Arbitrary Waveform Sequencing with Rohde & Schwarz Vector Signal Generators
Application Note

Products:

- R&S®SMBV100A
- R&S®SMW200A
- R&S®SMU200A
- R&S®SMJ200A
- R&S®AMU200A
- R&S®SMATE200A

Sequencing of waveforms is a technique used to play back multiple test signals fast and flexibly using an arbitrary waveform generator (ARB). Multiple ARB waveforms can be combined to generate all kinds of test signals sequences. Switching from one waveform to the subsequent waveform in the sequence is instantaneous, which enables high-speed operation for production testing.
This application note explains how to generate such signal sequences using vector signal generators from Rohde & Schwarz. The examples provided show the required instrument settings and possible fields of application for waveform sequencing.

Application Note

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ROHDE&SCHWARZ

Table of Contents

1 Introductory Note

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

- The R&S®SMW200A vector signal generator is referred to as SMW.
- The R&S®SMU200A vector signal generator is referred to as SMU.
- The R&S®SMBV100A vector signal generator is referred to as SMBV.
- The R&S®WinIQSIM2™ simulation software is referred to as WinIQSIM2.

2 Overview

Often, multiple test signals are required for measurements on devices under test (DUT), for example when measuring the distortion of amplifiers or when verifying different digital standards implemented in a mobile radio chip. Also, multiple test pulses or pulse scenarios are required for testing radar systems.
The ARB sequencer mode[1] is a feature of the SMW, the SMBV and the signal generators of the SMU family (i.e. SMU, R&S®SMJ100A, R&S®SMATE200A, R&S®AMU200A) that provides highly flexible playback of multiple test signals, without signal gaps between the different ARB waveforms. This enables high-speed operation, which is especially important for production testing. In general, the ARB sequencer is particularly useful whenever multiple waveforms and optimized testing times are required for device testing.

The ARB sequencer is based on the multisegment waveform feature of the signal generators. The sequencer can be used to create complex test sequences flexibly and easily from simple test signals that are contained in the multisegment waveform. For this reason, this application note starts by explaining what a multisegment waveform is, and how to create and play back such a multisegment waveform (section 3). The ARB sequencer mode is then described in detail in section 4 together with various examples. Besides the enhanced flexibility, further advantages of the ARB sequencer mode are that it saves calculating time and reduces the allocated memory on the instrument hard disk.

[1] The sequencer mode is available for the SMU family from firmware version 2.10.111.116 on. For the SMBV this feature is available from firmware version 2.15.085.47 on.

3 Multisegment Waveform

3.1 What is a Multisegment Waveform?

A multisegment waveform consists of multiple independent waveforms. Each of the individual waveforms represents one segment of the multisegment waveform (Fig. 1). The multisegment waveform can be loaded into the memory of an arbitrary waveform generator (ARB). The individual segments can then be played back in any order. One advantage of a multisegment waveform is rapid switching between individual waveforms. Changing from one waveform to another does not require a loading operation. Thus, delays due to loading operations are omitted, which makes high-speed operation possible. Another benefit is that multisegment waveforms can be used to create complex waveforms from small segments.
With the current implementation of the multisegment waveform feature (including the sequencer mode) in our vector signal generators, the different segments can be output in various modes. For example, switching can be automatic or triggered; the transition between signals can be abrupt or seamless; the signals can be output once, a specified number of times or continuously. The many different output modes provide high flexibility and ensure that the signal generation can be ideally adapted to the requirements of individual applications.

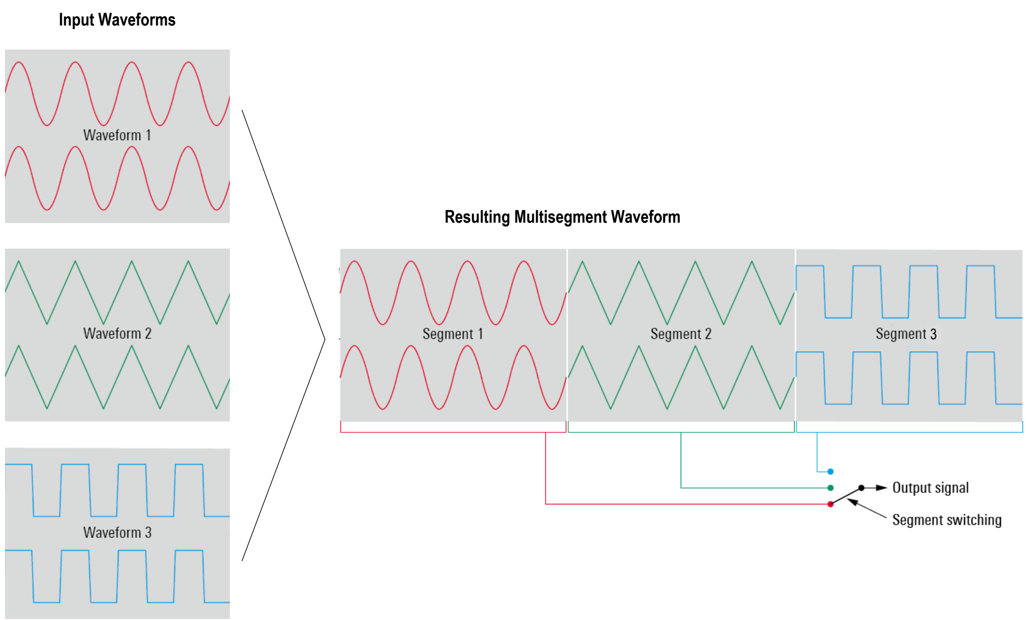


Fig. 1: Multisegment waveform concept.

3.2 Generation of a Multisegment Waveform

The individual waveforms can be combined to form a single waveform – the multisegment waveform – using either a signal generator (e.g. SMBV or SMW) or the WinIQSIM2 simulation software (installed on a Windows® computer).

3.2.1 Signal Generator

In the ARB main menu, clicking the “Multi Segment” button opens the ARB Multi Segment menu (Fig. 2).

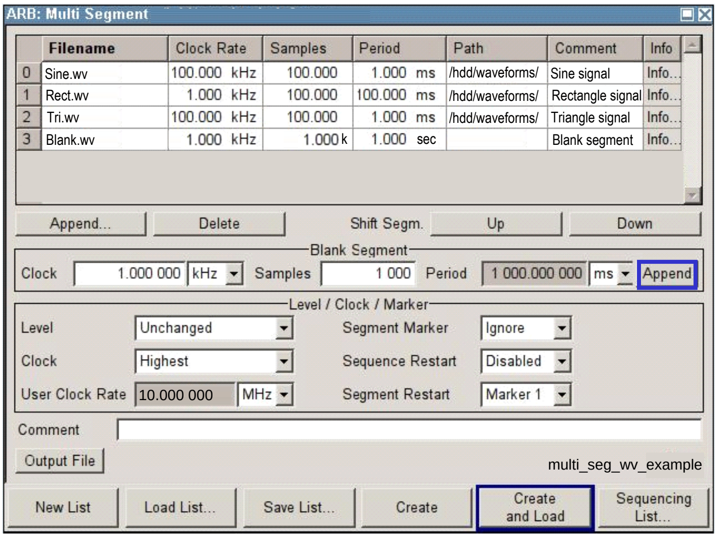


Fig. 2: ARB Multi Segment menu.

