TSMW Digital I/Q Interface Option K1
Application Note 1SP55

Products:

R&S®TSMW

This application note describes how to perform user specific RF measurements in block and continuous streaming mode using the R&S®TSMW and the R&S®TSMW-K1 option. The R&S®TSMW is a universal Radio Network Analyzer for IQ streaming and drive testing of mobile communication networks.

The test setup requires the radio network scanner R&S®TSMW with the digital I/Q interface option R&S®TSMW-K1 and a PC with Windows XP and R&S®TSMW-K1 installed. Measurements can be performed directly within MATLAB™, using a pre-compiled MATLAB™ Test Application or via user C++ applications.

In combination with R&S signal generators it is possible to replay selected parts of the recorded RF signal streams at the same or at different center frequencies.

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1 Overview

The TSMW Digital I/Q-Interface Option R&S®TSMW-K1 is a C++ software API that provides direct access to the TSMW for capturing I/Q data using MATLAB™ or a user specific C++ application. This allows for measuring RF signals with arbitrary center frequencies between 30 MHz and 6 GHz with a maximum bandwidth of 20 MHz. Both front-ends of the TSMW can be controlled, separately, allowing for MIMO measurements as well as measurements on different center frequencies, e.g. to capture mobile radio downlink and uplink band, simultaneously.

Furthermore, seamless streaming measurements are possible with recording lengths that only depend on hard disc space and host pc performance.

Using the R&S®TSMW IQ Interface Demo Application, it is possible to set measurement parameters, perform single or streaming measurements and export the measured data to the MATLAB™ workspace or to MATLAB™ binary files. The same functionality (apart from exporting to MATLAB™ format) is available using the C++ API functions. This allows for easy porting of MATLAB™ measurement applications to C++ in order to achieve higher performance.

2 Software Features

The software offers:

- Performing single- and double-front-end measurements on the TSMW
- Perform user-defined filtering and sample-rate reduction of the measured signal within the TSMW for analysis of the resulting signal
- Show the spectrum and the time-domain signal of the captured data for a quick overview on what was measured
- Export the measured data to the MATLAB™ workspace or to binary MATLAB™ files for further analysis
- Stream I/Q baseband data up to a total bandwidth of 20 MHz at a sampling rate of 22 MS/s (depending on computer performance).
- Conveniently load and analyze arbitrary parts of the I/Q data stream
- Convert selected parts of the I/Q data stream to R&S signal generator waveform and list formats for easy replay on R&S signal generators

3 Hardware and Software Requirements

- R&S®TSMW with firmware 1.4 or newer installed
- R&S®TSMW with R&S®TSMW-K1 option installed
- Full MATLAB™ Installation or MATLAB™ Runtime Environment (provided on TSMW-K1 installation disc) for users who do not have MATLAB™
- R&S®TSMW IQ Interface Demo Application version 1.2.0.0 or newer installed on Windows XP host pc

- Free Ethernet connector on host pc for connection to TSMW. For highest performance a PCI-e Gigabit Ethernet card is required
- Several GB free hard disc space for streaming. For highest performance during I/Q streaming a SATA-II hard disc with a continuous transfer rate of >80 MB/s is required. The actual necessary disc speed depends on the streaming parameters, see TSMW programming manual. The maximum of 22 MS/s @ 12Bit results in approximately 75 MB/s continuous hard disc write rate. This means a recording length of one hour results in approximately 263 GB of stream data. Note: The hard disc transfer rate usually depends on the physical position of the hard disc head. Care has to be taken that the hard disc offers enough transfer rate at all physical hard disc head positions, i.e. at different levels of hard disc space usage.
- R&S signal generator for replay of captured I/Q data

4 Installation of the R&S$^®$TSMW K1 Option and TSMW I/Q Interface Demo Application

R&S$^®$TSMW-Kx options can be installed via the R&S$^®$TSMW web interface. Using Microsoft Internet Explorer, you can access the R&S$^®$TSMW web interface by connecting to the IP address of the TSMW (default: 192.168.0.2). In the "Install Option Key" section you can either enter the path to an TSMW option key xml file or the option key id in order to install it. For details see the "Manual for TSMW Software Options".

