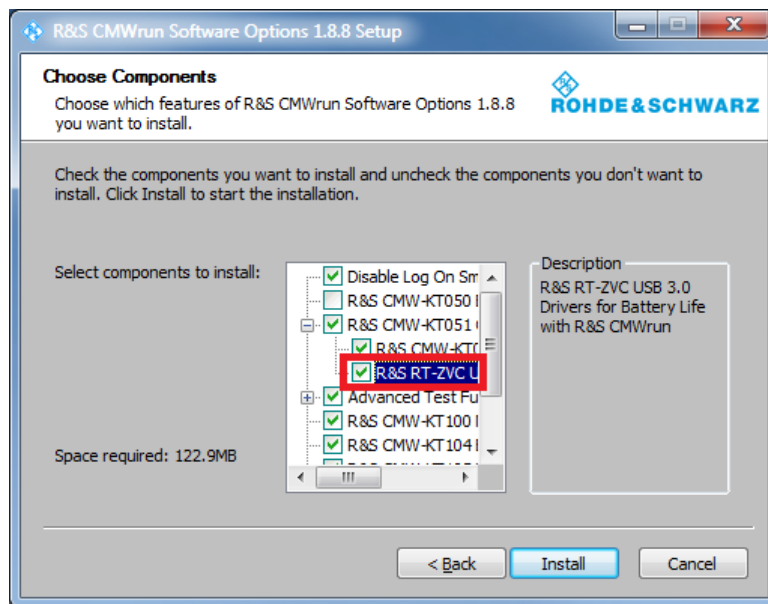


Figure 2-3: Select R&S RT-ZVC USB 3.0 option during installation of CMWrun

After successfully installing CMWrun with the required USB drivers, the RT-ZVC can be accessed from CMWrun using the option R&S[®]CMW-KT051 for remote controlling the power probe.

3 Preparing DUT for Power Measurements

For power measurements, both voltage and current can be measured simultaneously by the power probe. To characterize power intake on a complete DUT or parts thereof, some prerequisites are required. Generally speaking, to determine the power consumption of any device, both the overall voltage drop over the inputs of the device and the complete current flowing through the device have to be measured.

The following sections explain how to prepare a DUT for power measurements.

3.1 Probing the DUT

Power measurements can be conducted irrespective of the DUT being supplied via an AC adapter, USB, or battery. In any case, appropriate locations on the DUT for measuring voltage and current have to be determined. Also, individual parts of the DUT can be a target for power measurements to identify possible improvements in the design of individual components or the combination of those.

While it is possible to probe the circuit directly during development and testing, this may not be possible with the fully integrated device. In this case, the measurement can be conducted at the power supply of the DUT itself to measure the overall power and therefore also the overall battery lifetime in battery powered devices.

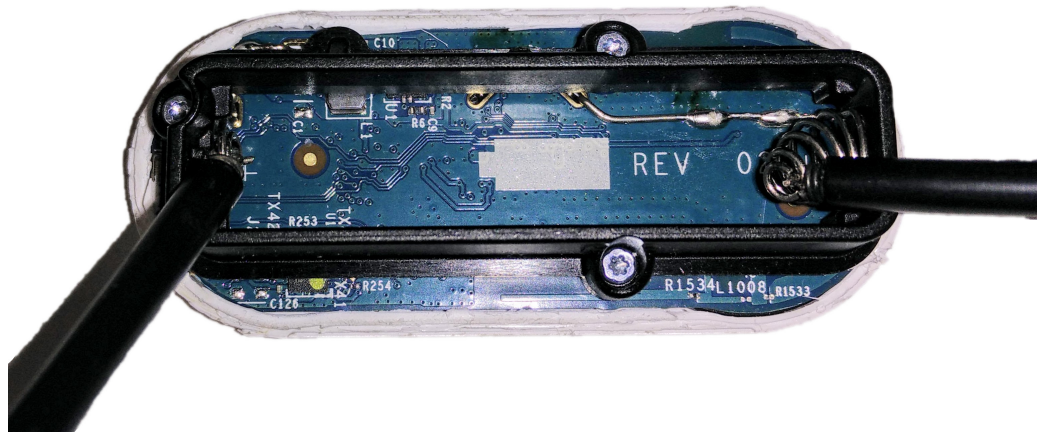


Figure 3-1: Probing AAA battery powered DUT

For battery powered devices, probing can be done at the battery connectors. [Figure 3-1](#) shows an AAA battery powered Wi-Fi device, where the clips have been attached to the contact faces of the DUT. Devices with non-removeable batteries may require special cables, adapters or other accessory for measuring the real power consumption.

A common power supply especially for small gadgets or handheld devices is USB. In this case, the V_{BUS} (Pin 1), which commonly features 5 Volt DC, and the ground (Pin 4)

can be probed for measurements. By inserting a probe mechanism between the USB power adapter and DUT, the original power supply for the DUT can be used. [Figure 3-2](#) shows a custom-built adapter for USB 3.0, where voltage and current can be probed. This adapter is used for measuring USB powered DUTs in this application note. Devices with internal battery and USB power supply may require special cables that ensure that the real power consumption of the device can be measured. Otherwise, the internal battery may be charged with constant voltage and current instead.

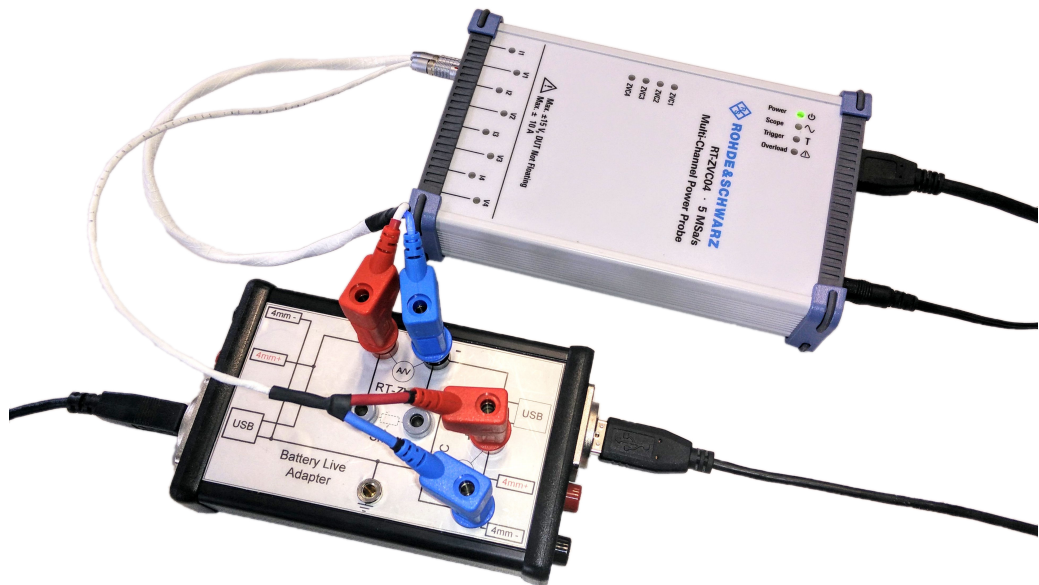


Figure 3-2: USB Battery Life Adapter setup



Always connect the ground connector of the RT-ZVC to the ground of the DUT and/or power supply to prevent wrong measurements or event damage of the probe.

3.2 Internal and External Shunts

Shunts are used to measure the current. During normal operation, the built-in amperemeter of the RT-ZVC measures the current. The circuit has to be opened and the amperemeter is placed in series with the DUT to route the current through the amperemeter, as shown in [Figure 3-3](#).

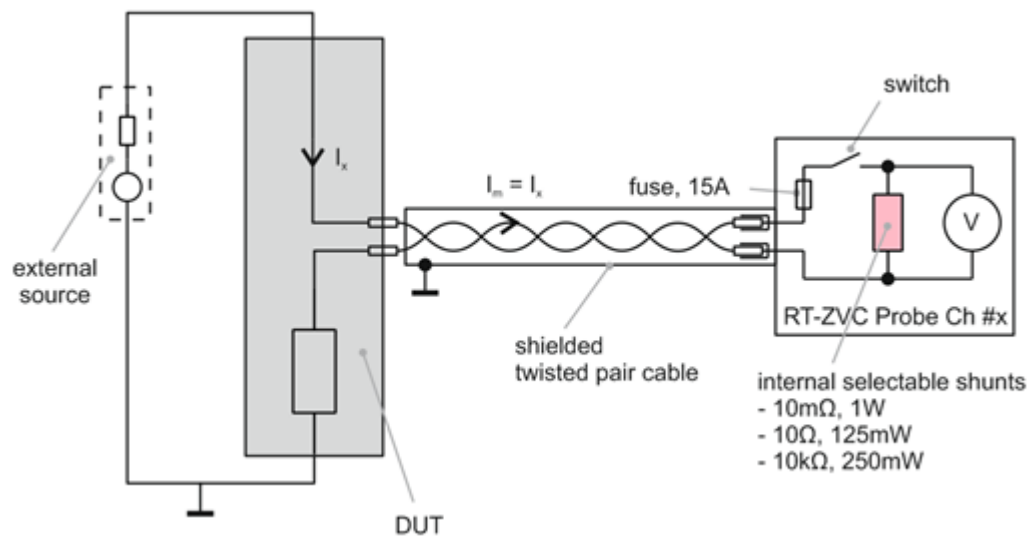


Figure 3-3: Using the internal shunt

While the ideal amperemeter has zero resistance, in reality this is not the case. Inserting the amperemeter in the circuit always affects the circuit itself. The main drawback is that both the internal shunt and the connecting cables introduce additional resistance that lead to a burden voltage over the input terminals of the probe. The burden voltage is the voltage drop caused by the measurement setup, influencing the voltage applied to the DUT and by that possibly affecting the DUT performance and behavior. Depending on the selected internal shunt (determined by the maximum current to be measured), the following burden voltage is experienced with the supplied standard cables (total round trip), taken from the data sheet:

- 10 kΩ shunt (4.5 μA, 45 μA): 10 mV/μA, max. 500 mV
- 10 Ω shunt (4.5 mA, 45 mA): 10.7 mV/mA, max. 535 mV
- 10 mΩ shunt (4.5 A, 10 A): 128 mV/A, max. 1.28 V

Figure 3-4 shows the burden voltage at the input terminals using the standard cables as function of the current that is measured.

For small currents, or in scenarios where the burden voltage may not have a considerable impact on the DUT, the internal shunts can be used for measuring the current.

Figure 3-3 shows the setup when using an internal shunt. Three internal shunts are available to the user: 10 mΩ, 10 Ω and 10 kΩ, corresponding to different input ranges. When using CMWrun, the input ranges are displayed to the user.

It is up to the user to decide when to use internal or external shunts. However, as a rule of thumb, it is recommended to use external shunts on the DUT to minimize the burden voltage when working with currents above 3 A. The internal shunt for the largest current range only has 10 mΩ of resistance but much more is added by cabling. Therefore, using external shunts, even with more than 10 mΩ resistance, can be advantageous as the overall voltage drop introduced to the DUT is smaller.

