I/Q Waveform File Conversion for Use with Precise Broadcast Signal Generators

Application Note

Products:

- R&S®IQ Converter / R&S®IQ Stream Extractor
- R&S®BTC / R&S®CLG / R&S®SLG / R&S®SFU / R&S®SFE / R&S®SFE100

I/Q waveform files contain the digital complex sample values of a radio signal. They can be synthetically computer-calculated for generating precisely defined contents, or they can represent the recording of a received live signal.

The structure of these files has never been standardized, which is why so many different formats are in use today.

R&S®IQ Converter and R&S®IQ Stream Extractor are programs that quickly and conveniently convert the contents of I/Q waveform files of nearly any structure into the I/Q format used by the R&S®BTC, R&S®CLG, R&S®SLG, R&S®SFU, R&S®SFE and R&S®SFE100 signal generators. This makes it possible for the signal generators to use their integrated ARB function to generate precise RF signals from nearly any I/Q waveform file.

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The following abbreviations are used throughout this document:
R&S®XYZ is abbreviated as R&S XYZ.

1 Overview

This application note describes the two programs, R&S IQ Converter and R&S IQ Stream Extractor, which can be used to convert nearly any I/Q waveform file into the proprietary format used by the R&S BTC, R&S CLG, R&S SLG, R&S SFU, R&S SFE and R&S SFE100 signal generators.

This chapter describes the individual elements of the application. Chapters 2 and 3 explain how to use the two programs. Finally, to make getting started with the programs easier, chapter 4 provides an application example and chapter 5 includes a list of frequently asked questions.

1.1 I/Q Waveform Files

I/Q waveform files contain the digital complex sample values of a radio signal. They can be synthetically computer-calculated for generating precisely defined contents. Possible applications include the evaluation of new broadcast standards or the generation of specific interfering signals.

I/Q sample values can also originate from a recording of a received live signal, and can then be used as a practical test for receivers under reproducible laboratory conditions.

The structure of these files has never been standardized, which is why so many different formats are in use today.

1.2 R&S IQ Converter

R&S IQ Converter is a program that converts the contents of nearly any non-packet-oriented I/Q waveform file quickly and conveniently into the proprietary file format used by the R&S BTC, R&S CLG, R&S SLG, R&S SFU, R&S SFE and R&S SFE100 signal generators.

Even files with an initially unknown structure can be converted using the application's powerful analysis functions.

Integrated signal processing modules, such as digital filters and resamplers, round out the scope of functions.

1.3 R&S IQ Stream Extractor

R&S IQ Stream Extractor is available for packet-oriented I/Q waveform files of any structure. This program splits the individually received, independent I/Q streams into separate output files and simultaneously strips away the packet structure so that the individual signals can be processed using R&S IQ Converter.

1.4 Supported Broadcast Signal Generators

	R&S BTC	R&S CLG R&S SLG	R&S SFU	R&S SFE R&S SFE100
				
General				
Frequency range	100 kHz to 6 GHz	47 MHz to 1002 MHz 250 MHz to 3000 MHz	100 kHz to 3 GHz	100 kHz to 2700 MHz
Level	–120 dBm to 18 dBm	up to -14 dBm per carrier	–120 dBm to 19 dBm	–110 dBm to 27 dBm
I/Q waveform generator				
Independent generators	8 per RF path (=8x2)	4	1	1
Memory	1 Gsample per RF path	8 Msample each 64 Msample (shared)	1 Gsample	256 Msample
Useful signal bandwidth	up to 125 MHz per RF path	8 MHz each 140 MHz (shared)	40 MHz	40 MHz
Interferer Management	yes	yes	yes	no
Digital I/Q output	yes	no	yes	no
Additional features				
Fading simulator	up to 4x40 paths	no	up to 2x20 paths	up to 12 paths no
Phase / impulsive noise generator	yes	no yes	yes	no
AWGN noise generator	yes	no yes	yes	yes
Remote control	GPIB, LAN, USB	LAN	GPIB, LAN	LAN

The Interferer Management function provided by R&S BTC, R&S CLG, R&S SLG or R&S SFU even allows the reconstructed I/Q signals to be combined with another broadcast signal generated in realtime. Depending on its position in the spectrum, the I/Q signal will then act as a co-channel or adjacent-channel interferer [1].

2 R&S IQ Converter

2.1 Scope of Functions

2.1.1 Supported Formats

The software supports any format displaying a combination of the following elements:

File structure

- I and Q data together in one file or in two separate files

Metadata

- None / header only / trailer only / header and trailer
- Text / binary (Little or Big Endian)

I/Q sample values

- Text: integer / floating point / hexadecimal

  or

  Binary (Little or Big Endian):
  - Floating point (32 bit / 64 bit)
  - Integer (8 / 16 / 32 / 64 bit, signed or unsigned)
- Sequence: IQ / QI / I only (Q is set to 0) / I only (Q is set to = I)
- Skip up to 10 markers before the I or Q sample value

Powerful analysis functions make it possible to identify the format elements used in an initially unknown file structure.