This menu is used to create the multisegment waveform. Click the “New List” button and enter a file name. All settings made in the ARB Multi Segment menu are saved under this file name by clicking the “Save List” button. Use the “Append…” button to load two or more existing waveforms (1024 waveforms at maximum). Note that only normal, i.e. non-multisegment waveforms can be loaded. The set of selected waveforms is displayed in a list. The order of these waveforms can be changed using the “Up” and “Down” buttons. The levels of the individual waveforms can be either left unchanged or scaled to a common RMS level. Likewise, the clock rates of the individual waveforms can be either left unchanged or resampled to a common clock rate. For example, a common clock rate is necessary for achieving fast switching times and seamless transitions between the waveforms (described in section 3.3).

If the waveforms contain marker signals, these markers can either be taken over into the multisegment waveform or be ignored. Additionally, it is possible to set a restart marker that marks the beginning of the first waveform in the table (i.e. segment #0) and/or the beginning of each waveform/segment. The SMU has four marker outputs that can be selected (marker 1 to 4); the SMW has three marker outputs (marker 1 to 3); the SMBV has two marker outputs (marker 1 and 2). Note that if a restart marker is set on one of the available outputs, e.g. on marker 2, it will completely overwrite any existing marker 2 that may have been defined in the individual waveforms.
It is also possible to include different blank segments in the multisegment waveform. A blank segment is a zero signal without any I/Q data content except zeros. Such a blank segment is useful for generating zero-signal phases with the multisegment sequencer mode (see section 4). Different blank segments can easily be generated directly via the ARB Multi Segment menu by just setting the clock rate and the number of samples. Clicking the “Append” button (blue in Fig. 2) will append the blank segments to the list.
Finally, enter an output file name and click the “Create & Load” button. The multisegment waveform will now be created in accordance with the specified settings and loaded into the ARB memory.

Note that the minimum length of a segment waveform is 512 samples. Waveforms that are shorter than this will be automatically extended during creation of the multisegment waveform by cyclically repeating the waveform until it exceeds the minimum length.

3.2.2 WinIQSIM2

The ARB Multi Segment menu of WinIQSIM2 is almost identical to the menu described in section 3.2.1.
Once created, the multisegment waveform must be transferred to the instrument, for example by a LAN connection or a USB stick, and loaded into the ARB memory.

3.3 Playback of a Multisegment Waveform

The segments of the multisegment waveform can be played back in many different ways. To explain the vast variety of possibilities, we can take a look at the Trigger menu (Fig. 3). There are two separate trigger sections: “Trigger In” and “Next Segment Trigger In”. The “Trigger In” settings (marked in red) apply to the waveform playback in general. As usual, this trigger starts or restarts the waveform playback. Basically, these trigger settings apply to the multisegment waveform as a unit, i.e. this trigger starts or restarts the multisegment waveform. In contrast, the “Next Segment Trigger In” settings (marked in green) apply to the segments. This trigger initiates the switching between the segments.

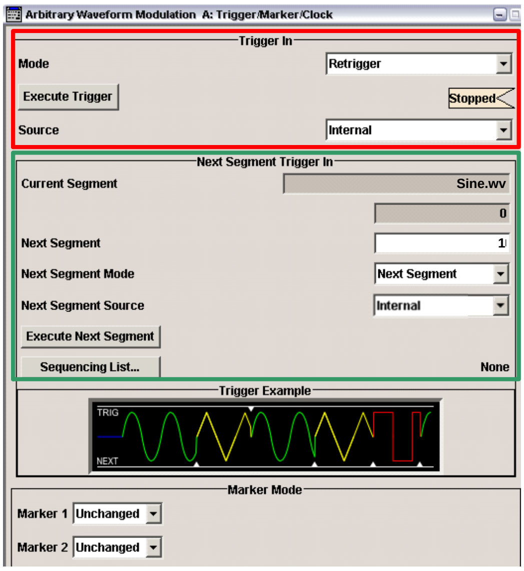


Fig. 3: Trigger/Marker/Clock menu of the arbitrary waveform generator.

- **Trigger settings:**
Either an internal or an external trigger signal can be used to (re)start the waveform. An external trigger signal can be fed in via the TRIG connector (SMBV), TRIGGER connector (SMU) or USER 3 connector (SMW). See section 3.3.1 for details.

- **Next Segment Trigger settings:**
The menu shows the file name and the index of the segment that is currently output.
Either an internal or an external trigger signal can be used to switch between the segments. Note that an external trigger can only be used if the segments have the same clock rate[2]. An external trigger signal can be fed in via the NEXT connector (SMBV), TRIGGER connector (SMU) or USER 4 connector (SMW). See section 3.3.1 for details.
The “Next Segment” parameter is important for manual operation. It determines the segment that will be played next. Changing the entry in the “Next Segment” field initiates a switchover to this particular segment.
The “Next Segment Mode” defines the way the switching between the segments takes place: If “Next Segment” is selected, switching to the next segment occurs abruptly, i.e. the output of the current segment stops promptly and the output of new segment starts (after a system-imposed signal gap). Fig. 4A shows this transition (upper trace) triggered by an external trigger signal (lower trace). If “Next Segment Seamless” is selected, transition between the segments is seamless, i.e. the current segment is completely output before the next segment starts. This avoids signal gaps and wrap-around problems. Fig. 4B shows this seamless transition. Note that seamless switching is possible only if the segments have the same clock rate[2].

[2] To achieve a common clock rate for all segments, simply set the “Clock” parameter to “Highest” or “User” (see Fig. 2) for automatic resampling when generating the multisegment waveform.

If “Sequencer” is selected, the segments are played back as defined in a separate sequencing list (see section 4 for details). The transition between segments is always seamless, i.e. signal gaps do not occur.

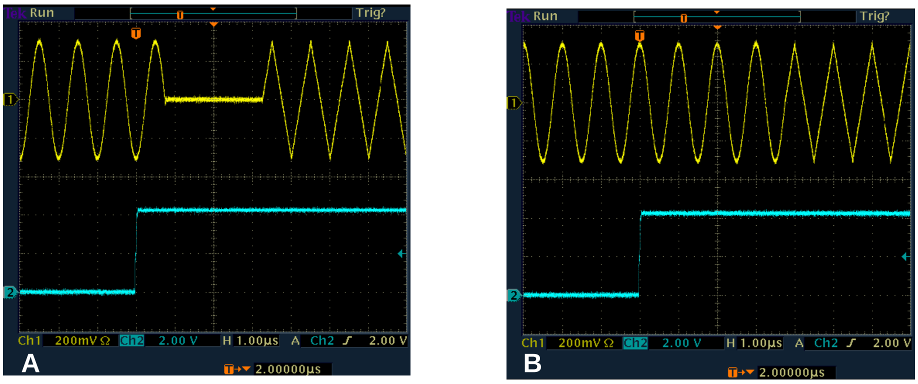


Fig. 4: Transition from one segment (sine signal) to another segment (triangle) triggered by an external trigger signal (shown on channel 2). A: Normal transition. B: Seamless transition.