For installing the R&S$^®$TSMW IQ Interface Demo Application (MATLAB™ or standalone) insert the R&S$^®$TSMW CD into the CD-ROM drive and continue with installing. For details see the R&S$^®$TSMW manual.

5 Starting the Software

The R&S$^®$TSMW IQ Interface Demo Application is available as MATLAB™ or as compiled standalone version. For running the MATLAB™ version, start MATLAB™ and type in the MATLAB™ prompt

TSMWIQInterfaceDemo

to start the R&S$^®$TSMW IQ Interface Demo Application. For running the compiled standalone version, start TSMWIQInterfaceDemo.exe from the demo folder.

The R&S$^®$TSMW has to be connected to the host pc via LAN. Initialize the application by clicking the *Init. Interface* button and connect to the TSMW via the *Connect* button. Note: The default IP address of the TSMW is 192.168.0.2, if the IP address of the TSMW has been changed, you have to enter the correct IP address in the corresponding field, see Figure 1.

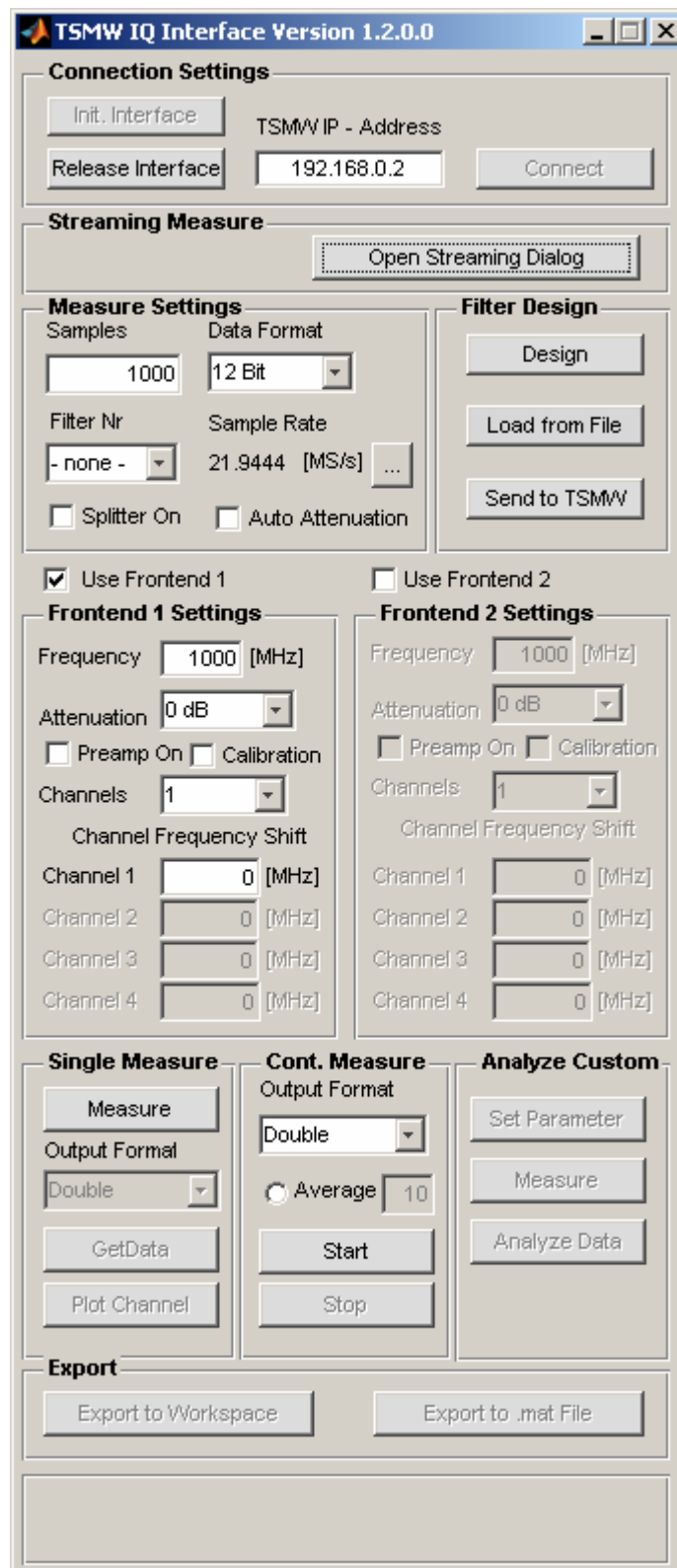After having established the connection to the TSMW, one can start to perform measurements.