2.1.2 Automatic Metadata Extraction

The Rohde & Schwarz file format includes not only the central I/Q sample values but also a user-specific comment field and the sampling frequency.

The software can determine these two parameters automatically from the source file metadata (header or trailer).

2.1.3 Support for Uninterrupted Playback

Because of their short runtime, I/Q waveform files are played back in an endless loop on the replay generators. Therefore, the end of the I/Q waveform should precisely match its start to prevent any discontinuity and the associated interference spectrum at the transition point.

To allow this, the software can be programmed to convert only a specific interval. An I/Q waveform preview of the transition from the end of an interval back to its start makes it easy to determine the optimum interval boundary that will result in the least amount of discontinuity.

2.1.4 Signal Processing

During the actual conversion, a number of interesting I/Q characteristics can be influenced in parallel:

Scale factor
Rohde & Schwarz waveform generators process integral I/Q sample values in the range of ±32767.
If the value range of the waveform to be converted is larger, then a scale factor of < 1 should be selected to prevent "clipping" (i.e., non-linear rounding up or down).
If the value range is smaller, on the other hand, a scale factor of > 1 is recommended to keep the quantization noise as low as possible.
The scale factor does not influence the performance of the last signal output by the Rohde & Schwarz waveform generator.
Although the optimum scale factor is determined automatically, manually defining the scale factor can cut the conversion time in half.

DC offset
The most efficient utilization of the value range on the Rohde & Schwarz waveform generators using the scale factor is possible only with a zero-mean input signal. However, unsigned integer input formats always result in a positive RMS value, which can be compensated for using the "DC offset" parameter.

Spectrum mirror
The I/Q data spectrum can be mirrored as needed. This corresponds to an inversion of the Q sample values.

Spectrum selection
Any segment of the I/Q spectrum can be shifted in order to position it symmetrically at the 0 Hz mark so that the remaining segments can then be suppressed using a low-pass filter. This is particularly useful when the input waveform includes multiple channels.

Sample rate reduction
If the input spectrum is not fully utilized up to the Nyquist frequency, this is because the I/Q sample values have been generated at a higher sample frequency than necessary. Since higher sample frequencies require higher data rates and thus shorter runtimes, the software makes it possible to reduce the sample rate by means of resampling as part of the spectrum selection process described above.

2.1.5 Batch Processing Mode

Any number of input files can be automatically converted in sequence.

2.2 System Requirements

The program requires a PC running Microsoft® Windows XP/ Vista / 7 (32 bit or 64 bit) and approximately 20 Mbyte disk space.

In addition, depending on size, each I/Q waveform file will require up to 4 Gbyte free disk space to store the conversion results.

The minimum monitor resolution is 1024 x 768; however, 1280 x 1024 pixels or more are recommended for better legibility.

2.3 Installation

The program is installed by launching the R&S IQ Converter Setup_X_X_X.exe" file, where the three "X" placeholders represent the current version. This file can be downloaded at no cost from the download page of this application note.

If a previous version of the program is already present on the PC, it will be uninstalled automatically during the installation process. Any user-defined configuration files will be retained and can be used in the updated software.

2.4 Operation

The user interface always displays the currently active configuration along the right-hand side of the screen. This configuration defines the conversion scheme that will be used to convert the I/Q input files. The number and flexibility of the individual configuration parameters make it possible to support the structure of many I/Q input files. Four different views are available on the left-hand side of the screen, although the Files view is always active whenever the program is launched. In this Files view, the integrated File Browser can be used to add I/Q waveform files to the job list for conversion. If a configuration already exists for the current input format, it is to be selected. Otherwise, the various analysis views (Metadata Analysis, IQ Analysis and Signal Processing) can be used to create a matching configuration, which can then be saved for later use. Finally, the "Start conversion jobs" button starts automatic processing of the job list.