For a complete description of the multisegment waveform functionality, please refer to reference [1]. Further details on multisegment waveforms and examples focusing on the R&S®SMATE200A and R&S®AFQ100A signal generators can be found in the application note “Speeding up production test with the R&S®SMATE200A” (1GP63).

3.3.1 Connectors

⚠ The SMBV, the SMU, and the SMW differ with respect to their trigger input connectors.

SMBV:
The SMBV has two separate trigger input connectors:

- TRIG for (re)starting the multisegment waveform.
- NEXT for switching between segments.

SMU:
In contrast, the SMU has no separate trigger input connector for switching between segments:

- TRIGGER for starting the multisegment waveform *and* for switching between segments.

As a consequence, some “Trigger In Mode” settings are not available for certain “Next Segment In Mode” settings, e.g. “Retrigger” is not available, if “Next Segment” is selected (see [1] for further details).

SMW:
The SMW has several configurable input connectors. See [1] for details. There are thus two separate trigger input connectors available:

- USER 3 is configured per default as “Global Trigger 1” for (re)starting the multisegment waveform.

- USER 4 must be configured as “Global Next Segment 1” trigger for switching between segments.

3.3.2 Switching Times

Multisegment waveforms permit fast switching between individual waveforms. The switching time depends on the trigger settings used. If an external trigger signal is used to output the segments consecutively, high-speed operation with switching times around 5 µs is possible, provided the segments have a high common clock rate (e.g. 50 MHz). The reason is that the switching time depends inversely on the clock rate used. If an external computer is used to control the instruments remotely (see section 3.3.4), switching times of approximately 20 ms can be achieved for segments with a common clock rate and approximately 500 ms for segments with different clock rates. If the transition mode is seamless, the switching time (i.e. the time between the trigger slope and the actual start of the next segment) depends on the length of the current segment, since switchover to the next segment does not take place until the current segment is completely output.

3.3.3 Marker Signals

Marker signals are very useful. For example, they can be used to trigger a device under test (DUT) or to synchronize with other measurement instruments.

The individual segments may contain one or more marker traces. These marker traces are inserted into the waveform during waveform generation. When building a multisegment waveform out of these individual segments, these marker signals can either be taken over, i.e. the individual waveforms keep their original marker traces, or they can be ignored, meaning that all marker signals are deleted. If the marker traces are taken over, the marker signals of each segment are output during the playback as usual.
In addition, during multisegment waveform generation special multisegment markers – a sequence restart and a segment restart marker – can be set. Note that these restart markers will overwrite any existing markers. For example, if a segment already contains a marker trace on marker 2, and a restart marker is then also set on marker 2, the MARKER 2 connector will output only the restart marker.
Finally, there is also the option of setting markers via the ARB Trigger/Marker/Clock menu (Fig. 3). Again, these markers will overwrite any existing marker signals, e.g. sequence and segment restart markers. For this reason, the marker mode is set to “Unchanged” by default. In this case, the marker traces are not overwritten.

Note that it is possible to delay the marker outputs. In a certain range, the delay can be set even during I/Q signal output without interrupting the signal output. A marker delay can be set for every marker signal, regardless of whether the marker originates from a waveform file, from the multisegment waveform or directly from the ARB.

3.3.4 Example 1 – Manual Operation

Desired playback:

- Manual (re)start of signal output
- Manual switching between the segments
- Playback order: Seg.#0, Seg.#3, Seg.#1

Required settings:

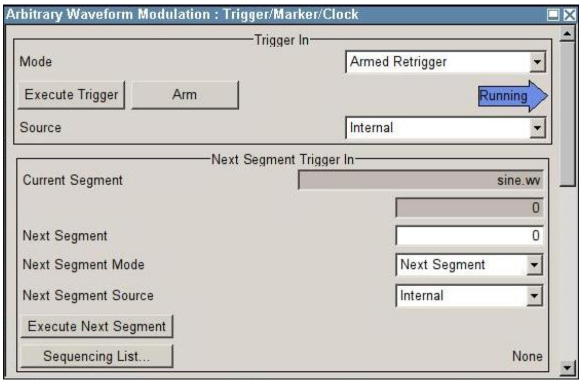


Fig. 5: Required trigger settings for Example 1.

- Mode: Armed Retrigger

The multisegment waveform is started by clicking the “Execute Trigger” button.
- Source: Internal

- Current Segment: Index 0 is displayed.

The first segment of the multisegment waveform (Seg.#0) is output *continuously*.
- Next Segment Mode: Next Segment

The transition between the segments will be abrupt.
- Next Segment Source: Internal
- Next Segment: Change the index from 0 to 3.

This stops output of the current segment Seg.#0 and starts output of the new segment Seg.#3. The index displayed in “Current Segment” changes from 0 to 3. The new segment Seg.#3 is now output *continuously*.
- Next Segment: Change the index from 3 to 1.

This stops output of Seg.#3 and starts output of Seg.#1. The index displayed in “Current Segment” changes from 3 to 1. The new segment Seg.#1 is now output *continuously*.
- Arm: Click this button.

This stops signal generation, i.e. output of Seg.#1 is stopped. No ARB signal is output.
- Execute Trigger: Click this button.

This restarts signal generation, i.e. Seg.#1 is output *continuously*.
- Execute Trigger: Click this button again.

This causes a restart of the current segment, i.e. the instantaneous output of Seg.#1 is stopped and Seg.#1 starts from the beginning.

If the desired playback order is incremental, i.e. Seg.#0, Seg.#1, Seg.#2, Seg.#3,… the “Execute Next Segment” button can also be used to manually switch to the following segment. In this case, the index in the “Next Segment” field does not have to be changed.

3.3.5 Example 2 – External Triggering

Desired playback:

- External trigger for start of the multisegment waveform, no retriggering
- External trigger for switching between segments
- Continuous output of a single segment until a trigger event occurs
- Seamless transition between segments
- Incremental playback order: Seg.#0, Seg.#1, Seg.#2, Seg.#3

Required settings:

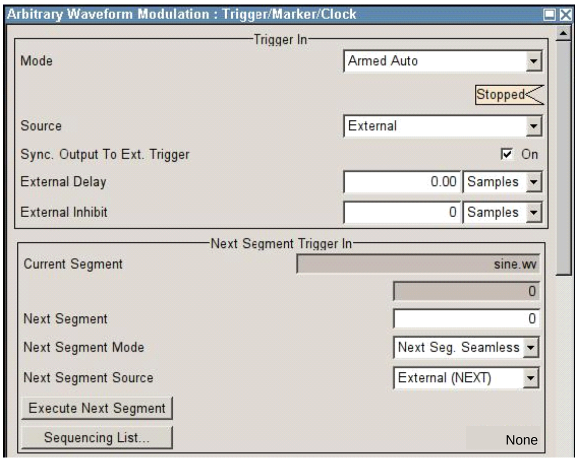


Fig. 6: Required trigger settings for Example 2.

- Mode: Armed Auto

The multisegment waveform is started by the first trigger event.