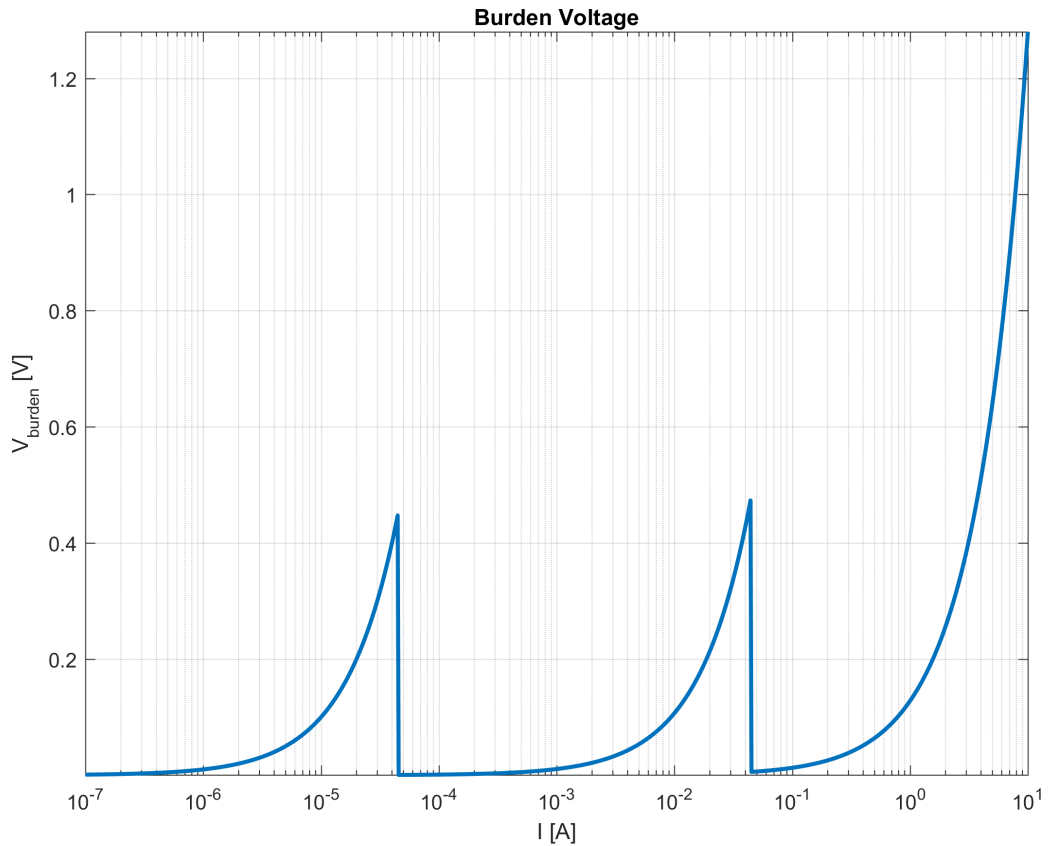


Figure 3-4: Burden voltage at input terminals using internal shunts with standard cables

When using external shunts, the RT-ZVC acts as a high impedance voltmeter. Using CMWrun, one of the two possible voltage ranges can be selected (up to 45 mV or up to 450 mV) and the resistance of the used shunt can be defined as shown in Figure 3-5. CMWrun automatically determines the current that flows through the shunt based on the measured voltage and the given resistance.

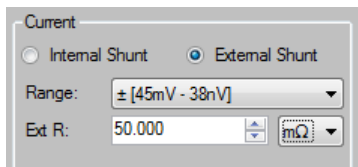


Figure 3-5: Defining external shunt in CMWrun



Independent of whether internal or external shunts are used, the current is always measured with the I1 to I4 channels at the RT-ZVC.

Choose the resistance of the external shunt based on the expected current flowing through the DUT to fit one of the possible voltage ranges. Given an expected current of 0.5 A, and a desired burden voltage of less than 45 mV, the shunt resistor must have less than 90 mΩ resistance, since $45 \text{ mV} / 0.5 \text{ A} = 90 \text{ m}\Omega$.

4 Battery Life Measurements with CMWrun

One of the key features of using the RT-ZVC with CMWrun is the ability to combine power measurements with a network emulation running in a CMW, to which the DUT connects. Using multi-threaded testplans, DC power measurements and connectivity testplans can run concurrently. It is also possible to place signaling event markers in the power measurement chart, indicating events that occur in the signaling test plan. These events can represent an established connection in LTE, an incoming SMS or call, and so on.

4.1 Set Up CMWrun, CMW500 and RT-ZVC

The following procedure explains how to connect to the CMW in CMWrun.

1. Make sure that the Ethernet cable is plugged in to the CMW Remote LAN port and is connected to the same network as the host PC that runs CMWrun .
2. On the running CMW, push the SETUP hardkey.
3. Select "System" > "Lan Services" and select "Lan Remote" as network adapter.
4. Enable DHCP or enter a static IP address, depending on your network architecture. Most commonly, DHCP is used, which assigns an IP address to the device automatically.
5. In CMWrun, go to "Resources" > "SCPI Connections" and click "Add..." to add a new device connection.
6. Click "Assistant" to show the "Remote Interface Assistant" and fill in the required fields:
 - "Alias" is a nickname for the CMW
 - "Resource Name" is filled in by the assistant: select "VXI11 (Network)" as "Interface Type" and fill in the "Host Name" or "IP Address" as presented by the CMW. The resulting "Resource Name" can look like
`TCPIP::CMW500::inst0::INSTR.`
7. Accept the new connection by clicking "OK".
8. In the "SCPI Connections" window, the new connection can be tested by clicking "Test Connection".



Please make sure, that the correct device connection is selected as default.

D	Alias	Resource Name	Timeout
<input type="checkbox"/>	LocalHost	TCPIP0:127.0.0.1::INSTR	20000
<input checked="" type="checkbox"/>	CMW500	TCPIP::CMW50050-101440::inst0::I...	20000

Figure 4-1: Select default SCPI connection in CMWrun

Following the described procedure, the *GLOBAL SCPI Connections* are set up. By default, new testplans use the global settings. However, you may also choose to set up individual connections per testplan, by selecting the "Resources" button in the testplan view as shown in [Figure 4-2](#).

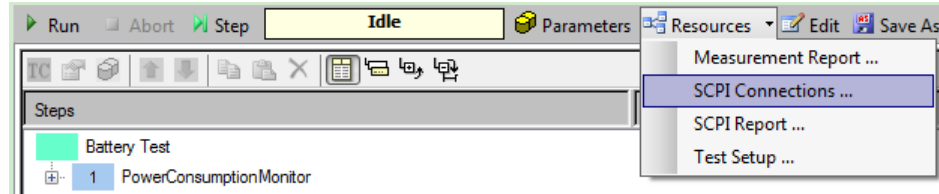


Figure 4-2: SCPI connection settings for individual testplans

There is no need to set up the RT-ZVC power probe individually. After installing the USB drivers during installation of CMWrun version 1.8.8 or newer, the probe can be accessed using CMWrun without further setup. The probe only has to be plugged in to its power supply (6 V DC, 2 A) and connected to the host PC that runs CMWrun using an USB 3.0 cable.

4.2 Setting Up a Power Consumption Monitor Testplan

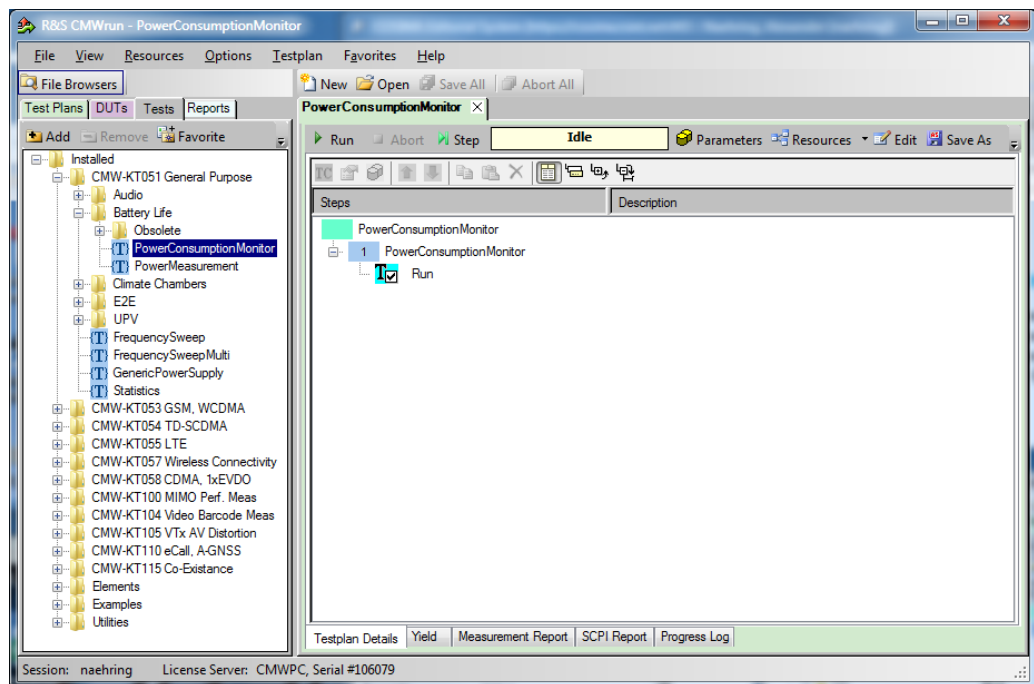


Figure 4-3: Opening the PowerConsumptionMonitor test in CMWrun

The first step of using the RT-ZVC power probe with CMWrun is setting up a testplan, using the *CMW-KT051 General Purpose* option for power consumption measurements. In the CMWrun "File Browser" under "Tests", open the "PowerConsumptionMonitor"

test by double clicking the entry in the "Tests File Browser". A new testplan is created and opened, with "PowerConsumptionMonitor" as the sole step as shown in [Figure 4-3](#).

Before starting the measurement, configure the test parameters. For that, double-click the "PowerConsumptionMonitor" step in the testplan overview with the blue square pictogram on the left. The "Power Consumption Meas" window opens, where the test-specific parameters can be adjusted. By default, the RT-ZVC probe is selected as the measurement device at the top of the window. If not, select it from the dropdown menu. Now, the window should look similar to [Figure 4-4](#).

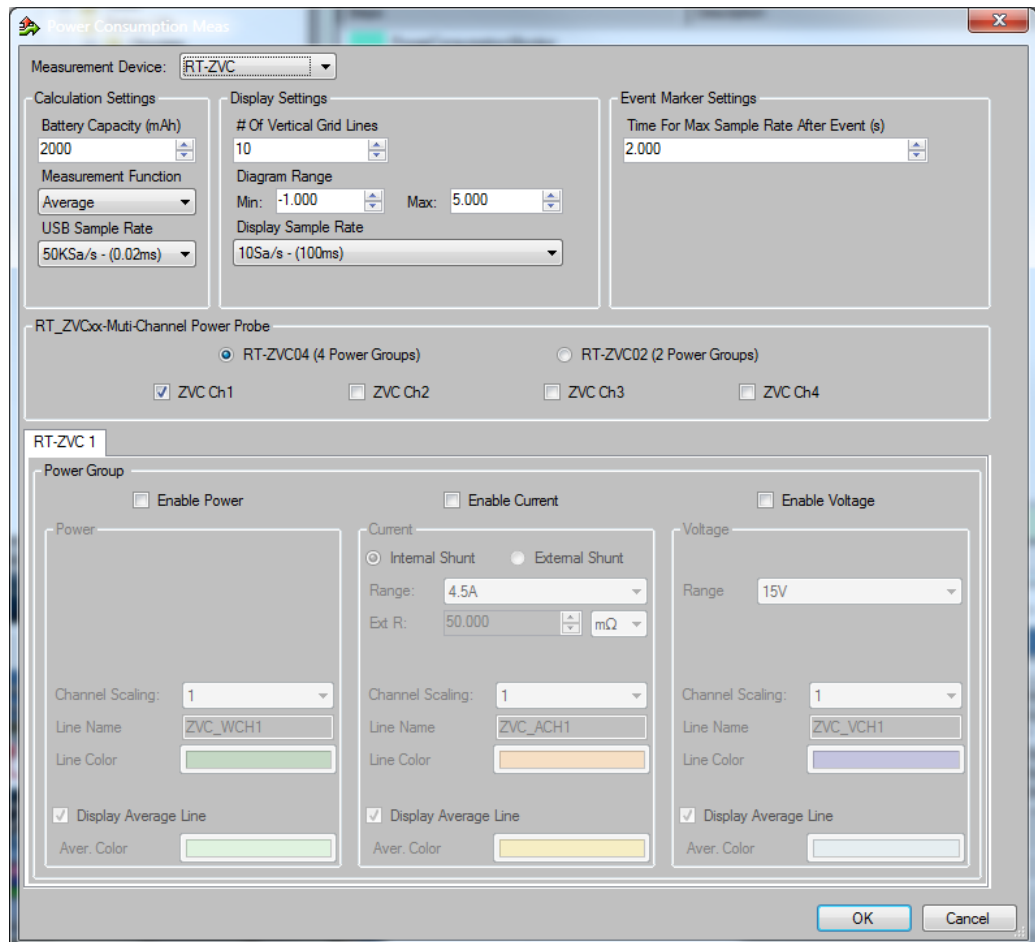


Figure 4-4: Power consumption measurement configuration window in CMWrun

The top three setting groups define general parameters, while the lower "RT-ZVC" settings configure the power probe channels. Starting at the top left, define the battery capacity in order for CMWrun to calculate battery lifetime based on the measured consumption. It is possible to set the measurement function to either peak or average, which affects how the measurement rate of 5 MSa/s by the RT-ZVC is decimated to the slower sample rate sent over USB. The transmit sample rate is set under "USB Sample Rate", with a maximum of 50 kSa/s, limited by the data transfer over USB.