2.4.1 User Interface

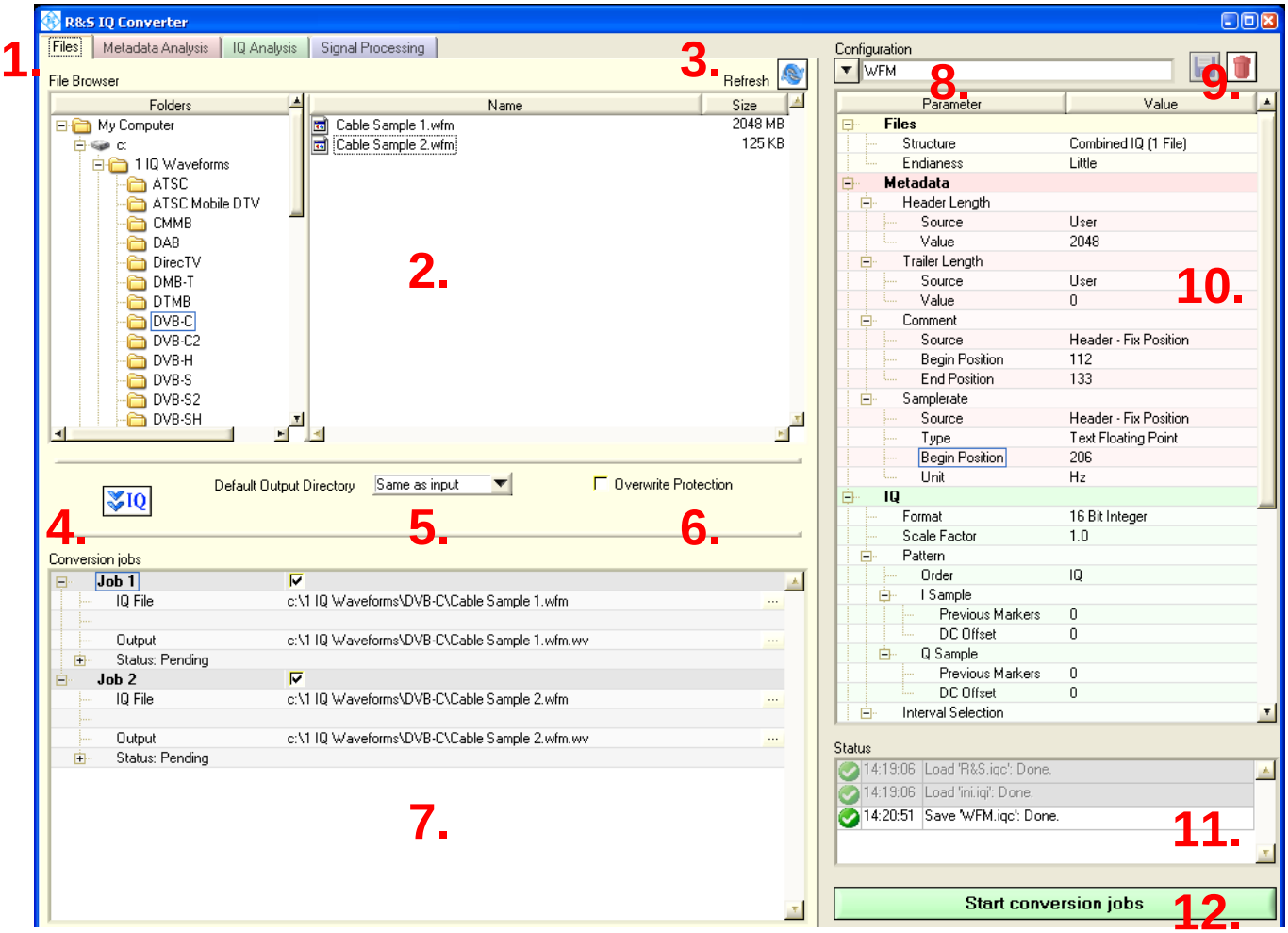


Fig. 1: Files view.

This section uses Fig. 1 to describe the options available in the Files view on the left-hand side of the screen, as well as the static controls on the right-hand side:

1. View tabs
Used to switch between the Files view and the three different analysis views (Metadata Analysis, IQ Analysis and Signal Processing) on the left-hand side of the screen.

2. File Browser
Serves to select the files to be converted. Double-clicking a file adds it directly to the job list (see 7). Alternatively, multiple files can be highlighted and then added to the job list by clicking the "Add IQ" button (see 4).

3. "Refresh" button
Updates the File Browser.

4. "Add IQ" or "Add I" / "Add Q" button
Moves the currently selected files in the File Browser to the job list. The subsequent display depends on the file structure defined in the configuration on the right-hand side of the screen:

"Combined IQ (1 File)"

"Separate I/Q (2 Files)"

5. Default Output Directory
For every new job in the list, the storage location and name of the output file are automatically defined during insertion based on the storage location defined here. Changes will not affect jobs already present in the list.