- Source: External

The multisegment waveform is started by an external trigger signal (TRIG connector at SMBV, TRIGGER connector at SMU, USER 3 connector at SMW).

- Current Segment: Index 0 is displayed.

The first segment of the multisegment waveform (Seg.#0) is output *continuously*.

- Next Segment: Leave unchanged.
- Next Segment Mode: Next Seg. Seamless

The transition between the segments is seamless to avoid wrap-around problems.

- Next Segment Source: External

Switching from one segment to another is triggered by an external trigger signal (NEXT connector at SMBV, TRIGGER connector at SMU, USER 4 connector at SMW). A trigger event stops output of the current segment Seg.#0 (after completion of this segment) and starts output of the following segment Seg.#1. The index displayed in “Current Segment” changes from 0 to 1. The new segment Seg.#1 is now output *continuously* until a further trigger event starts the output of the next segment Seg.#2, and so on.

If the desired playback order is not incremental, but for example Seg.#0, Seg.#3, Seg.#4, Seg.#1, the sequencer mode must be used (see section 4).

Additional playback mode for SMBV and SMW only

- External trigger for *(re)start* of the multisegment waveform, *retriggering*

This requires the same settings as above, except:

- Mode: Armed Retrigger

The multisegment waveform is (re)started by trigger events at the TRIG (SMBV) or USER 3 (SMW) connector. Regardless of which segment is currently output, if a trigger event at the TRIG (SMBV) or USER 3 (SMW) connector occurs, the output of the current segment stops *immediately* and the multisegment waveform starts from the beginning (after a system-imposed signal gap of about 5 μs). This means the first segment of the multisegment waveform (Seg.#0) is now output *continuously*.

Note that this playback mode is only available for the SMBV and SMW, since these signal generators have two separate trigger inputs: TRIG and NEXT (SMBV) or USER 3 and USER 4 (SMW).

3.3.6 Example 3 – Remote Operation

Desired playback:

- Remote start of the multisegment waveform, no retriggering
- Remote switching between the segments
- Playback order: Seg.#0, Seg.#3, Seg.#5

Required settings:

- Mode: Auto
  SCPI command: `SOUR:BB:ARB:SEQ AUTO`

The multisegment waveform starts as soon as the ARB generator is activated with the SCPI command “`SOUR:BB:ARB:STAT ON`”. The segment Seg.#0 is then output *continuously*.

- Source: Internal
  SCPI command: `SOUR:BB:ARB:TRIG:SOUR INT`

- Next Segment Mode: Next Segment
  SCPI command: `SOUR:BB:ARB:TRIG:SMOD NEXT`
- Next Segment Source: Internal
  SCPI command: `SOUR:BB:ARB:WSEG:NEXT:SOUR INT`
- Next Segment: Change the index from 0 to 3.
  SCPI command: `SOUR:BB:ARB:WSEG:NEXT 3`

This stops output of the current segment Seg.#0 and starts output of the new segment Seg.#3. Seg.#3 is now output *continuously*.

- Next Segment: Change the index from 3 to 5.
  SCPI command: `SOUR:BB:ARB:WSEG:NEXT 5`

This stops output of the current segment Seg.#3 and starts output of the new segment Seg.#5. Seg.#5 is now output *continuously*.

4 Sequencer Mode

This feature makes it possible to play back the individual segments of a multisegment waveform *in virtually any order*. This is achieved by defining a sequencing list. This sequencing list is a kind of playlist similar to a playlist on an MP3 player. Segments are played back according to this playlist with *seamless transitions* between the individual segments.
The multisegment waveform contains the different I/Q signals in the form of individual segments. The separate sequencing list defines the play order and number of repetitions of these segments (Fig. 7). Changing the play order requires changing only the sequencing list – the multisegment waveform does not have to be recalculated. In this way, a complex sequence can be easily built up without entailing long calculation times.

For the sequencer mode it is mandatory that all segments of the multisegment waveform have the same clock rate.

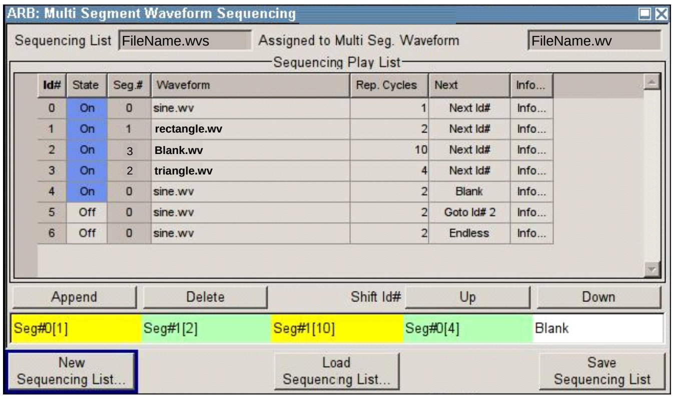


Fig. 7: Menu for configuring the sequencing list.

In sequencer mode, the segments are automatically played back according to the predefined play order and number of repetitions. The sequencer mode can be set either directly via the ARB main menu or via the Trigger/Marker/Clock menu (Fig 3). Set the “Next Segment Mode” to “Sequencer”. The sequencing list (Fig. 7) can be opened by clicking the “Sequencing List” button.

- The first column of the sequencing list shows the incrementing number of the playlist.
- The second column allows the user to activate or deactivate a row of the sequencing list. Rows that are set to “Off” are not played back.
- The third column shows the segment index. This is the index of the selected segment within the multisegment waveform.

- The fourth column allows the user to select a segment from the multisegment waveform. The file name of the selected segment is displayed. (The file name and the segment index displayed in the third column are equivalent.)
- The fifth column is used to set the number of repetitions. This number defines how often a segment is repeated cyclically before the next segment of the playlist is output. In this way, the segment can be repeated up to 65535 times (SMBV/SMU) using only one sequencing list entry. The SMW supports even up to 8388607 repetitions.
- By means of the sixth column, the user can define a row of the sequencing list that will be executed next. The following options are available:
  – Next Id#:
  After the output of the current segment is completed (including repetitions), the subsequent segment in the playlist will be output. For example, Id# 0 → Id# 1.
  – Goto Id# x:
  After the output of the current segment is completed (including repetitions), the segment defined in row x of the sequencing list will be output (with x = 0 to 95 for SMU and 0 to 1023 for SMBV/SMW).This option can be used to program loops within the playlist.
  – Blank:
  After the output of the current segment is completed (including repetitions), the I/Q signal is blanked until a signal restart event (e.g. retrigger) triggers a restart of the sequencing list. For example, Id# 0 → no output.
  – Endless:
  The current segment will be output continuously until a signal restart event (e.g. retrigger) triggers a restart of the sequencing list. For example, Id# 0 → continuous output Id# 0.

Rows can be added to or deleted from the sequencing list by clicking the “Append” or “Delete” buttons. The “Up” and “Down” buttons can be used to shift a row within the sequencing list. The sequencing list is also illustrated graphically, showing the resulting sequence of segments and the number of repetitions (in square brackets).