Figure 1: R&S®TSMW I/Q Interface Demo Application Window
after having established a connection to the TSMW, successfully.

6 Performing Measurements

6.1 Measurement Parameters

The measurement parameters can be entered in the **"Measure Settings"** area for general parameters and the **"Front-end 1 Settings"** and **"Front-end 2 Settings"** area. Parameters in the **"Measure Settings"** area apply to both RF channels, parameters in the **"Front-end 1 Settings"** only to RF channel 1 and parameters in the **"Front-end 2 Settings"** only to RF channel 2. Table 1 summarizes the general measurement parameters.

Samples	Number of I/Q samples to measure
Data Format	Data format for compressed data transfer to the host pc. The A/D converter bit width is 14 Bit, the internal filter output width is 20 Bit. In order to reduce the amount of data to transfer to the host pc, I/Q samples are block-wise compressed. This means that every block of 64 samples is compressed to the corresponding bit width by adding an exponent to this block. On the host PC, the data blocks are decompressed, again. For high-quality I/Q measurements with 20 MHz bandwidth, 12 Bit proves to be sufficient.
Filter ID	ID of the filter to use for the measurement. Filters have to be designed using the filter design toolbox of the TSMW. Several example filters are available in the installation directory.
Splitter on	Check to activate the RF splitter. This splits the RF input signal at RF input 1 to both, RF 1 and RF 2 channels. Note: When using the active splitter, the signal of front-end 2 passes through the pre-selector path of front-end 1, this measurement only makes sense when measuring on both frontends at closely spaced center frequencies that lie in the same pre-selector band[1].
Auto attenuation	Check to activate auto attenuation mode. When using this mode, the TSMW restarts measurements with reduced sensitivity when overflows have been detected. Note: This option is only available for block measurements.

Table 1: General Measurement Settings

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[1] There are 5 pre-selector bands. A low pass band for 30 MHz – 600 MHz, three tuneable bands that reach from 600 MHz – 1.2 GHz, 1.2 GHz – 1.7 GHz and 1.7 GHz – 2.5 GHz with a tracking filter bandwidth >40 MHz and a high pass band for 2.5 GHz – 6 GHz.

By activating the "**Use Front-end 1**" check box one activates measurements on front-end 1, by selecting the **"Use Front-end 2"** check box, measurements on front-end 2 are activated. To perform simultaneous measurements on both frontends, select both check boxes. Front-end specific measurement parameters are summarized in Table 2.

Frequency	Center frequency
Attenuation	Attenuator setting to use. Possible values are 0-15dB. In auto attenuation mode this is the initial attenuation to use. Note: The optimum attenuator value for measurements with enabled preamplifier depends on the center frequency. By changing the attenuator, one can trade off between noise figure and intermodulation free dynamic range.
Preamp on	Check to activate the preamplifier. In auto attenuation mode this is the initial preamplifier setting to use.
Calibration	Check to activate the calibration path. If checked, the calibration input signal (CAL input connector) is added to the RF 1 input signal. Note: The calibration input connector is designed to allow exact phase synchronization between both frontends by providing a known input signal to both input paths simultaneously. There exists, however, no level calibration for the CAL input. This means it is not possible to perform level-accurate measurements through the CAL input. The actual measured level will differ from the input level on the CAL input and will change over frequency.
Channels	Select the number of sub-channels the input signal shall be split into. The input signal of each front-end is split into 1-4 sub-channels, where each sub-channel can be shifted by +/- 10.9722 MHz prior to low pass filtering. This allows to extract up to 4 sub-channels from the front-end bandwidth of 20 MHz.
Channel Frequency Shift	Frequency shift that is applied to each sub-channel prior to filtering. Values between +/-10.9722 MHz are supported.