The display settings define the look of the result chart, which plots the selected channels over time. Choose the diagram range corresponding to the expected voltage, cur-

rent and power. In order for the plotted lines to be visible on the chart, the values have to be in the selected range. When measuring a USB device with 5V DC, a meaningful range would be from -1 to 6. This ensures, that values as low as 0 and as high as 5 are clearly visible. Since all values (voltage, current and power) are plotted in the same chart, the ranges apply to all values. However, it is possible to scale each value by a chosen factor.

The display sample rate defines the time resolution at which values are displayed in the event chart in CMWrun. Lower sample rates ensure a better graphical overview of the measurement. The default display sample rate can be increased dynamically every time an event occurs during the measurement. This feature provides better insight into the real (dynamic) consumption of the DUT during transitional events such as an operation mode change of the DUT. The increased time resolution is triggered by "event markers" and causes a display sample rate equal to the USB sample rate. The duration of the increased display rate is defined under "Event Marker Settings".

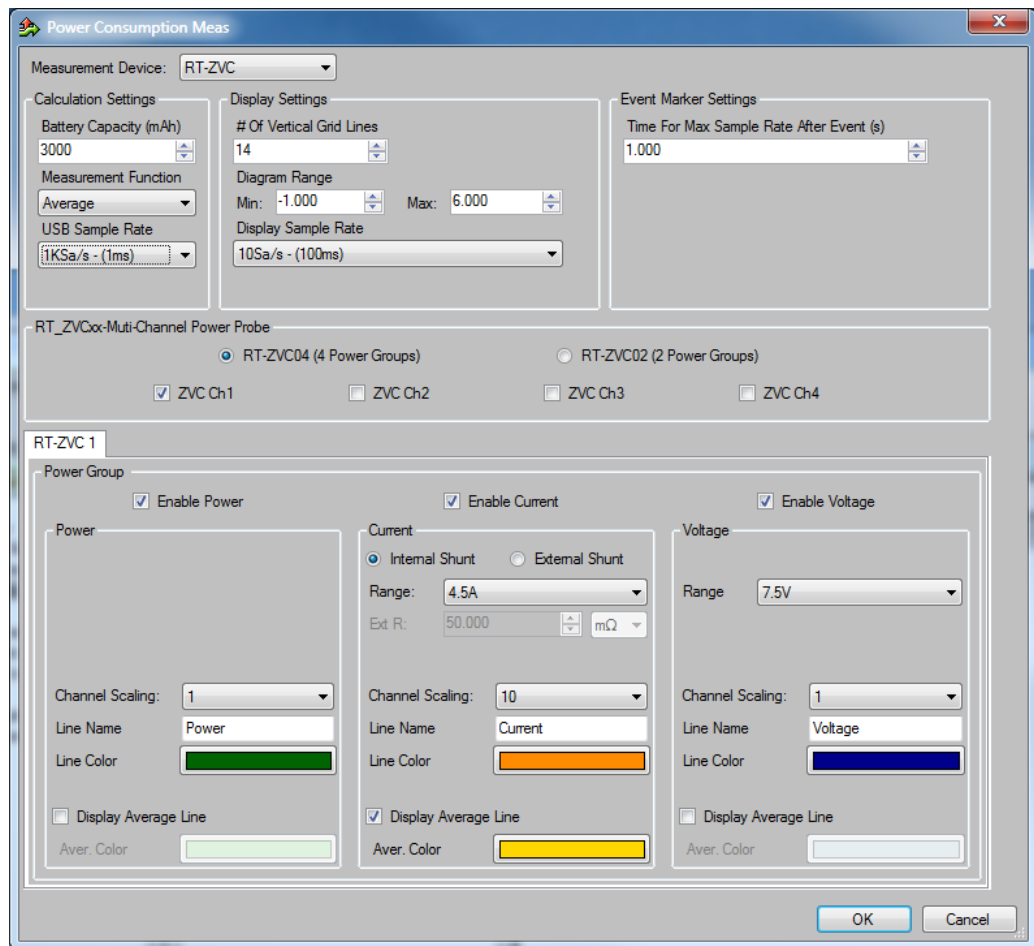


Figure 4-5: Configured power consumption measurement in CMWrun

Under "RT_ZVCxx-Multi-Channel Power Probe", select the used hardware model, activating the options for the available channels of the probe. Selecting one of the available channels enables the "Power Group" settings, where the individual measurement settings per channel are defined. For the selected channel, power, current and voltage measurements can be switched on or off. For voltage and current, select the specific

measurement ranges. In case the voltage or current exceeds the selected range during measurement, the RT-ZVC indicates this by flashing the red *Overload* LED and the affected channel LED.

A fully set up power consumption measurement test can look like [Figure 4-5](#). In this case, the probe is set up to measure a USB device, with a voltage of around 5 V, hence the diagram range of up to 6 and voltage range up to 7.5 V. The minimum in the diagram is set to -1 to show values of 0 in the diagram as well. The current is measured using the internal shunt up to 4.5 A and the current is scaled by a factor of 10 to fit in the same diagram with expected currents of below 600 mA.

Selecting a test from the "Tests File Browser" is a quick way to create testplans. However, a single testplan can consist of multiple tests that are arranged in steps. Testplans (file extension .rstp) reference one or more tests (file extension .dll) and arrange those tests in an order and containing the configuration parameters for each test. To edit an opened testplan, use the "Edit" button to open the test in "Edit Mode". There, add new tests as steps and rearrange, remove or configure existing steps. [Figure 4-6](#) shows the CMWrun window with the testplan open in edit mode.

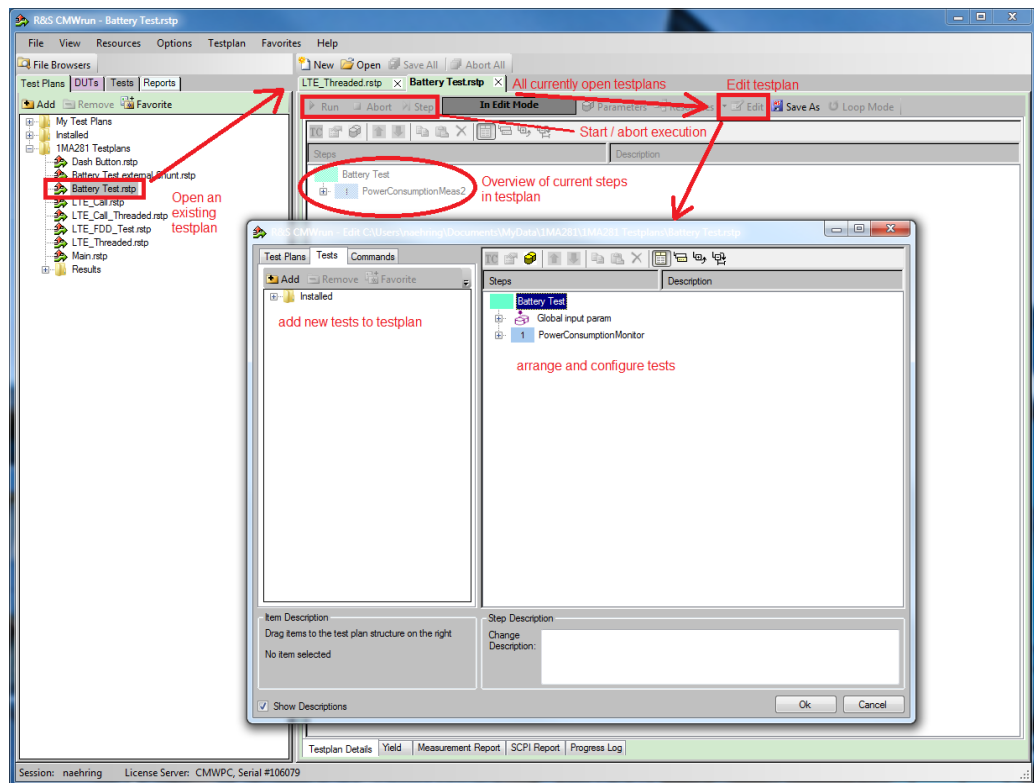


Figure 4-6: Open, edit and run testplans in CMWrun

If the testplan is ready to go, save it using "Save", and execute the testplan by pressing "Run".

4.3 Creating Multi-Threaded Testplans

One of the main advantages of using the RT-ZVC with CMWrun is the ability to create multi-threaded testplans in CMWrun which enables us to combine network emulations with power measurements in real time. The best and also easiest way to achieve this is using multi-threaded testplans where multiple testplans run in parallel.

To deploy parallel testing, use the "TestPlan_Start" test which can be found under "Elements" > "Parallel Testing". In this test, another testplan can be defined to be started and executed in parallel. The configuration window is shown in [Figure 4-7](#). The path to this testplan can be saved either as an absolute or relative path. When both the main and the secondary testplan belong to the same project and are saved in a common directory, relative path should be selected. This way, the project can easily be moved without breaking the link between the testplans. By default, the report of the testplan is merged into the main testplan report after finish. In any case, a report is created for all testplans. This can be switched off by deselecting the option in the window.

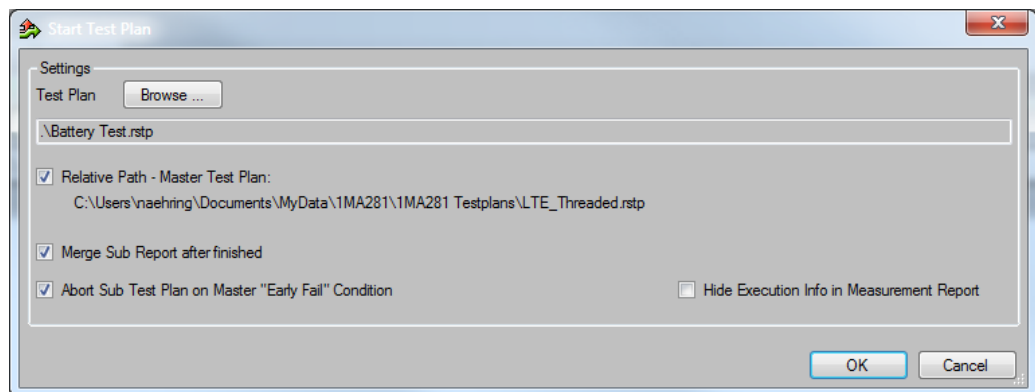


Figure 4-7: Configure CMWrun parallel testing

Since the power consumption monitor test runs indefinitely until it is stopped, start the power consumption testplan as the secondary thread. [Figure 4-8](#) represents the control flow of parallel testing for power consumption measurements with automatic merge of test reports activated.