The last row in the sequencing list defines how to continue signal generation after the sequencing list reaches its end. If “Next Id#” is selected, the sequencing list will start from its beginning at Id# 0. If “Goto Id# x” is selected, the sequencing list will start at Id# x (with x = 0 to 95 for SMU and 0 to 1023 for SMBV/SMW). Both settings, “Next Id#” and “Goto Id# x”, result in a loop. Besides looping, it is also possible to run through the sequencing list just once. If “Blank” is selected, signal generation is stopped after completing the list. If “Endless” is selected, signal generation is continued after completing the list by outputting the last segment continuously.

In principle, the sequencing list is independent of the multisegment waveform. However, generally the sequencing list is assigned to a particular multisegment waveform and can be saved under the same file name as this multisegment waveform, except that the file extension is “.wvs”. Note that the sequencing list saves only the segment indices, not the file names of the segments. Thus, the sequencing list can be applied to different multisegment waveforms. Of course, it is also possible to define more than one sequencing list for a single multisegment waveform.

4.1 Sequencer Example 1 – Simple Sequence

Desired signal:

- Manual trigger for starting the sequence
- Continuous playback of the following simple waveform sequence

Required settings:

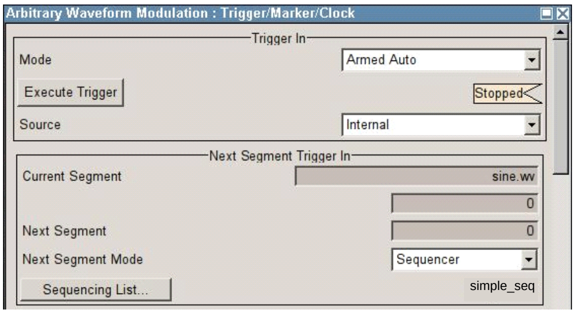


Fig. 8: Required trigger settings for Sequencer Example 1.

- Mode: Armed Auto
- Source: Internal
- Next Segment Mode: Sequencer

The segments are played back automatically as defined in the sequencing list.

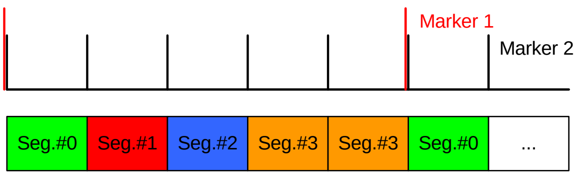
Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	waveform_0.wv	2	Next Id#	Info...
1	On	2	waveform_2.wv	1	Next Id#	Info...
2	On	3	waveform_3.wv	3	Next Id#	Info...
3	On	1	waveform_1.wv	1	Next Id#	Info...

Fig. 9: Required sequencing list for Sequencer Example 1.

4.2 Sequencer Example 2 – Sequence with Markers

Desired signal:

- External trigger for starting the sequence
- Marker traces indicating the start of the sequence (on marker 1) and the start of the segments (on marker 2)
- Continuous playback of the following waveform sequence



The marker traces must be inserted into the multisegment waveform. This can be easily done during generation of the multisegment waveform (see settings below). Marker signals can be used to trigger a DUT or to synchronize with other measurement instruments, for example. For precise adjustment, it is possible to delay the marker outputs during I/Q signal output without interrupting the signal output.

Required settings:

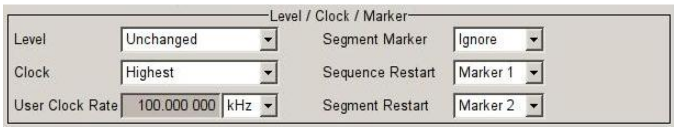


Fig. 10: Required settings for multisegment waveform generation.

- Segment Restart: Marker 2
A restart marker is generated at marker output 2 (MARKER 2 connector) that indicates the beginning of a segment. An already existing marker 2 trace that may be defined in a segment file will be completely overwritten.
- Sequence Restart: Marker 1
A restart marker is generated at marker output 1 (MARKER 1 connector) that indicates the beginning of the first segment of the multisegment waveform (i.e. Seg.#0). Any already existing marker 1 trace possibly defined in a segment file will be completely overwritten. This marker can be used to indicate the beginning of the whole sequence, i.e. it can be used as a sequence restart marker. For this purpose, the playlist must start with Seg.#0 as shown in Fig. 12 and Seg.#0 can have only one repetition cycle (as the marker corresponds to the start of Seg.#0).

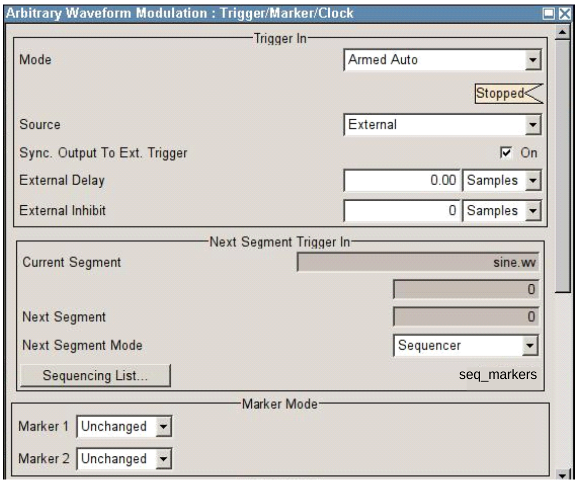


Fig. 11: Required trigger and marker settings for Sequencer Example 2.

- Mode: Armed Auto
- Source: External
- Next Segment Mode: Sequencer
The segments are played back automatically as defined in the sequencing list.

- Marker Mode 1/2: Unchanged

Note that if a setting other than “Unchanged” is selected, the markers in the multisegment waveform will be completely overwritten.

- Marker Delay 1/2: as required, default is 0 Samples.

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	waveform_0.wv	1	Next Id#	Info...
1	On	1	waveform_1.wv	1	Next Id#	Info...
2	On	2	waveform_2.wv	1	Next Id#	Info...
3	On	3	waveform_3.wv	2	Next Id#	Info...

Fig. 12: Required sequencing list for Sequencer Example 2.

4.3 Sequencer Example 3 – Sequence with Loop

Desired signal:

- External trigger for (re)starting the sequence
- Continuous playback of the following waveform sequence until a trigger event restarts the sequence

Seg.#0	Seg.#1	Seg.#1	Seg.#2	Seg.#3	Seg.#3	Seg.#2	Seg.#3	Seg.#3	Seg.#2	Seg.#3	Seg.#3	Seg.#2	...

Required settings:

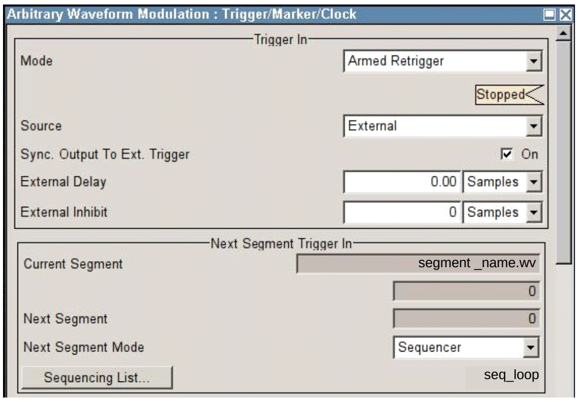


Fig. 13: Required trigger settings for Sequencer Example 3.