Table 2: Front-end specific measurement parameters

6.2 Resampling Filters

In order to perform resampling (for user specific sampling rates) within the TSMW, it is essential to design (or load a predefined) resampling filter. The R&S®TSMW IQ Interface Demo Application includes a Filter Design Toolbox to create a custom defined resampling filter allowing arbitrary sampling rates within the valid range of 0.22 MS/s up to 21.9444 MS/s. Optimum performance is achieved with sampling rates above 1MS/s. The actual used sampling rate will slightly differ (in the range of 1ppm) from the selected one due to a limited bit width of the resampling filter. For that reason, the actual sampling rate is returned with each measurement result.

For designing user specific resampling filters press the **"Design"** button in the **"Filter Design"** area. This opens the R&S®TSMW Filter Design Tool window.

6.2.1 Using Pre-Defined Resampling Filters

Load a pre-defined resampling filter with the **"Load"** button in the **"Filter Design"** section. Such filter files are MATLAB™ (.mat) data files including a structure named "FilterSpec" containing the filter specification. After a filter specification has been loaded, it has to be transferred to the TSMW in order to use it. A filter specification is selected by its filter id. Each time a new filter is loaded into the demo application, it gets assigned the next free filter id. When pressing **"Send to TSMW"** all filter specifications are sent to the TSMW.

When selecting a filter specification with the **"Filter ID"** combo box, the corresponding sampling rate is displayed next to it. Pressing the **"…"** button shows the transfer function of the selected filter.

After having loaded a filter specification and transferred it to the TSMW, it can be selected and used for measurements.

6.2.2 Creating User Specific Resampling Filters

One of the key-features of the TSMW is the ability to perform user-defined resampling. This means that arbitrary sampling rates within the valid range can be used. The R&S®TSMW IQ Interface Demo Application includes a filter design tool for easy and efficient design of resampling filters. This tool can also be started by entering

TSMWFilterDesignTool

at the command prompt. The same tool is also supplied as a compiled version in order to allow designing a filter without having MATLAB™ installed.

The TSMW Filter Design Tool provides three different types of Low-pass filter designs:

- Modified Equiripple Low-pass
- Least Squares Low-pass
- Raised Cosine Low-pass

Best results will usually be given with the "least squares" design. Consider the following example.

You want to measure a signal with a bandwidth of 5 MHz. The minimum sampling frequency for doing this is 5 MS/s. To sufficiently suppress aliasing products, however, the sampling frequency has to be 10-20% higher than the bandwidth of the signal. We will therefore use 6 MS/s.

The signal bandwidth of interest will lie between +/- 2.5 MHz (1/2 of the total bandwidth), hence 2.5 MHz would be a sensible choice for the pass band frequency **fpass**. (If the resulting attenuation at 2.5 MHz is too high to be accepted, the pass band frequency can be increased slightly).

The maximum input frequency that does not lead to aliasing products is sampling frequency / 2. In our case 3 MHz. This means we need a stop band frequency **fstop** of 3 MHz or lower. (If the achieved attenuation at 3 MHz is not acceptable, the stop band frequency can be decreased).

The two other parameters **wpass** and **wstop** are the weighting factors for the pass band and stop band. The standard values of 1 and 1000 for the pass and the stop band, respectively, will usually be a good choice. Sometimes it might be necessary to increase the stop band weighting factor **wstop** to 10000 for better attenuation results. Usually, this results in higher pass band ripple.

Having selected the 5 parameters, you can press **"Design Filter"** in order to start the filter designer. The other buttons will become active when it has finished.

"View Transfer Function" allows now to check the resulting transfer function. In this plot, only the positive frequencies of the total bandwidth are shown because the filter is symmetric about the zero frequency. The black line in the transfer function plot shows ½ of the sampling frequency, which is the maximum input frequency that does not produce aliasing products. This means that higher frequencies shall be suppressed sufficiently. A value of >60 dB is usually a sensible attenuation.

If the filter does not fulfil the requirements, one can change the input parameters and start a new filter design after pressing **"New Filter"**.

Finally, when the filter fulfills your needs, you can save it with **"Export to .mat File"**, which allows for loading it into the R&S®TSMW IQ Interface Demo Application, afterwards. Alternatively, you can press **"Save & Close"** to transfer it directly to the Main GUI. This however, does not allow you to save the filter specification.