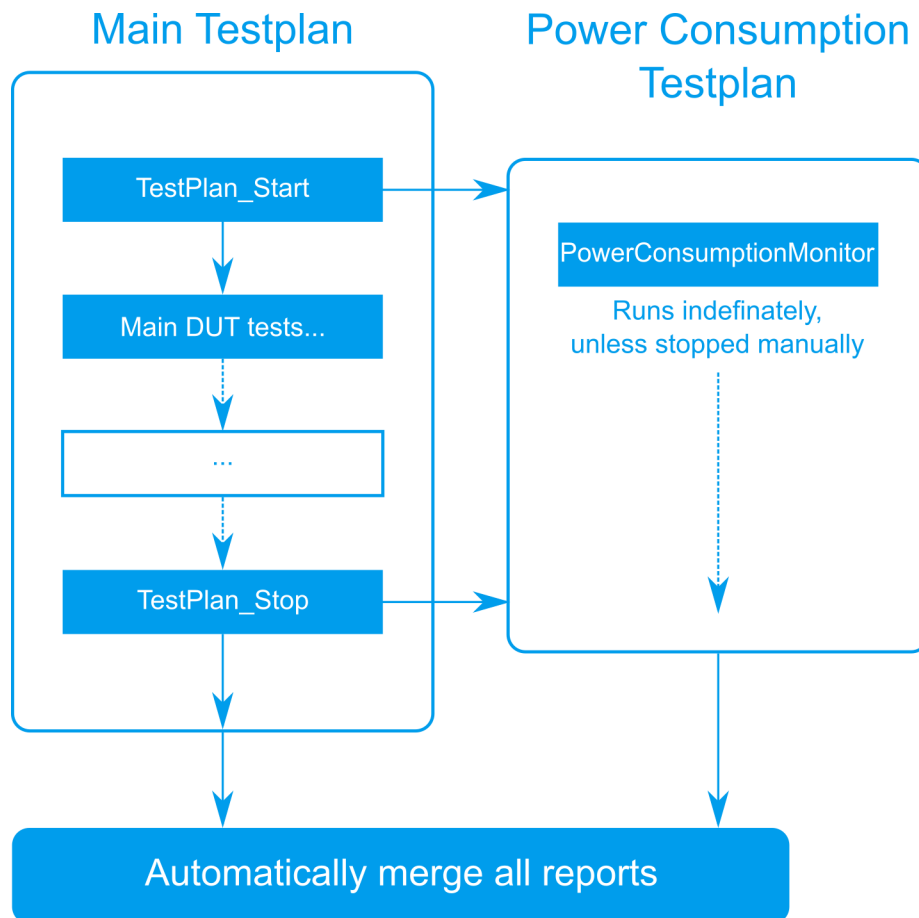


Figure 4-8: CMWrun parallel testing flowchart

4.3.1 Event Markers

Event markers help to track network events in the power consumption event chart and can be created in two ways. The first way, is to define custom event markers and place them in the testplan. To create event markers manually at certain steps in a testplan, use the "EventChartMarker" test which can be found under "Elements" > "Report". There, set a custom text which appears together with an event marker in the event chart.

Secondly, event markers can be created automatically by CMWrun. CMWrun steps with an impact on the signal of the DUT and consequent change of the power consumption are able to fire event markers. There are different types of event markers that can be fired automatically:

- Signaling state change: fired out of CallSetup steps
- Configuration steps: fired by cell configuration changed like "SetClosedLoopPower" (set up power) or "ChannelReconfig" (set BW, modulation, RBs, ...)
- User defined markers

- IP event markers: a separate type of marker created by the "IP Analysis Tool" of CMW500 (CMW-KM051 option)

The first three types are signaling markers, which are displayed in red, while the IP event markers are displayed in blue.

In addition to helping us track what happens at certain moments in the event chart and thus correlate instantaneous power consumption to network events or operation states of the DUT, event markers also establish a basis for further analysis in CMWrun. First, values like average and maximum voltage, current and power are plotted for the overall measurement as well as for individual segments in the event chart that is segmented by event markers. Therefore, event markers help to automatically get information about the average or peak power for the defined timeslots. Also, event markers trigger enhanced time resolution (higher sampling rate) for the chart, as described in [Chapter 4.2, "Setting Up a Power Consumption Monitor Testplan"](#), on page 12.

4.4 Using the IP Throughput Monitor in CMWrun

CMW and CMWrun not only allow control over the signaling to and from the DUT but also enable to use and monitor IP traffic and display throughput figures for both uplink (UL) and downlink (DL) using IP traffic analysis (CMW-KM051). The IP traffic throughput is displayed in an event chart, similar to the power consumption chart. Combining IP throughput monitoring with power consumption monitoring helps to indicate how and which IP traffic affects the battery lifetime of the DUT. The markers triggered by IP activity are shown in both the power consumption monitor and the IP throughput monitor.

Like the power consumption monitor, the end to end testset (E2E) / IP throughput monitor should be used in a multi-threaded configuration. As explained in [Chapter 4.3, "Creating Multi-Threaded Testplans"](#), on page 16, create an extra testplan (.rstp) which starts the E2E_testset. In contrary to setting up the power consumption as a threaded testplan, the E2E_testset also communicates with the CMW. Therefore, configure the IP monitor testplan to use a second SCPI port of the CMW to communicate in parallel to the main testplan, which uses the primary SCPI port (by default).

First, create a testplan in CMWrun, with "E2E_Testset" as the sole test step. Save this testplan as "data_thruput_monitor.rstp". With the testplan open, select "Resources" -> "SCPI Connections ..." to edit the SCPI connections for this testplan.

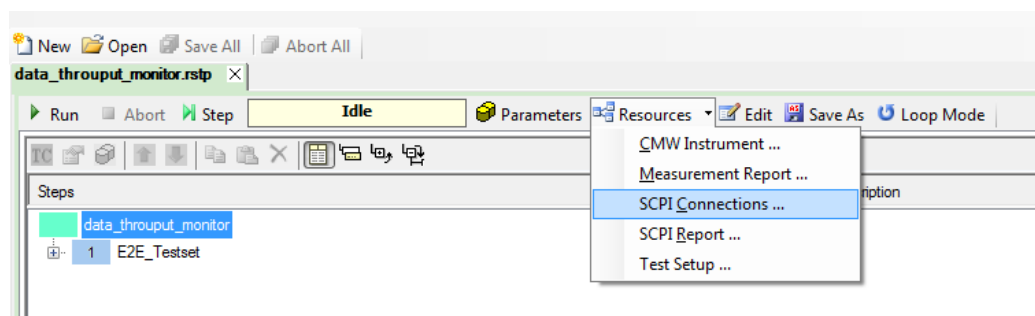


Figure 4-9: Local SCPI connections

By default, all testplans use the global SCPI connections already set up. However, each testplan can be assigned settings that are only applied locally. As shown in [Figure 4-9](#), click "Create Specific Settings" in the "SCPI Connections" window, to enable the testplan-specific SCPI settings. Select the CMW connection that is already set up and click "Configure ..." to edit the connection. Now, use the "Assistant" to select another "Sub Instrument". By default, "Sub Instr. 0" is used. Therefore, use "Sub Instr. 1" for the IP throughput testplan, as in [Figure 4-10](#).

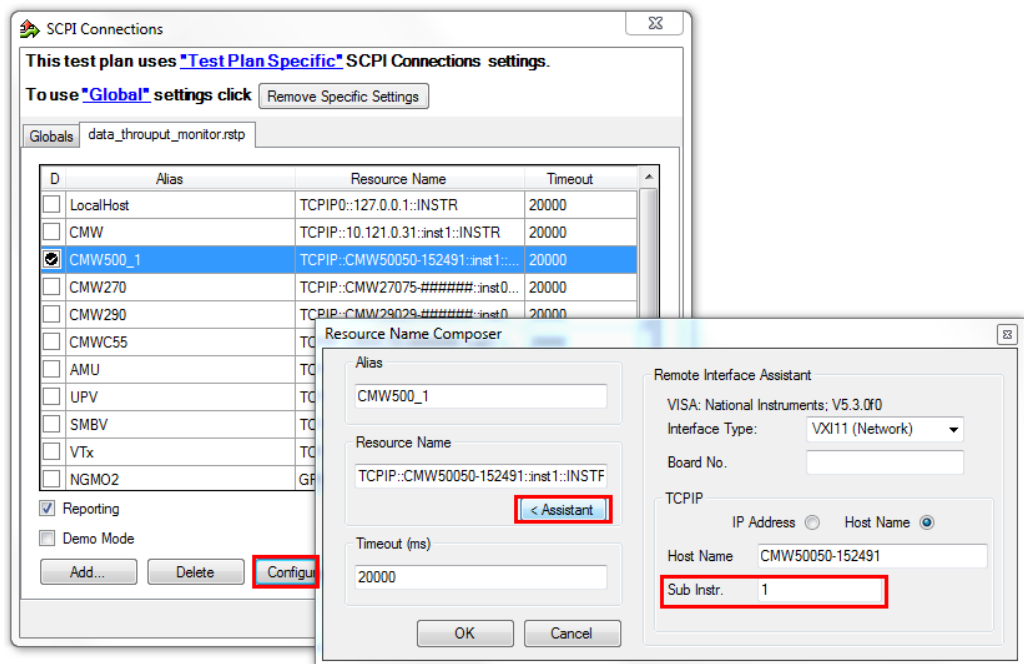


Figure 4-10: Set up local SCPI connection to sub instrument 1

Close the open windows and apply all changes. Now, this testplan can communicate with the same instrument as the main testplan in parallel.

In the next step, the E2E testset is set up to monitor the IP throughput with activation of the IP traffic monitor using IP traffic analysis (CMW-KM051). Double click the E2E_Testset step to open the configuration window of the test step. Set the "Repetition" to "Continuous", activate the "IP Analysis" event chart and enable the sending of events. The full configuration is shown in [Figure 4-11](#).

A filter over the different IP layers can be set to show only IP events of interest. [Figure 4-12](#) shows the filter window and an example of how to only show FTP traffic-related events.