- Mode: Armed Retrigger
- Source: External
- Next Segment Mode: Sequencer

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	waveform_0.wv	1	Next Id#	Info...
1	On	1	waveform_1.wv	2	Next Id#	Info...
2	On	2	waveform_2.wv	1	Next Id#	Info...
3	On	3	waveform_3.wv	2	Goto Id# 2	Info...

Fig. 14: Required sequencing list for Sequencer Example 3.

In this example, the subsequence Seg.#0, Seg.#1, Seg.#1 forms a preamble. The “Goto Id# x“ option is used to cyclically repeat the subsequence Seg.#2, Seg.#3, Seg.#3. This loop continues until a trigger event occurs (at TRIGGER for SMU, TRIG for SMBV, USER 3 for SMW) that leads to a restart of the whole sequence (starting with the preamble).

4.4 Application Example 1 – Pulsed Signal

Desired signal:

- Short pulses with steep edges for radar applications
- Very long off-time between pulses

In principle, this signal can also be generated via a single waveform that includes the complete pulse shape with on- and off-times. However, it is beneficial to generate this signal via a multisegment waveform using the sequencer mode, for the following reason. To achieve steep pulse edges, a high clock rate is necessary for waveform calculation to get a high time resolution. The signal pauses between the pulses contain only zeros in terms of I/Q data. However, the high clock rate must also be used for these pauses. As a result, the size of the resulting waveform file becomes very large – especially when long signal pauses are required, for example in some radar applications. Now, with a multisegment waveform in sequencer mode, it is possible to create such pulsed signals very easily from small waveform files. Basically, only two waveforms are needed: one waveform containing the pulse I/Q data and one small waveform containing only zeros. This blank signal can be generated directly via the multisegment waveform menu, and the resulting blank segment can be appended to the multisegment waveform (Fig. 16). The waveform containing the pulse I/Q data can be generated by using the R&S®Pulse Sequencer Software (for SMU and SMBV), for example. The sequencing list is configured as shown schematically in Fig. 15. A long pulse off-time is achieved by cyclically repeating the short blank segment. In this way, the desired pulsed signal is generated from only two small waveforms (segments). In addition, it is possible to vary the pulse off-time easily without any recalculation, by increasing or decreasing the number of repetitions of the blank segment.

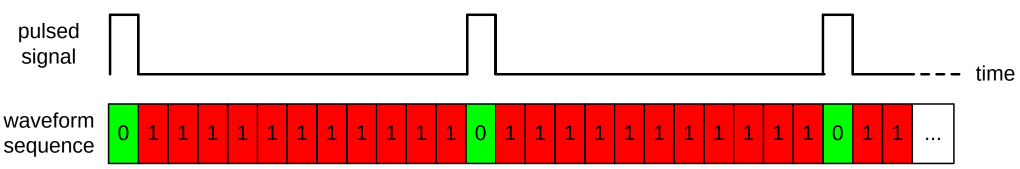


Fig. 15: Generation of a pulsed signal via a multisegment waveform.

Required settings:

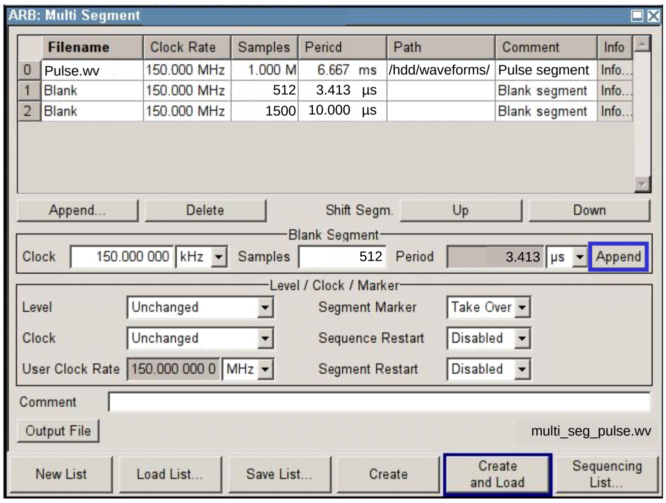


Fig. 16: Required settings for multisegment waveform generation.

In this example, the waveform containing the pulse is added to the multisegment waveform as Seg.#0 by clicking the “Append…” button. The blank segment is added as Seg.#1 by clicking the “Append” button (blue in Fig. 16). The blank segment must have the same clock rate as the waveform containing the pulse. A small number of samples is sufficient. (The minimum length is 512 samples – even for blank signals.) The resulting signal period of the blank segment is displayed.
Note that it is possible to define more than one blank segment, e.g. a second blank segment (as Seg.#2) with a different number of samples. Since the number of cyclic repetitions is limited to 65535 in the SMBV and SMU, a longer blank segment permits a longer pulse off-time. The SMW permits up to 8388607 cyclic repetitions.

If the waveform containing the pulse also includes a marker trace, for example indicating the start of the pulse or the pulse on-time, then this marker can be taken over into the multisegment waveform by setting the “Segment Marker” to “Take Over”. For instance, this marker can then be used to control the optional pulse modulator of the SMW, SMU or SMBV [1] in order to increase the signal on/off ratio up to 90 dB.

For example, to generate a continuous pulsed signal, the sequencing list must contain at least two rows (Fig. 17). One row is assigned to the pulse waveform with only one repetition and the other row is assigned to the blank waveform with several repetitions. The number of repetitions multiplied by the signal period of the blank waveform gives the pulse off-time, which can be arbitrarily long. For example, if the trigger mode is “Auto” or “Armed Auto” with trigger source “Internal”, then the playlist will be repeated continuously. This will generate a continuous pulsed signal.

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	Pulse.wv	1	Next Id#	Info...
1	On	1	Blank.wv	100	Next Id#	Info...

Fig. 17: Required sequencing list for generating a continuous pulsed signal.

For example, to generate a defined number of pulses, the sequencing list can be configured as shown in Fig. 18. The first pulse is followed by a blank period, followed by a second pulse and so on. The fourth pulse is followed by a continuous blank period. This is achieved by setting the “Next” parameter to “Blank”. This blank period continues until a restart event occurs that causes a restart of the playlist. The trigger mode must be set, for example to “Retrigger” or “Armed Retrigger” with trigger source “Internal” or “External” (connector: TRIGGER for SMU, TRIG for SMBV, USER 3 for SMW). This configuration will generate exactly four pulses after each trigger event.

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	Pulse.wv	1	Next Id#	Info...
1	On	1	Blank.wv	100	Next Id#	Info...
2	On	0	Pulse.wv	1	Next Id#	Info...
3	On	1	Blank.wv	100	Next Id#	Info...
4	On	0	Pulse.wv	1	Next Id#	Info...
5	On	1	Blank.wv	100	Next Id#	Info...
6	On	0	Pulse.wv	1	Blank	Info...

Fig. 18: Required sequencing list for generating a defined number of pulses.