Figure 32 shows the Filter Design Tool with a transfer function plot resulting from the previously discussed parameters. The transfer function shows the average and the point-wise worst case transfer function. The latter shows for each frequency point the worst case attenuation when considering different fractional delays as they appear during resampling. Usually, only the average transfer function will be important.

Generally, the TSMW resampling FIR filter works with real-valued low-pass filters. If special low-pass filter shapes are required by a user application, a user can use their own filter design tool to produce different filter shapes. This is described in detail in Section 7.2.
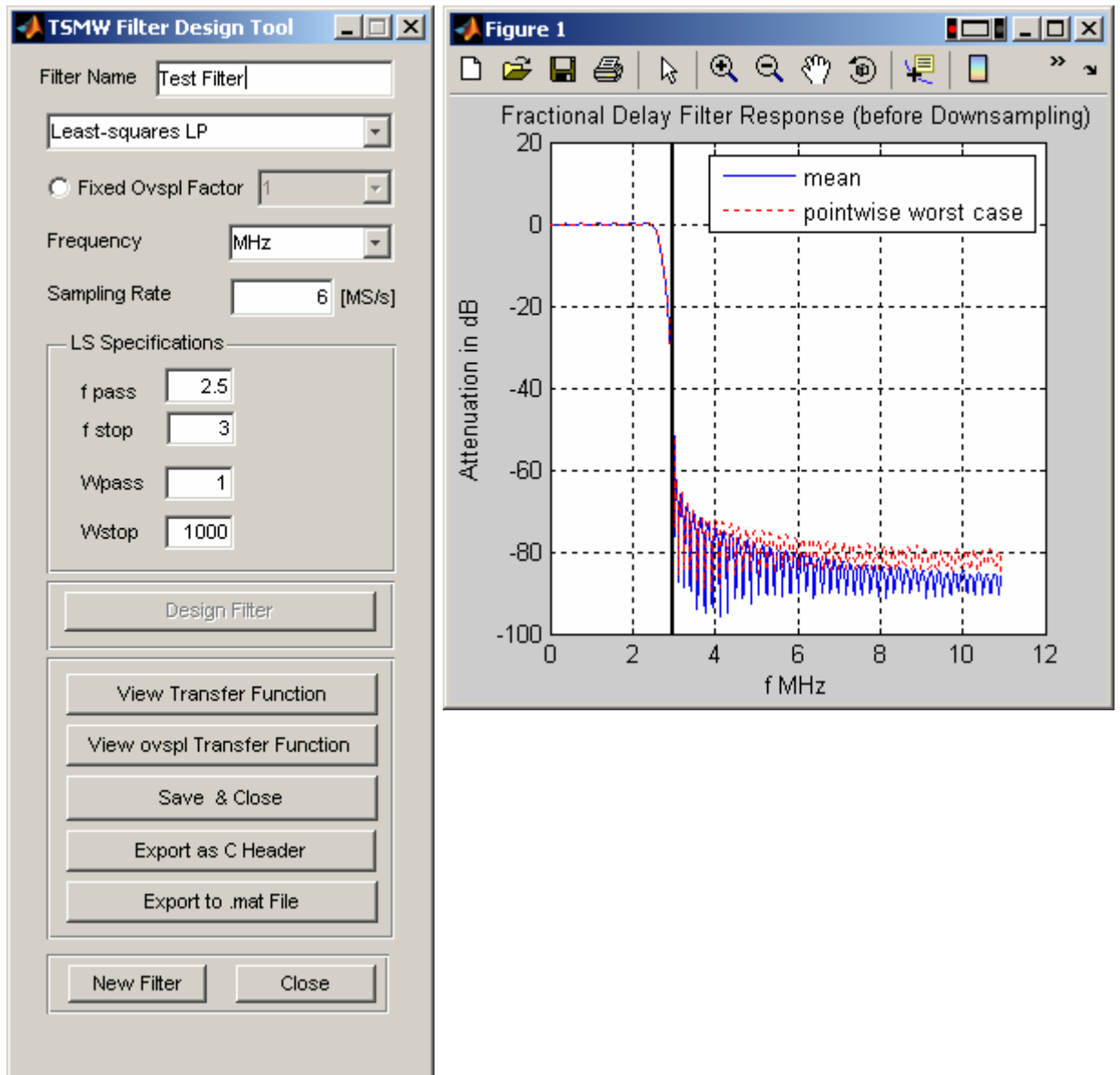
Figure 2: R&S®TSMW Filter Design Tool with example filter transfer function.