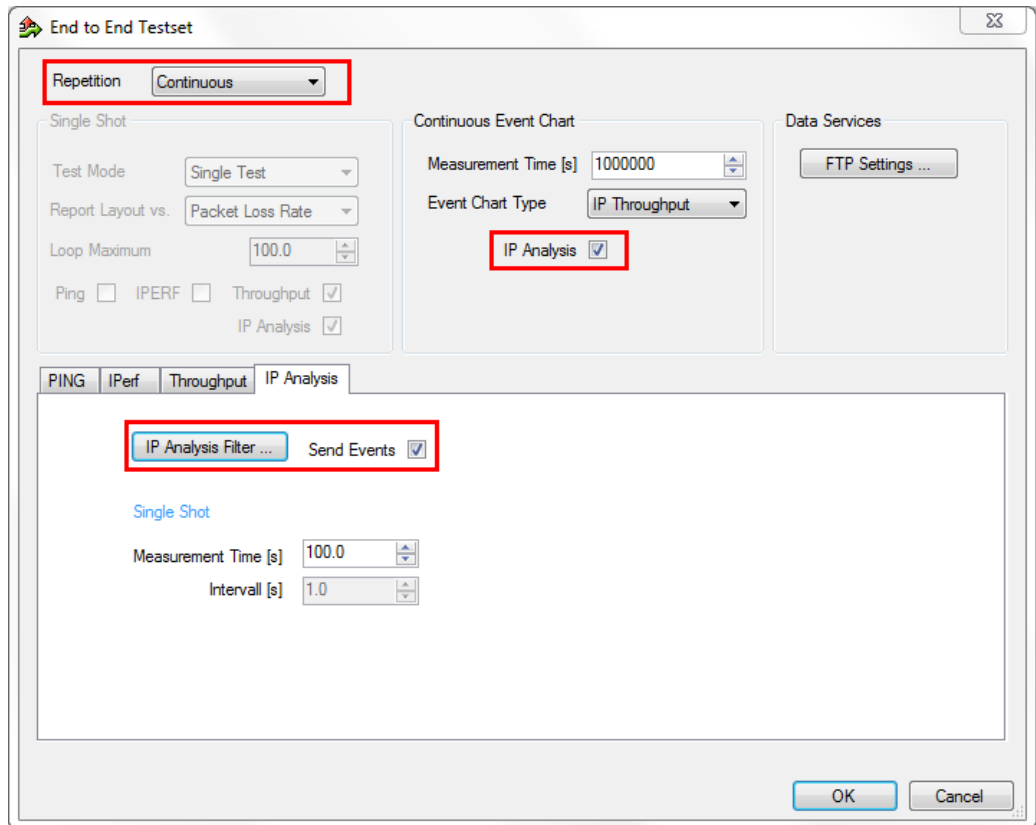


Figure 4-11: End to end (E2E) testset configuration

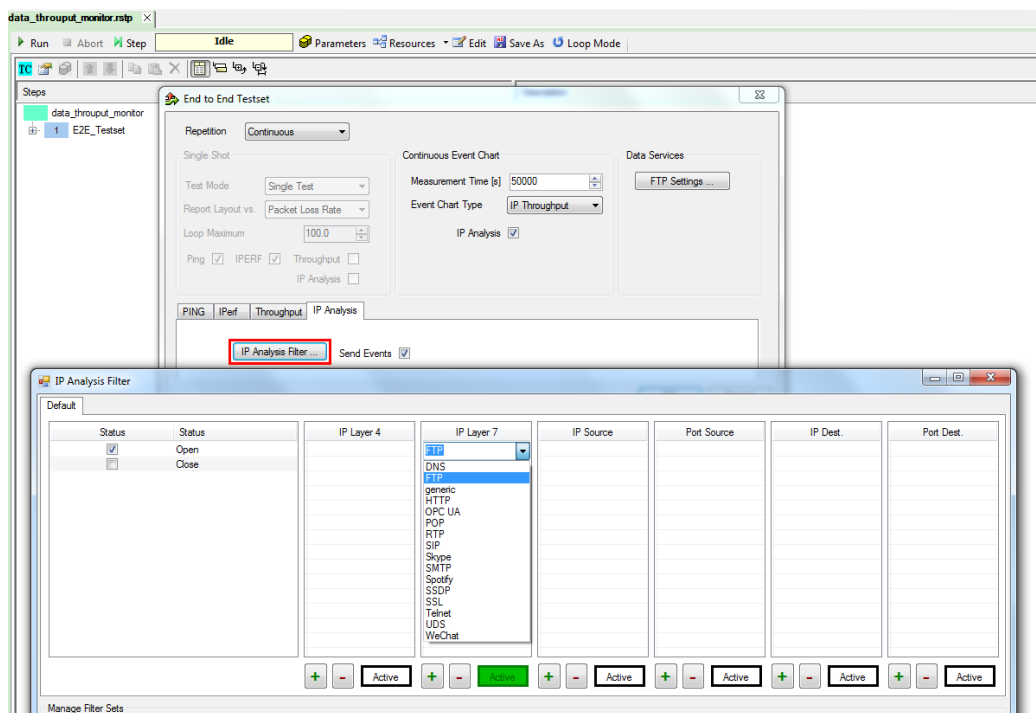


Figure 4-12: E2E testset IP layer filter

5 Example Test Plans for CMWrun

This chapter gives examples for using the RT-ZVC power probe with CMWrun as both an autonomous measurement and as part of a multi-threaded test with a CMW for combined power and signaling measurements. The general concept provided in the example test plans can be expanded for other types of devices or communication standards.

5.1 USB Powered LTE Cat0 Device

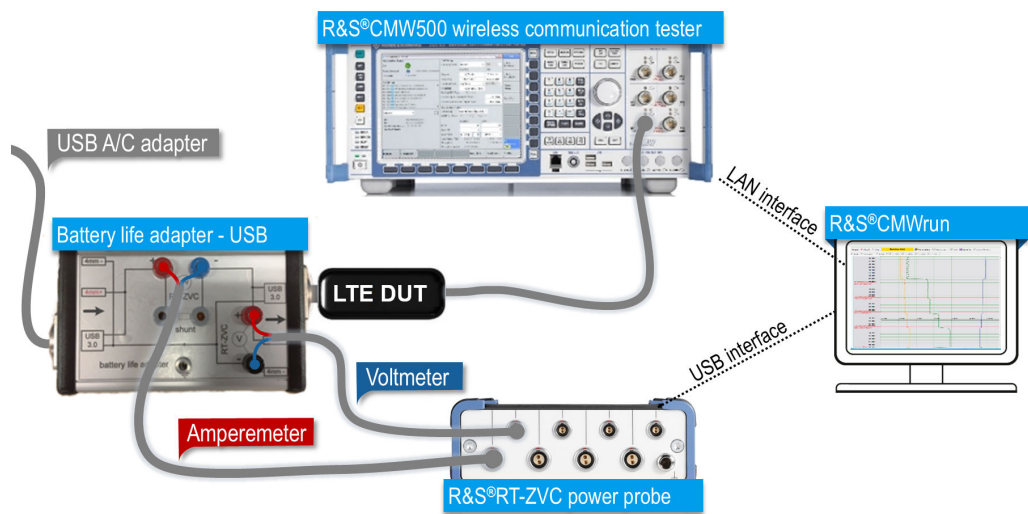


Figure 5-1: Measurement setup for LTE DUT

In this setup, an LTE Cat0 device is connected to a CMW500 for network emulation while the RT-ZVC measures the power consumption of the USB powered device. [Figure 5-1](#) shows the used DUT for this example.

As a prerequisite, set up the CMW and RT-ZVC as described in [Chapter 4.1, "Set Up CMWrun, CMW500 and RT-ZVC"](#), on page 11.

The DUT is powered via USB and is probed directly at the USB cable. For easy probing, a custom-made adapter box enabling access to the cable is used in this setup. For operation, the USB 3.0 cables can be plugged in at both ends and 4mm plugs are used to measure voltage and current. It is possible to either use the internal shunt of the RT-ZVC or an external shunt that can be fitted on the box.

For the power supply, an R&S®HMC power supply, an off-the-shelf USB power adapter or any other device with powered USB output, like a computer, can be used. The adapter box only affects the power cables (pins 1 and 4) and allows normal data transmission over the USB cable, if needed. In this scenario, the DUT is powered using an R&S®HMC 8043 power supply.

For the power consumption measurement, use parallel testing, as shown in [Figure 4-8](#). First, set up the power consumption testplan. Create a testplan by double clicking the

"PowerConsumptionMonitor" test in the "Tests File Browser". Activate voltage, current and power on channel group 1, and choose the measurement ranges according to the expected values.

As defined in the USB standard, the voltage is around 5 V with a maximum current of 0.9 A. Scale the current by 10, which fits nicely in the event diagram ranges from -1 to 6 with currents below 600 mA. Also, activate a 1 second long resolution zoom after event markers. [Figure 5-2](#) shows the used configuration for the power consumption monitor testplan. With all parameters set, accept the configuration and save the testplan as "Battery Test.rstp".

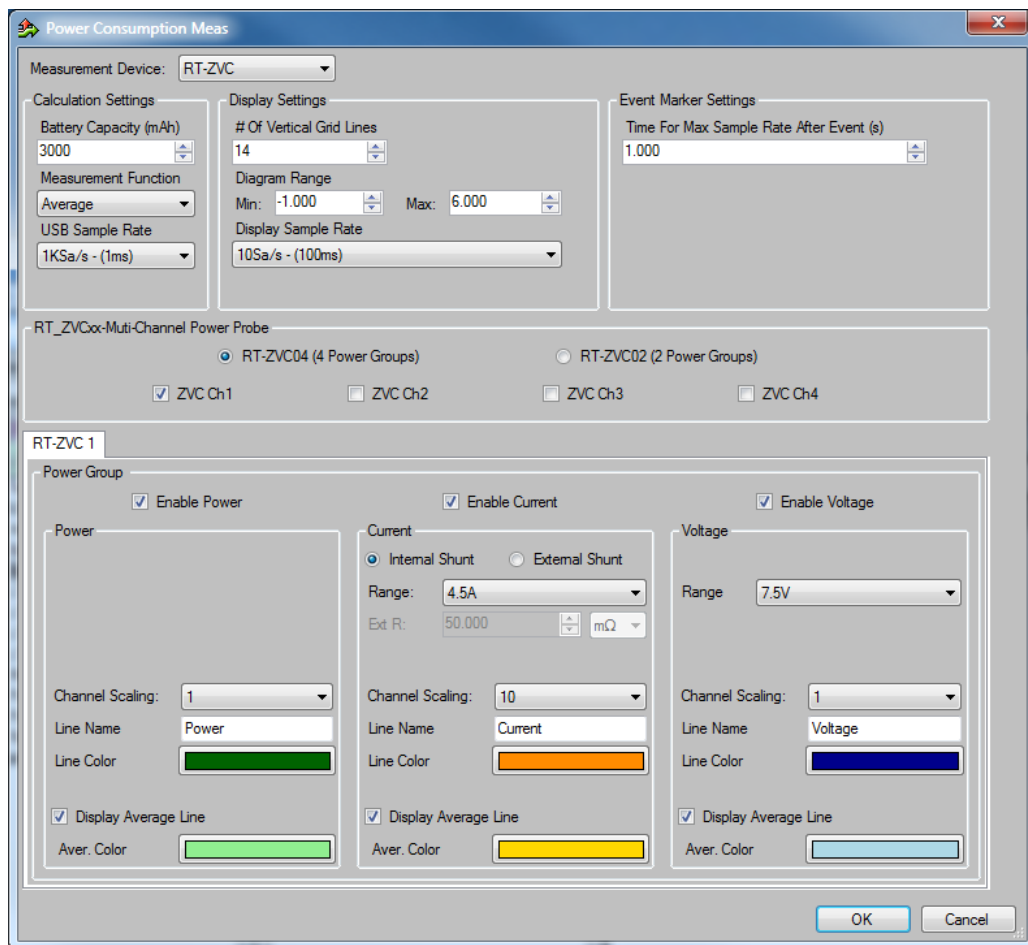


Figure 5-2: Power consumption measurement configuration for LTE DUT

For the main testplan, create a new empty testplan file by clicking "New". Now, add multiple tests to the testplan. [Figure 5-3](#) shows the steps of the main testplan. First, the power consumption measurement is started in parallel using "TestPlan_Start". "Delay" is used to halt main testplan execution for a defined time, in this case, 2000 milliseconds.

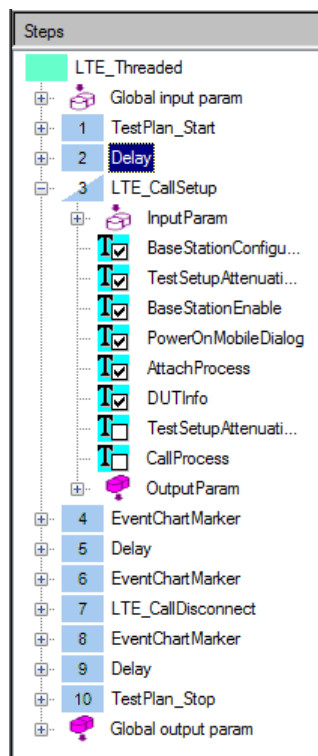


Figure 5-3: Steps of main testplan

Subsequently, the "LTE_CallSetup" test is used to enable the CMW for an LTE base station emulation in band 4 and wait for the DUT to attach. Deactivate the "CallProcess" by removing the checkbox from this step, as the used DUT does not support accepting calls. Place some manual event chart markers in between the steps to create points of reference in the event chart, and to create separate sections for the displayed values. At the end, the base station is disabled and after an additional delay, the "Battery Test" testplan is explicitly stopped using "TestPlan_Stop".

Save the testplan as "LTE_Threaded.rstp".

When executing the main testplan, it automatically starts the power consumption measurement in parallel and also plots the measured values in real time to the event chart. After execution, CMWrun will merge the reports of both testplans into a single report. The report consists of the standard reporting of the executed testplans and the results of the power consumption monitoring.