4.5 Application Example 2 – Burst Signal

Desired signal:

- Signal bursts with different data content
- Sequence restart marker

Again, this signal can principally be generated via a single waveform that includes the complete burst sequence. The benefit of generating this burst signal via a multisegment waveform is flexibility. For example, testing may require changing the number of individual bursts, their order or the duration of the blank periods. Also, it may be necessary to exchange one burst for another burst while keeping the remaining bursts constant. Normally, all these changes would require a recalculation of the complete waveform. This recalculation can be avoided by using a multisegment waveform together with the sequencer mode. This provides a great degree of flexibility. Each individual burst is stored as a single, independent waveform. In our example, these bursts are named A to G. The single bursts are then combined into a multisegment waveform together with one or more blank segments. Now, a burst signal can be generated by configuring the sequencing list as needed, for example as shown schematically in Fig. 19. The individual bursts are separated by a blank segment that can be easily exchanged for another blank segment having a different signal period. Bursts can easily be added or removed from the sequencing list, simply by changing the “State” parameter from “Off” to “On” or vice-versa. Also, exchanging one burst (e.g. D) for another burst (e.g. G) is simple. Any changes to the signal can be made fast and very flexibly.

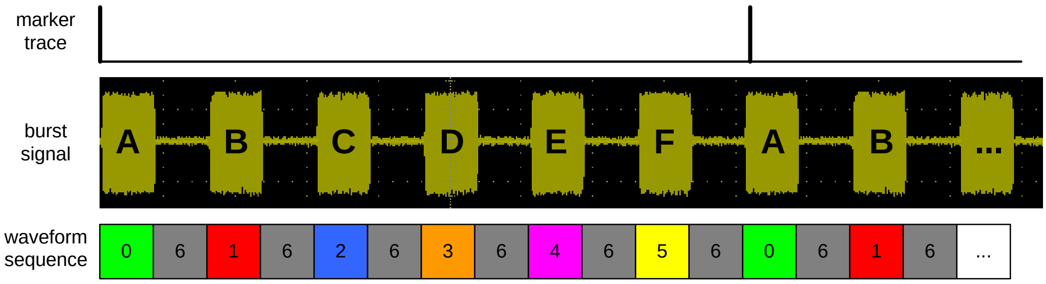


Fig. 19: Generation of a burst signal via a multisegment waveform.

Required settings:

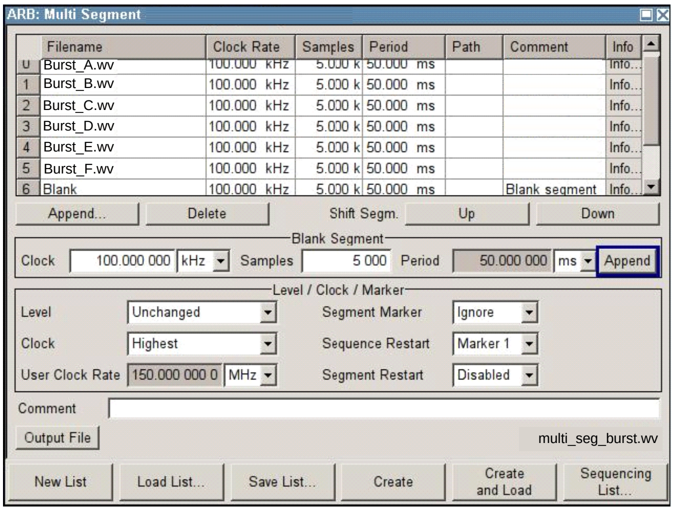


Fig. 20: Required settings for multisegment waveform generation.

In this example, the waveforms containing the bursts are added to the multisegment waveform by clicking the “Append…” button. The blank segments are added by clicking the “Append” button (blue in Fig. 20). All segments should have the same clock rate. If the segments do not have the same clock rate, then set the “Clock” parameter to either “Highest” or “User”. A restart marker can be used to mark the first burst of the sequence (Fig. 19). Set “Sequence Restart” to “Marker 1”. This will generate a marker signal at marker output 1 (MARKER 1 connector) that indicates the beginning of the first segment of the multisegment waveform, which in this example is burst A – the first burst.

To generate the burst signal shown in Fig. 19, the sequencing list must be configured as shown in Fig. 21. The bursts A to F are listed consecutively but separated by a blank segment. The burst G is also included but disabled (its “State” is “Off”). To repeat the playlist continuously, set the trigger mode to e.g. “Auto” with trigger source “Internal”. In this way, the burst signal will be generated continuously. Marker 1 will indicate the start of the sequence.

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	Burst_A.wv	1	Next Id#	Info...
1	On	6	Blank.wv	1	Next Id#	Info...
2	On	1	Burst_B.wv	1	Next Id#	Info...
3	On	6	Blank.wv	1	Next Id#	Info...
4	On	2	Burts_C.wv	1	Next Id#	Info...
5	On	6	Blank.wv	1	Next Id#	Info...
6	On	3	Burts_D.wv	1	Next Id#	Info...
7	On	6	Blank.wv	1	Next Id#	Info...
8	On	4	Burst_E.wv	1	Next Id#	Info...
9	On	6	Blank.wv	1	Next Id#	Info...
10	On	5	Burts_F.wv	1	Next Id#	Info...
11	On	6	Blank.wv	1	Next Id#	Info...
12	Off	7	Burts_G.wv	1	Next Id#	Info...

Fig. 21: Required sequencing list for generating a burst signal.

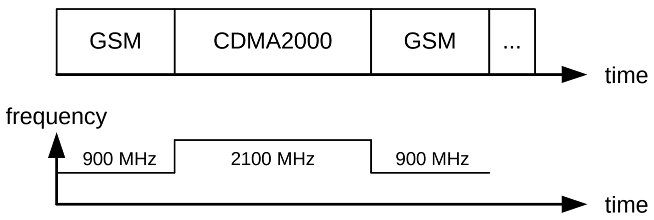
4.6 Application Example 3 – Frequency Hopping

Desired signal:

- Two (or more) different signals
- Different RF frequency for each signal
- Different RF level for each signal

It is possible to combine the playback of a multisegment waveform with the RF list mode function [1] of the signal generator. In RF list mode, the RF signal is generated on the basis of a predefined list which contains frequency and level value pairs. The list entries are processed step-by-step. The RF list mode enables fast frequency and/or level hopping.

For example, two different waveforms (one containing a GSM, the other containing a CDMA2000 signal) shall be played back at different RF frequencies, 900 MHz and 2100 MHz respectively.



Required Settings:

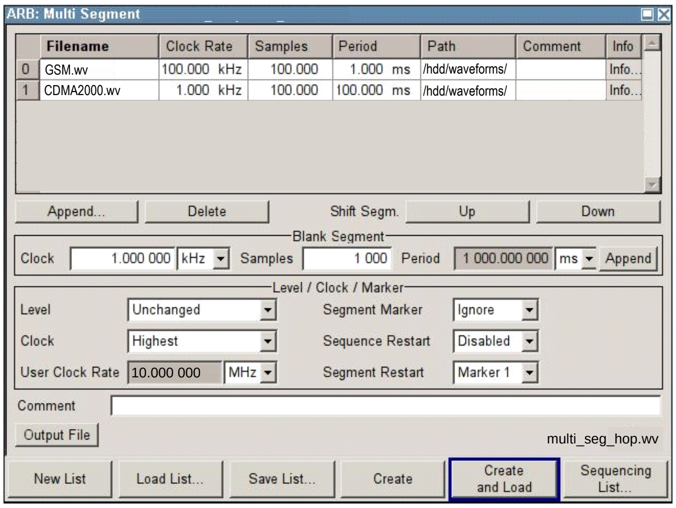


Fig. 22: Required settings for multisegment waveform generation.