6.3 Block Measurements

Block measurements are I/Q measurements with a limited number of samples. The maximum number of samples for block measurements is currently 8 million samples. Block measurements can be performed directly within the R&S®TSMW IQ Interface Demo Application or via the corresponding C++ API functions.

The "**Single Measure**" area shows control buttons for single block measurements. A measurement with the selected measurement parameters is started by pressing the "**Measure**" button (this corresponds to calling the MATLAB™ function TSMWIQMeasure). Pressing "**GetData**" calls the corresponding MATLAB™ (and therefore C++) API function to unpack the measured data to the wanted output format, and transfers it to MATLAB™. "**Plot Channel**" creates one plot window per selected front-end where within each window, the signals of the corresponding sub-channels are shown. For each sub-channel the power spectrum and the I and Q components are plotted in sub-plots.

Continuous measurements can be started using the "**Cont. Measure**" area. This performs all steps of "**Single Measure**", i.e. start a measurement, get the data and plot the result. After the results have been plotted, a new measurement is started. This is done until "**Stop**" is pressed.

The "**Analyze Custom**" area has been provided for user specific enhancements. A MATLAB™ user can easily use the corresponding callbacks to set parameters, perform the specific measurement task and analyze and possibly plot the results.

6.4 Stream measurements

6.4.1 Recording I/Q streams

Stream measurements are performed with the Streaming Dialog. This dialog can be opened using the "**Open Streaming Dialog**" button. This can be done as soon as the R&S®TSMW IQ Interface has been initialized by pressing "**Init. Interface**". This allows you to open an already recorded stream data file without having to connect to a TSMW.

The Streaming Dialog (Figure 3) allows for starting streaming measurements as well as performing basic analysis of selected parts of the recorded I/Q data stream. Furthermore, stream data files can be converted into the R&S signal generator waveform and list format for easy replay on R&S signal generators.

I/Q streaming is generally performed with the parameters that are given in the main dialog. However, these values are only taken when the streaming dialog is opened. This means that for changing the I/Q streaming parameters, one has to close the streaming dialog, change the measurements parameters and reopen the streaming dialog.

I/Q streaming supports all possible measurement modes of the TSMW. That is, it is possible by using a single front-end or both frontends, you can use one or several sub-channels on each front-end etc. The sum of the sampling rates of all activated channels, however, cannot exceed 22 MS/s @ 12Bit resolution. This results in approximately 75 MByte/s transfer rate over GBit-LAN, which is the maximum that can be achieved.

The following I/Q streaming parameters exist:

Stream buffer size	Host PC buffer space in MByte that is reserved for streaming. A minimum of 200MB is recommended. This buffer is the maximum amount of memory used for stream data before stream data blocks are skipped in case that the data could not be written to disc or was not processed already.
Maximum stream size	Only used for streaming to hard disc. This is the maximum amount of data that is streamed to disc before streaming is automatically stopped. Note: Nevertheless, **"Stop streaming"** has to be pressed in order to perform the final steps for stopping a stream.
Stream file name	This is the file name (without counter and extension) which will be used for saving the stream data. Stream data will be split into several files as soon as a file size of 2 GByte is exceeded. The files will get the names <FileName>_XXX.dat, where XXX starts at 000.
Description	Arbitrary textual description of the stream data.

Table 3: General Measurement Settings

Streaming is started by pressing **"Start streaming"** and stopped with **"Stop streaming"**, where stopping the stream may need several seconds in order to write the buffered data to disc.