Settings			Value	Unit
Global Settings				
Capacity of Battery			3000.000	mAh
Data				
Global Data				
Voltage Average (ZVC VCH1)			4970.502	mV
Voltage Max (ZVC VCH1)			5012.967	mV
Current Average (ZVC ACH1)			252.415	mA
Current Max (ZVC ACH1)			383.034	mA
Current Battery Life (dec) (ZVC ACH1)			11.885	h
Power Average (ZVC WCH1)			1253.361	mW
Power Max (ZVC WCH1)			1897.810	mW
Time			0:01:38.200	
Info				
Marker				
##### Test Start ==> LTE Call - Attached #####	#####	#####	#####	#####
Voltage Average (ZVC VCH1)			4983.278	mV
Voltage Max (ZVC VCH1)			5012.967	mV
Current Average (ZVC ACH1)			141.395	mA
Current Max (ZVC ACH1)			372.124	mA
Current Battery Life (dec) (ZVC ACH1)			21.217	h
Power Average (ZVC WCH1)			703.283	mW
Power Max (ZVC WCH1)			1844.361	mW
Time			0:00:34.000	
##### LTE Call - Attached ==> Wait some time... #####	#####	#####	#####	#####
Voltage Average (ZVC VCH1)			4958.783	mV
Voltage Max (ZVC VCH1)			4960.238	mV
Current Average (ZVC ACH1)			352.744	mA
Current Max (ZVC ACH1)			364.304	mA
Current Battery Life (dec) (ZVC ACH1)			8.505	h
Power Average (ZVC WCH1)			1749.180	mW
Power Max (ZVC WCH1)			1805.844	mW
Time			0:00:00.600	
##### Wait some time... ==> disable BS #####	#####	#####	#####	#####
Voltage Average (ZVC VCH1)			4960.770	mV
Voltage Max (ZVC VCH1)			4963.017	mV
Current Average (ZVC ACH1)			336.986	mA
Current Max (ZVC ACH1)			383.034	mA
Current Battery Life (dec) (ZVC ACH1)			8.902	h
Power Average (ZVC WCH1)			1671.700	mW
Power Max (ZVC WCH1)			1897.810	mW
Time			0:00:30.700	
##### disable BS ==> BS disabled #####	#####	#####	#####	#####
Voltage Average (ZVC VCH1)			4962.665	mV
Voltage Max (ZVC VCH1)			4964.406	mV
Current Average (ZVC ACH1)			321.240	mA
Current Max (ZVC ACH1)			358.124	mA
Current Battery Life (dec) (ZVC ACH1)			9.339	h
Power Average (ZVC WCH1)			1594.192	mW
Power Max (ZVC WCH1)			1775.363	mW
Time			0:00:02.100	
##### BS disabled ==> Test End #####	#####	#####	#####	#####
Voltage Average (ZVC VCH1)			4966.861	mV
Voltage Max (ZVC VCH1)			4986.874	mV
Current Average (ZVC ACH1)			284.027	mA
Current Max (ZVC ACH1)			336.533	mA
Current Battery Life (dec) (ZVC ACH1)			10.562	h
Power Average (ZVC WCH1)			1410.711	mW
Power Max (ZVC WCH1)			1669.018	mW
Time			0:00:30.800	

Figure 5-4: Results of LTE Cat0 power measurement in CMWrun

Figure 5-4 shows the results from the power measurement. At first, the "Global Data" gives information about the measured values for the selected channels over the complete measurement duration. Afterwards, the measurement is divided into segments split by the event markers. From there, the power consumption of the DUT can be put into context. In the segment "Wait some time... ==> disable BS", the results show that the DUT used 1.671 W on average while being attached to the BS. Based on the provided battery capacity in mAh (see Figure 5-2), CMWrun also calculates the expected

battery life based on the consumption during the test, respectively during each segment of the test.

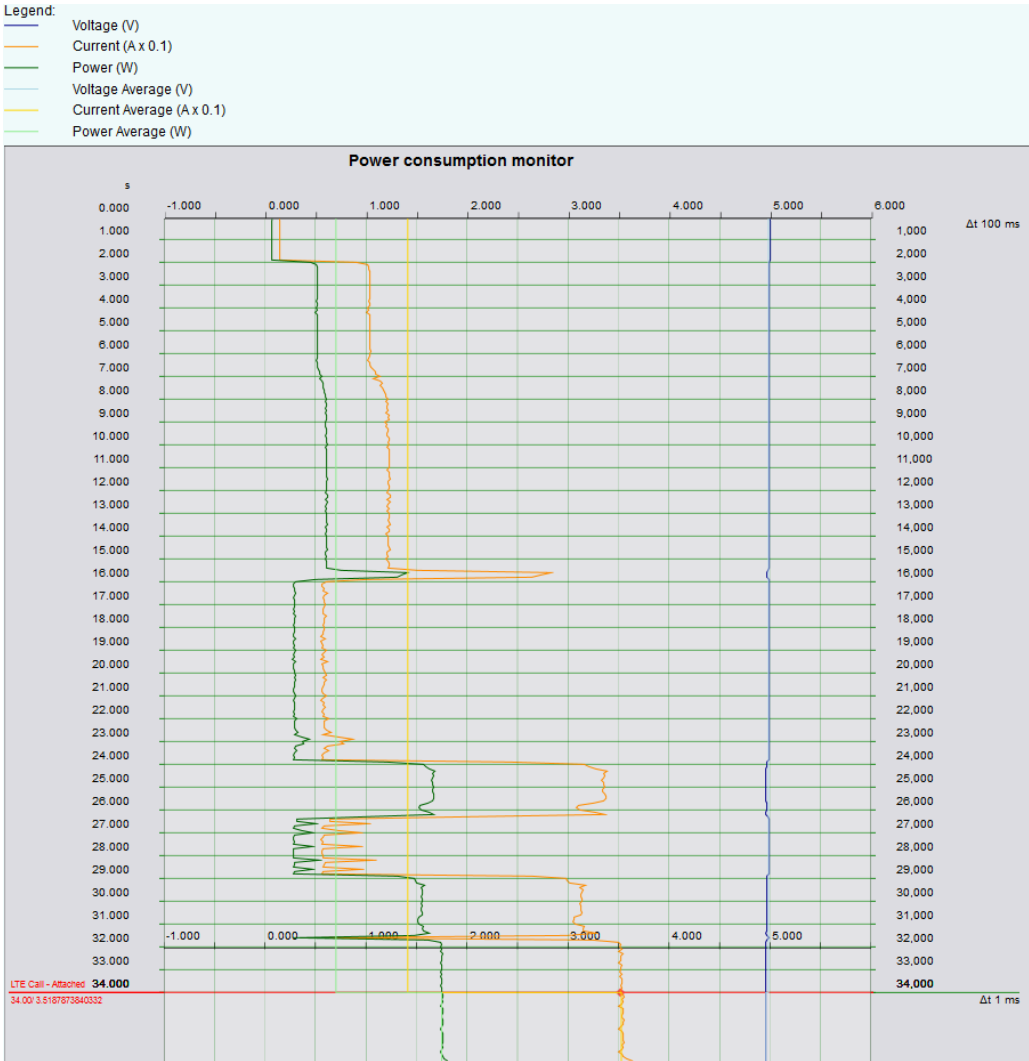


Figure 5-5: First part of event chart of LTE Cat0 power measurement with CMWrun

The event chart gives an intuitive overview of the consumption and represents all values graphically over time. Figure 5-5 shows the first part of the event chart. The DUT is powered on at about t = 2 s, after which the boot sequence is started. After about 24 seconds into the test, the device starts searching for the LTE base station (BS). At 34.00, the "LTE Call" test emits an event marker, announcing that the DUT has attached to the BS. The time resolution changes due to the event marker as defined in the power consumption testplan.

In addition to the measured value, CMWrun also plots the average values for each segment, if defined in the test configuration. With good placement of event markers, average consumption for different operation modes of a DUT can be measured in one single measurement.

This basic example shows the setup of an LTE DUT with CMWrun and CMW. It can be expanded easily with advanced signaling methods and IP traffic as supported by CMW

and CMWrun. The following sections give a short introduction to the possibilities offered by combining high precision power monitoring with the signaling capabilities of the CMW.

5.1.1 Monitoring the Impact of UL Power and Allocated Bandwidth

The testplan from the basic example is now expanded with other CMWrun steps to control the UL power of the DUT, change the used bandwidth and perform handovers during a test mode connection (stimulating UL transmission of the DUT all the time). [Figure 5-6](#) shows the extended testplan for this measurement. All added steps fire their own signaling event markers to the power consumption monitor. There is no need for custom placed markers in this testplan.

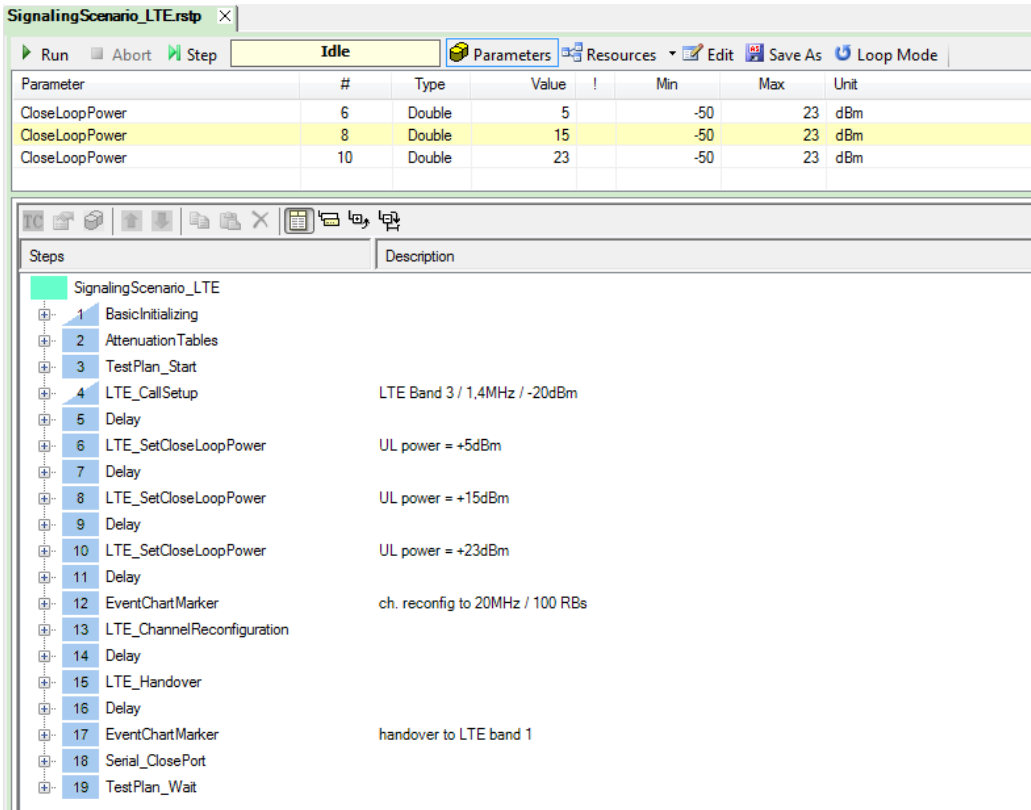


Figure 5-6: Testplan with advanced LTE signaling

[Figure 5-7](#) shows the resulting power consumption diagram for this setup.



Figure 5-7: Results for advanced LTE signaling testplan

5.1.2 Monitoring Power Consumption with PSM (Power Save Mode)

In the field of IoT devices power consumption measurements are of great interest, especially with the new signaling features recently defined by 3GPP for reducing the power consumption of machine type communication (MTC) devices. One of these features, aiming to allow battery lifetimes of 10 years or more, is PSM (power save mode). During PSM, the UE saves power and is not reachable by the network, but remains registered with the network without the need to reattach or reestablish PDN connections upon waking up.

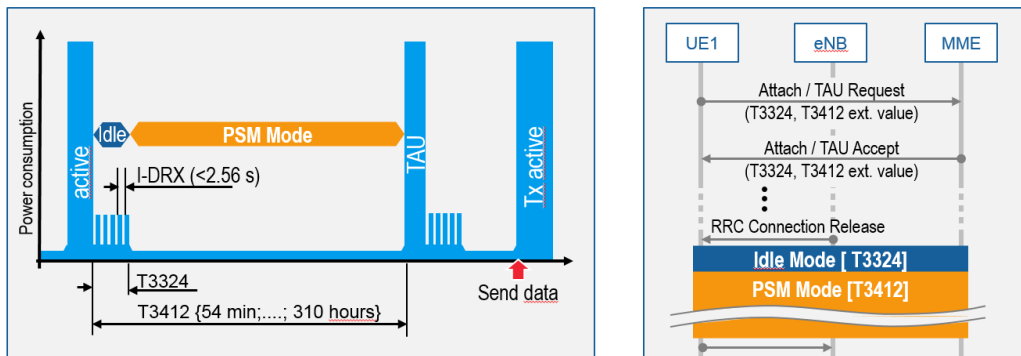


Figure 5-8: Overview LTE PSM timer

In this testplan, the CMW is set to enable PSM conditions like in a real network. As a result, the UE first goes to idle (T3324 timer) after a certain inactivity time, and later to PSM (ExtendedT3412 timer). Figure 5-8 shows the PSM timer in a graphical manner.

In this measurement, the following settings are applied directly at the CMW (alternatively, they can also be set using CMWrun):

- Keep RRC off: set inactivity time to 2 s
- TAU timer: set periodic tracking area update by the UE (T3412) to 20 s
- PSM: set to enabled (on)

The DUT is configured to inform the CMW over TAU request with T3324 = 5 s and ExtendedT3412 set to 20 s. These short timer values are exemplary for better visibility in the CMWrun power monitor. In reality, these timeouts are much longer.