In this example, the waveforms containing the GSM and CDMA2000 signals are added to the multisegment waveform as Seg.#0 and Seg.#1. To assure that both segments have the same clock rate, set the "Clock" setting to "Highest". A segment restart marker is inserted into the multisegment waveform to mark the beginning of the waveforms. This marker is used to trigger the RF list mode. Set "Segment Restart" to "Marker 1". This will generate the marker signal at marker output 1 (MARKER 1 connector).

To play back the two waveforms one after another, the sequencing list must be configured as shown in Fig. 23. To repeat the playlist continuously, set the trigger mode to e.g. "Armed Auto" with trigger source "Internal".

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	GSM.wv	1	Next Id#	Info...
1	On	1	CDMA2000.wv	1	Next Id#	Info...

Fig. 23: Required sequencing list.

The RF list mode is triggered externally by the segment marker signal which indicates the start of a new waveform. When a trigger event occurs, the next frequency and level entry in the list is executed. When the end of the list is reached, the list starts from the beginning. The required RF list mode settings are shown in Fig. 24. Set the "Mode" to "Extern Step". (With this setting the "Dwell Time" setting is ignored.) Configure the RF list mode list. In our example, we have two entries corresponding to the two waveforms. The GSM signal shall be output at 900 MHz with a level of 0 dBm whereas the CDMA2000 signal shall be output at 2100 MHz with a level of -3 dBm.

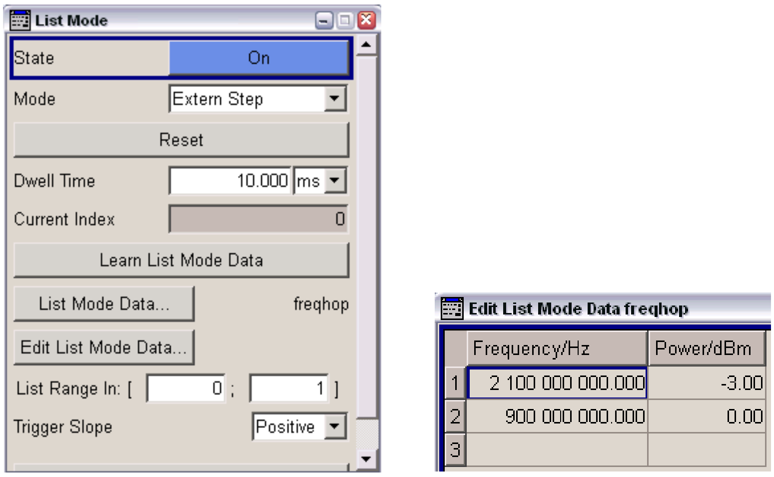


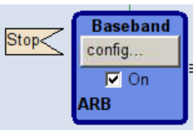
Fig. 24: Required RF list mode settings and RF list mode list.

Required Connections:

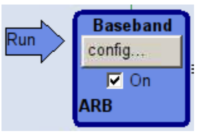
Connect the MARKER 1 connector to the INST TRIG connector using a short cable.

Synchronization of ARB and RF list mode:

To make sure that the waveforms are output at the right frequency, the ARB and the RF list mode need to be synchronized.
The first step is to turn on the ARB. Set the trigger mode to “Armed Auto”. The ARB should be turned on but the signal must not run yet (armed status).



The second step is to turn on the list mode. The first entry in the list is now active, 2100 MHz in our example (although no signal is currently generated).
The third step is to actually start the waveform playback in the ARB by executing the ARB trigger. The signal is now running (running status).



Together with the start of the waveform a marker signal is issued which triggers the list mode to step to the next list entry. The *second* entry in the list is now active, 900 MHz in our example. As a result, the GSM signal is played back at 900 MHz as desired. All further marker events will trigger the list mode to step to the next frequency such that the waveforms are output at alternating RF frequencies.

Note that it is easily possible to do the same with more waveforms and correspondingly more list entries (i.e. frequencies/levels). Fig. 25 illustrates the general principle.

Playback

Seg1.wv @ Frequency Seg1
Seg2.wv @ Frequency Seg2
Seg2.wv
Seg3.wv @ Frequency Seg3
Seg4.wv @ Frequency Seg4

Sequencer

Id#	State	Seg.#	Waveform	Rep. Cycles	Next	Info...
0	On	0	Seg1.wv	1	Next Id#	Info...
1	On	1	Seg2.wv	2	Next Id#	Info...
2	On	2	Seg3.wv	1	Next Id#	Info...
3	On	3	Seg4.wv	1	Next Id#	Info...

RF list mode

Frequency Seg4
Frequency Seg1
Frequency Seg2
Frequency Seg2
Frequency Seg3

Fig. 25: Matched lists for sequencer and RF list mode.

With the settings mentioned above, the *first* segment in the sequencing list is output at the frequency specified in the *second* list entry of the RF list mode. The *last* segment in the sequencing list is output at the frequency specified in the *first* list entry of the RF list mode as the list starts from the beginning after its end has been reached.

5 Summary

This application note explains how to create and play back a multisegment waveform with a focus on waveform sequencing.
The ARB multisegment feature is a versatile tool for generating a vast variety of test signal sequences. Thus, signal generation can be ideally adapted to the requirements of individual applications. In particular, ARB sequencing makes it possible to create complex playback scenarios fast and flexibly.

The following table gives an overview of the parameters related to the playback of a multisegment waveform:

Multisegment Waveform Playback – Parameter Overview						
	SMW		SMBV		SMU Family	
Parameter	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Number of waveforms per multisegment waveform	2	1024	2	1024	2	1024
Length of waveform	512 samples	depends on ARB size	512 samples	depends on ARB size	512 samples	depends on ARB size
Number of entries (lines) in the sequencing list	1	1024	1	1024	1	96
Number of (different) waveforms usable with one sequencing list	1	1024	1	1024	1	1024
Number of repetitions per list entry (line)	1	1048575	1	65535	1	65535
“Goto Id#” function available for list entries (lines)	0	1023	0	1023	0	95
valid for FW version and later	3.20.xxx		2.20.160.51		2.10.111.153	

6 References

[1] Operating manual of the SMW, SMU or SMBV vector signal generators (available at www.rohde-schwarz.com)

7 Ordering Information

Please visit the Rohde & Schwarz product websites at www.rohde-schwarz.com for comprehensive ordering information on the following Rohde & Schwarz signal generators:

- R&S®SMW200A vector signal generator
- R&S®SMU200A vector signal generator
- R&S®SMATE200A vector signal generator
- R&S®SMBV100A vector signal generator
- R&S®SMJ100A vector signal generator
- R&S®AMU200A baseband signal generator and fading simulator

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- ISO 14001-certified environmental management system

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