During streaming, the number of received stream data blocks and the number of lost (skipped) stream data blocks can be observed. In case of sufficient host PC performance, no stream data blocks will be skipped. If however a stream data block is skipped, a corresponding block with zero samples will be inserted in order to avoid unknown time gaps in the I/Q data.
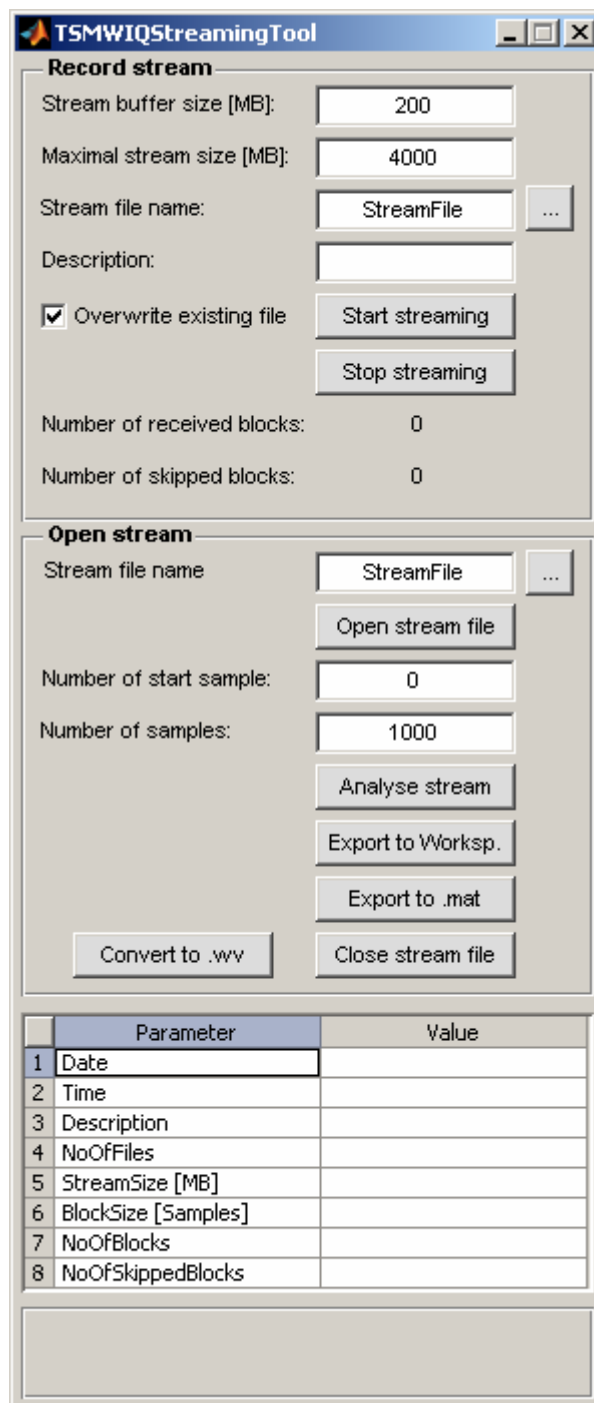
Figure 3: TSMW I/Q Streaming Dialog with default parameters.

6.4.2 Reading / processing recorded I/Q data

A recorded I/Q stream can be read using the second part of the Streaming Dialog. **"Open stream file"** opens a stream data file. Note: You have to select the first stream data file. After having opened the stream data file, the stream data parameters will be shown in the lower panel.

A specific part of the I/Q stream can be extracted by entering the corresponding I/Q start sample and the number of requested samples and pressing **"Analyse stream"**. This loads the data from the stream data file and shows the corresponding spectrum and time functions. **"Export to Worksp."** allows for exporting the I/Q data to the MATLAB™ workspace for further processing. **"Export to .mat"** exports to a MATLAB™ binary file.

The function **"Convert to .wv"** allows converting the selected number of samples to R&S signal generator waveform and list format in order to allow RF-replay on R&S signal generators. For that purpose, the corresponding signal is normalized prior to conversion in order to achieve best replay performance. The necessary signal generator level for regeneration at exact the same signal level is written into the comment section of the resulting .wv file.

Closing the corresponding file can be done using the button **"Close stream file"**.

7 MATLAB™ and C++ Programming Examples

Several MATLAB™ and C++ programming examples are included in the "Examples" subfolder of the R&S®TSMW-K1 installation folder. In "Examples\MATLAB™" a MATLAB™ script file and a filter specification file are included. The MATLAB™ script file performs several measurements with the TSMW and illustrates some of the TSMW measurement capabilities.