The CMWrun testplan starts an LTE connection, the power consumption monitor and monitoring the signaling state changes which create signaling event markers in the diagram as shown in Figure 5-9.

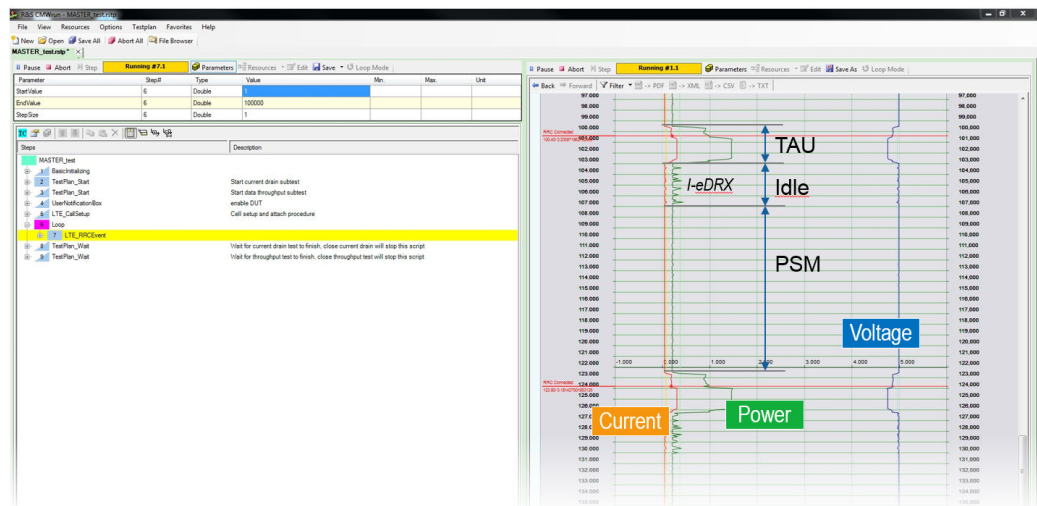


Figure 5-9: LTE PSM testplan in CMWrun with result view

5.1.3 Monitoring the Power Consumption and IP Traffic

Now, the LTE CAT0 DUT is connected to a client PC over USB to monitor its behavior as if in a real network, with occasional IP traffic in the uplink and deep sleep (PSM) during inactivity. The CMWrun testplan can monitor power and IP traffic with the test "E2ETest.dll".

Now, the power consumption can be measured while creating a context using IP events in the result chart. In the given example, the DUT is idle and switches to PSM after the defined timeout. Then, a TCP FTP connection is started from the DUT, and both the signaling and IP event markers can be observed in the event chart, shown in Figure 5-10

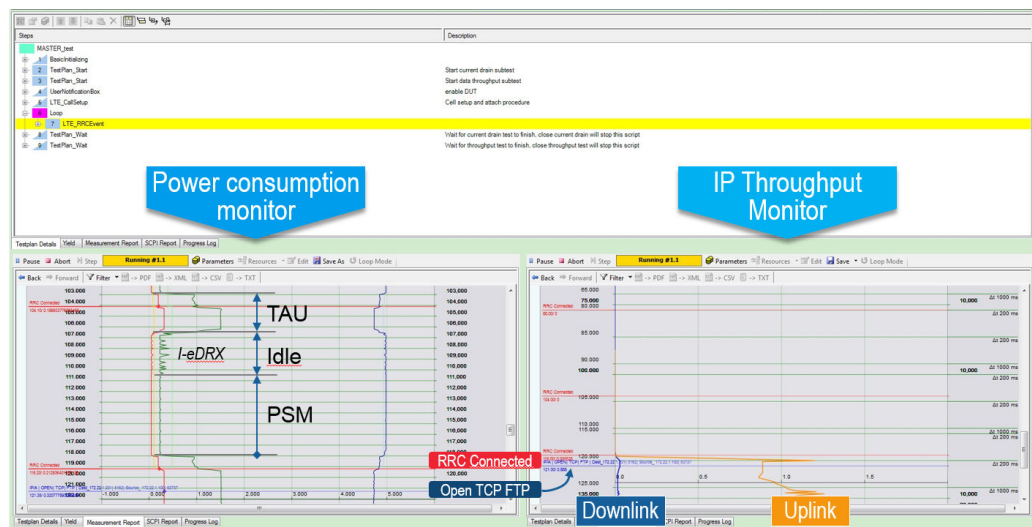


Figure 5-10: CMWrun power consumption and IP monitoring testplan

5.2 Battery Powered Off-the-Shelf Device

In this example, an off-the-shelf battery powered Wi-Fi device by a major online retail shop is examined. The device is used to order items from the retailer over Wi-Fi when the device button is pressed and remain idle the rest of the time. The DUT has two operating modes. First, a one time setup is used to configure the device. During this, Bluetooth and Wi-Fi are used to communicate with the outside world. Second, the device sends small packages over Wi-Fi every time the button is pressed.

Normally powered by an AAA battery, the battery is removed from the device to connect clips to the contacts as can be seen in Figure 5-11. The device can either be powered with the original battery or using an external power supply. For this demonstration, again the R&S®HMC 8043 is used.

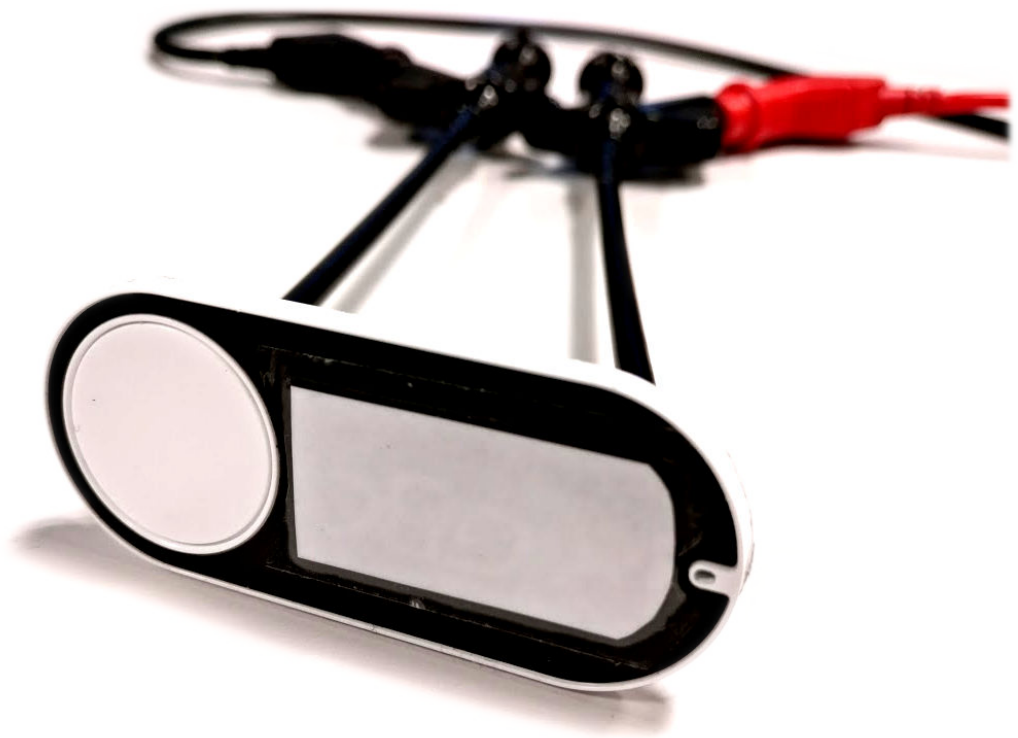


Figure 5-11: Battery off-the-shelf device

Figure 5-12 shows the schematics of the measurement setup in this scenario. Again, CMWrun controls the RT-ZVC power probe for power measurements. As opposed to the setup in Chapter 5.1, "USB Powered LTE Cat0 Device", on page 21, the CMW is not used in this scenario. Therefore, connect the RT-ZVC to the host PC with CMWrun and the required drivers installed as prerequisite.

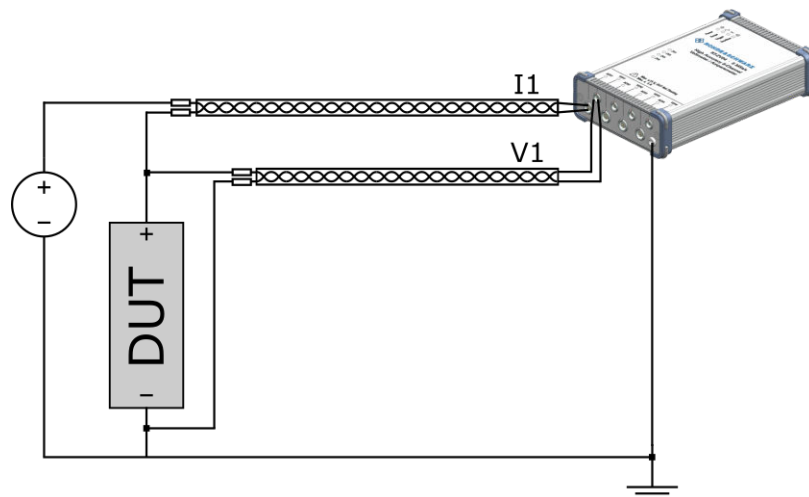


Figure 5-12: Schematic for measuring Wi-Fi DUT power consumption

First, create a testplan in CMWrun. Either double click the "PowerConsumptionMonitor" test in the "File Browser" or click "New" to create an empty testplan and add the

"PowerConsumptionMonitor test" from the "Tests" tab. Then, double click the "Power-ConsumptionMonitor" test step in our newly created testplan to configure the test parameters.

Activate RT-ZVC Ch 1 and enable power, current and voltage. With a voltage of 1.5 V, select "1.88V" as the range for the voltage. Under current, select "4.5A". Scaling is set to 1 for all lines. Set custom names for the lines and enable average lines if desired. Ignore the "Event Marker Settings", as event markers are not used in this setup. Select an appropriate range for the diagram under "Display Settings". As the maximum current is expected to be below 2 A, this example uses limits of -0.25 and 2 to ensure both extremes are not cut off. With 9 grid lines this provides lines every 0.25 units. Leave "USB Sample Rate" on the maximum setting while choosing the "Display Sample Rate" as desired. In this example, "10Sa/s - (100ms)" is used. [Figure 5-13](#) shows the resulting settings window.

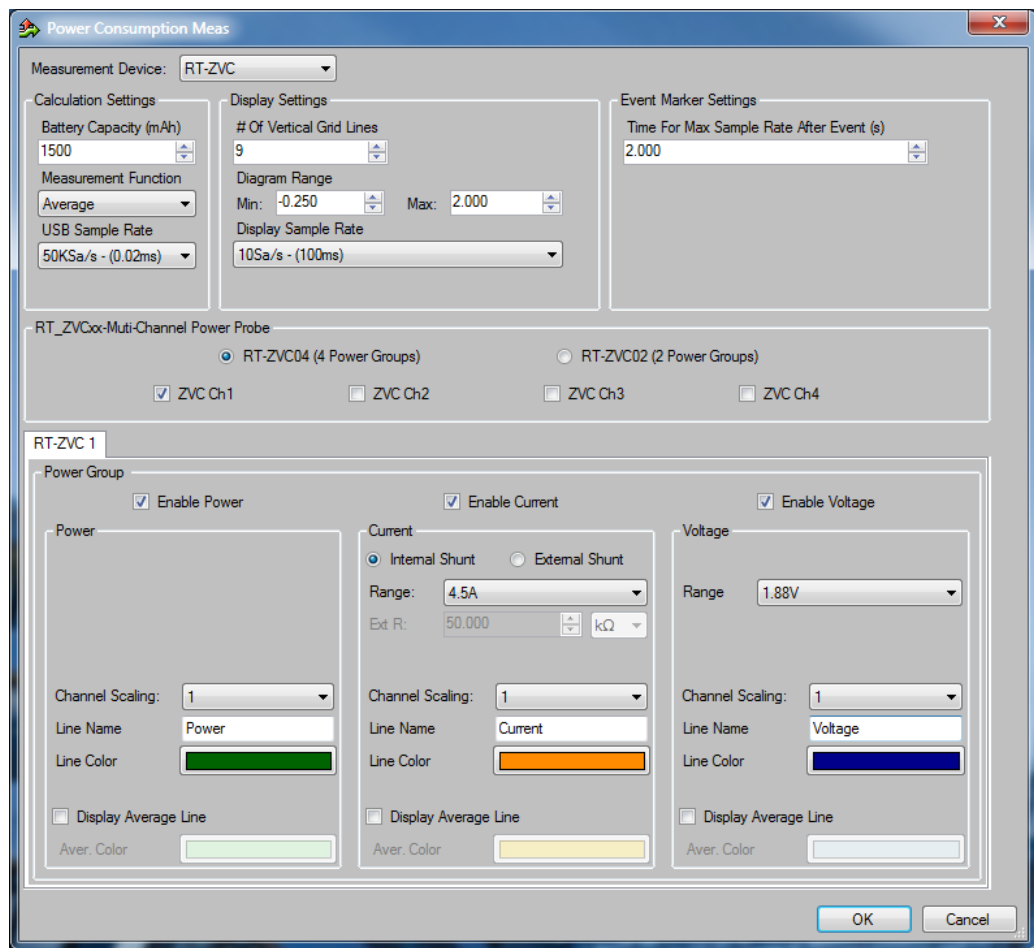


Figure 5-13: Power consumption measurement configuration for battery powered off-the-shelf device