In the "Examples\CPP" folder, C++ example applications for I/Q baseband streaming are provided. Under "Examples\CPP\TestStreaming", online-processing of stream data is demonstrated. Given a corresponding input signal at the TSMW (see C++ source code), this example demonstrates that I/Q streaming is performed seamlessly. A similar test application is included in "Examples\CPP\TestStreamingFile", where in a first step, the I/Q data is streamed onto disc and post-processed, later.

7.1 How to perform a simple measurement using the MATLAB™ API

Performing measurements with the R&S®TSMW-K1 API is conceivably simple. The following R&S®TSMW-K1 MATLAB™ commands perform a simple measurement with the TSMW and calculates the average power in dBm:

```
TSMWInitInterface;            % Load Dll and initialize interface

[ec, TSMWID] = TSMWConnect('192.168.0.2');
                             % Connect to TSMW with given IP-
                             % Address

MeasCtrl = MeasCtrlTemplate_RF1;
                             % Get MeasCtrl structure template
                             % for measurement on front-end 1

[ec, MeasRequestID] = TSMWIQMeasure(TSMWID, [], MeasCtrl);
                             % Start measurement without
                             % explicit start time

[ec, IQResultParam, IQData, Ovfl, Cal] = TSMWIQGetData(TSMWID,
MeasRequestID, 1000, MeasCtrl.MeasCtrl.NoOfSamples, 1);
                             % Get measurement result (with
                             % specific measurement request id)

10*log10(mean(abs(IQData).^2))
                             % Calculate average power in dBm
```

For further details on how to perform measurements, use measurement priorities and change measurement parameters, please see the R&S®TSMW Interface & Programming Manual.

7.2 How to Design Low-Pass Filters with a User-specific Filter Shape

The TSMW resampling filter bank uses a polyphase interpolator for performing filtering and down sampling, simultaneously. Such a polyphase interpolator uses N_{ovspl} sets of filter coefficients, where N_{ovspl} is the oversampling factor. The oversampling factor and the total number of filter coefficients that have to be used is given by the TSMW resampling filter structure. In order to get these parameters, the MATLAB™ function TSMWGetFIRParam is supplied. This function needs as an input parameter the down sampling factor, which is the factor by which the native TSMW sampling rate of 21.94444 MS/s shall be reduced. The down sampling factor is therefore 21.94444 MS/s divided by the required output sampling rate.

Consider an output sampling rate of 2 MS/s. The resulting down sampling factor is therefore 21.94444 MS/s / 2 MS/s = 10.9722. Calling the function TSMWGetFIRParam gives then a total number of filter coefficients of N_{coeff} = 2688 with an oversampling factor of 8. This means that 8 polyphase filter sets, each with 336 filter coefficients are needed.

In order to design such a set polyphase filter, one can use every filter design algorithm that provides N_{coeff} filter coefficients using normalized pass and stop band frequency limits f_{pass} / N_{ovspl} and f_{stop} / N_{ovspl}. This means, all polyphase filter coefficients are designed at once.

Consider a filter specification that has a pass band frequency of 0.9 MHz and a stop band frequency of 1 MHz. With a normalized frequency interval of -0.5 to 0.5 (corresponding to -10.9722 MHz .. 10.9722 MHz), the normalized pass and stop band frequencies become 0.0820 and 0.0911. In order to design the polyphase filter, one has now to use the pass and stop band frequencies 0.0820 / 8 = 0.0103 and 0.0911 / 8 = 0.0114 and design a filter with N_{coeff} = 2688 coefficients (taps). The resulting filter coefficients together with the given down sampling and oversampling factor can be used directly for the TSMW.

To summarize, one can use any filter design algorithm that provides the given total number of filter coefficients when scaling every frequency limit by 1 / N_{ovspl}.

Note: TSMW resampling filters have to be real-valued low-pass filters, hence they have a symmetric transfer function. Furthermore, one has to keep in mind that a TSMW resampling filter is always connected to a specific down sampling factor.

8 Additional Information

This Application Note and the associated software are updated from time to time. Please visit the TSMW web page **www.drivetest.rohde-schwarz.com**

9 Ordering Information

R&S®TSMW	Scanner Hardware Platform	1503.3001.02
R&S®TSMW-K1	IQ Streaming Option	1503.3960.02
R&S®TSMW-Z1	Power Supply 110/230 VAC	1503.4608.02

About Rohde & Schwarz
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