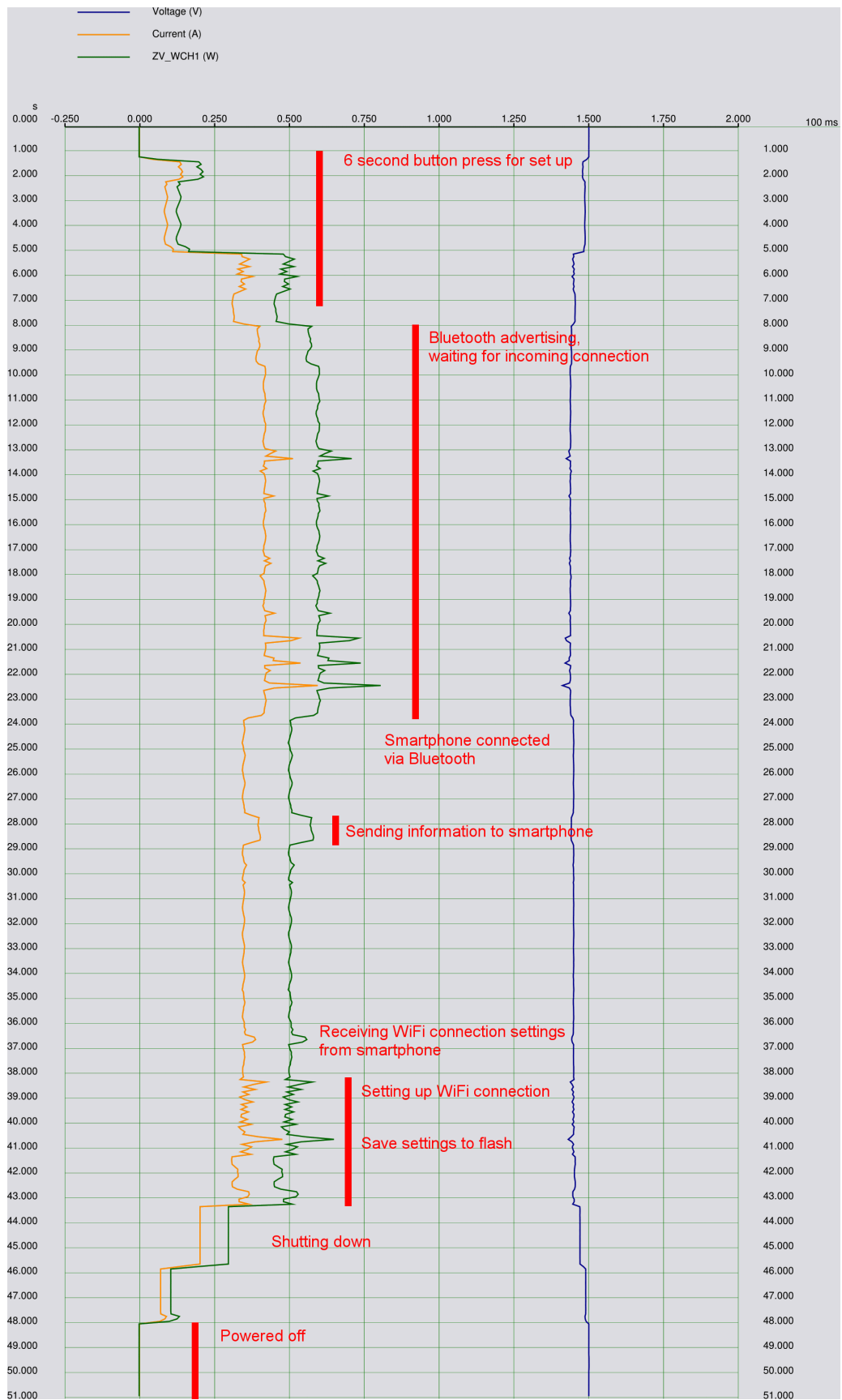


Figure 5-14: Event chart for one-time setup of DUT

As previously mentioned, the device has two modes of operation: a configuration mode and a normal operating mode. The configuration mode is measured first, and here the device is controlled manually with the help of a smartphone app. First, the single button on the DUT is pressed for 6 seconds. This causes the DUT to switch on Bluetooth and wait for an incoming connection from the smartphone app which sends the settings to the device. In the app, the DUT is configured to connect to a Wi-Fi access point after which the DUT saves the settings and shuts down, fully configured. Figure 5-14 shows the resulting event chart, measuring the full procedure.

With the DUT configuration complete, now the normal operating mode is measured. In this mode the DUT connects to the configured Wi-Fi and sends a small package to an Internet server every time there is a button press. The same testplan as before can be used without changing any of the parameters. In this test, the testplan is started and then the button on the DUT is pressed.

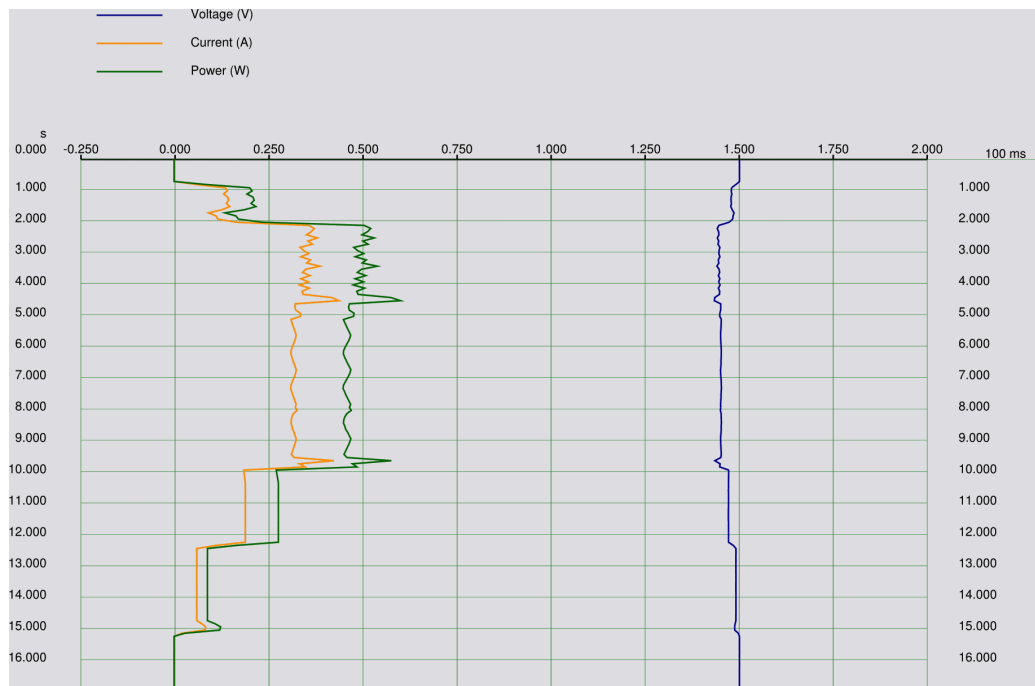


Figure 5-15: Event chart for ordering process of DUT

Settings			Value	Unit
Global Settings				
Capacity of Battery			1000.000	mAh
Data			Value	Unit
Global Data				
Voltage Average (ZVC VCH1)			1469.545	mV
Voltage Max (ZVC VCH1)			1873.196	mV
Current Average (ZVC ACH1)			199.105	mA
Current Max (ZVC ACH1)			1581.459	mA
Current Battery Life (dec) (ZVC ACH1)			5.022	h
Power Average (ZVC WCH1)			287.570	mW
Power Max (ZVC WCH1)			1990.098	mW
Time			0:00:16.900	

Figure 5-16: Results for ordering process of DUT

With the first impression from the event chart in Figure 5-15, a look at the results in Figure 5-16 gives insights about battery lifetime. Given an estimated capacity of 1000 mAh of the alkaline battery, the number of times an item can be ordered before the battery runs dry can be estimated. With an average current of 199.105 mA over a period of 16.9 s, a total of 0.935 mAh is used per button press. This gives about 1070 button presses before the full 1000 mAh are used. The same result can be calculated by taking the estimated battery life of 5.02 h as calculated by CMWrun and divide this by 16.9 s per press. Given one press per week, 1000 button presses translate to over 19 years worth of battery life. Although not taking the decreasing capacity of the battery over time into account, it can safely be assumed that the device will remain operational for a sufficient period of time.

6 Ordering Information

Designation	Type	Ordner No.
Multi-Channel Power Probe, 2 × 4 voltage/ current channels for R&S®CMWrun	R&S®RT-ZVC04	1326.0259.24
Multi-Channel Power Probe, 2 × 2 voltage/ current channels for R&S®CMWrun	R&S®RT-ZVC02	1326.0259.22
Wideband Radio Communication Tester	R&S®CMW500	1201.0002K50
CMW00 Basic Assembly, 70MHz to 3.3GHz	R&S®CMW-PS505	1208.8921.02
CMW module H100A, Baseband Measure- ment Unit, with 1GByte digitizer memory	R&S®CMW-S100A	1202.4701.02
CMW module H550M, Baseband interconnec- tion, flexible link, for multibox/non-signaling/ signaling/IQ access	R&S®CMW-S550M	1202.4801.14
CMW module H570B, RF Converter (TRX)	R&S®CMW-S570B	1202.5008.03
CMW module H590D, RF Frontend, advanced functionality	R&S®CMW-S590D	1202.5108.03
CMW module H600B, CMW500 frontpanel with display/keypad	R&S®CMW-S600B	1201.0102.03
CMW module H052S, Solid State Drive (SSD)	R&S®CMW-S052S	1202.4201.20
CMW module H300B, Signaling Unit Wide- band (SUW), for WCDMA / LTE	R&S®CMW-B300B	1202.6304.03
CMW module H450D, Data Application Unit	R&S®CMW-B450D	1202.8759.05
CMW module H570B, Extra RF Converter (TRX)	R&S®CMW-B570B	1202.8659.03
CMW module H660A, Option Carrier	R&S®CMW-B660A	1202.7000.02
CMW module H661A, Ethernet switch	R&S®CMW-B661A	1202.7100.02
CMW LTE FDD Release 8, SISO, signaling/ network emulation, basic functionality	R&S®CMW-KS500	1203.6108.02
CMW LTE Release 8, SISO, signaling/network emulation, advanced functionality	R&S®CMW-KS510	1203.9859.02
CMW LTE TDD (TD-LTE) Release 8, signal- ing/network emulation, basic functionality	R&S®CMW-KS550	1204.8904.02
CMWrun sequencer software tool	R&S®CMW-KT051	1203.4157.02
CMWrun sequencer software tool, LTE	R&S®CMW-KT055	1207.2107.02
Application testing / IMS bundle, including : IP data interface R&S®CMW-KA065/100/150, measurements R&S®CMW-KM050/051, IMS services R&S®CMW-KAA20 and -KA065	R&S®CMW-PK45	1207.6354.03

7 Rohde & Schwarz

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- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership



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