6. Overwrite Protection
If enabled, existing output files will not be overwritten.

7. Conversion jobs (job list)
This area lists the individual conversion jobs and their status:

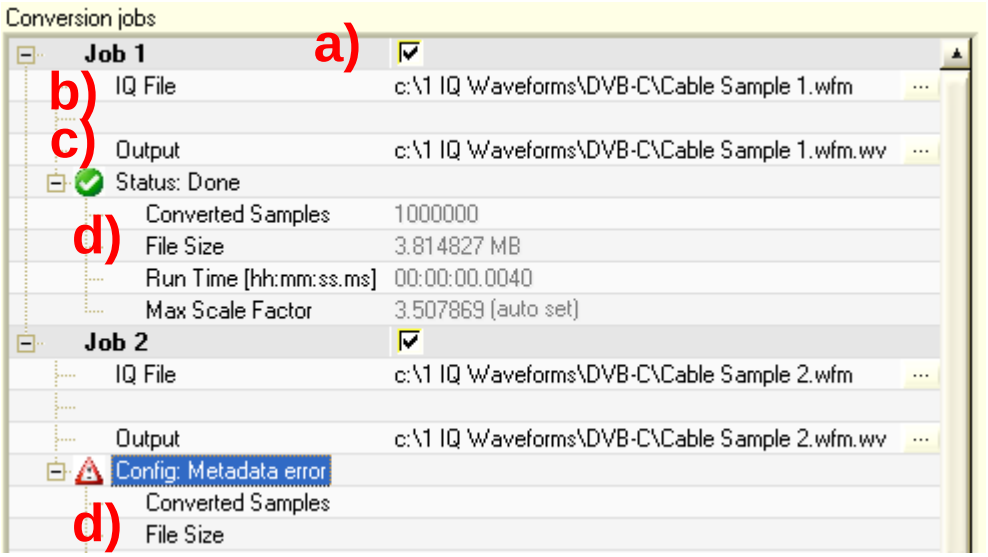


Fig. 2: Job list.

7a) Job: Delete
Clear this checkbox to remove the job from the list.

7b) Job: Source file(s)
Click the ellipsis (...) button at the far right-hand side of the line to change the source file used for the job. In cases where the configuration parameter "File Structure" is set to "Separate I/Q (2 Files)", two lines will appear here.

7c) Job: Output file
Displays the selected output file and allows changes in the same manner as described in (7b).

7d) Job: Status

- If the job has not yet been processed, "Pending" will be displayed here and the detail fields will remain empty.
- If the job could not be processed (see the second job in Fig. 2 as an example), an error message will be displayed along with the configuration parameters that did not match the source file.
- The progress is displayed while a job is being processed:

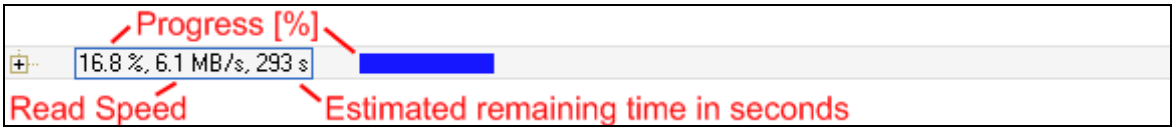


Fig. 3: Status and progress display during job processing.

- After a job is processed successfully, "Done" is displayed along with the following details:
  Number of converted samples, size of the output file, runtime of the waveform, and

  Maximum scale factor
  As described in (2.1.4), the scale factor for minimizing quantization noise and nonlinearities during clipping should be selected so that the value range provided by the Rohde & Schwarz waveform generators is utilized to the greatest extent possible during conversion, without exceeding it.

  As a default, the optimum scale factor for every individual job is determined and used automatically. In this case, "(auto set)" is displayed after the numeric value.

  Manually assigning the scale factor can cut the conversion time in half. However, the following must be taken into consideration when working in this *expert mode*:

  To determine the maximum scale factor (s) before conversion, the maximum sample value (a) present in the input waveform must already be known:

$$s = \frac{Maximum\ value\ of\ \ R\,\&\,S}{Maximal\ \ value\ of\ \ input\ \ waveform} = \frac{32767}{|a|}$$

Therefore, the software provides an option in the IQ Analysis view (2.4.3) to scan the source file and automatically determine the maximum scale factor. However, because it is possible for the file to grow into the Gbyte range, the software saves time by analyzing only a subset of all sample values. The result should therefore be considered as a guideline, as it might not represent the optimum value.
In addition, selecting certain signal processing components, such as spectral shift or spectrum selection using a lowpass filter (2.4.4), can have an unpredictable effect on the value range of the output waveform.

After a job has been converted, however, the software knows all of the sample values for the output waveform, and the status details will therefore display the maximum scale factor for this job.

If the currently selected scale factor is greater than the calculated ideal value, then an output file will not be written due to clipping. The conversion must then be repeated using the optimum scale factor.

The same applies in cases where the currently selected scale factor falls below 70 % of the ideal value.

8. Select configuration
Use this area to select the configuration to be used.

9. Manage configuration

- Create
  Type the new configuration name in (8) and then click ->Save.

-  Save
  The "Save" button is available whenever changes are made to the currently selected configuration.

  The file is saved in the program directory with the filename: *[configuration_name].iqc*.

  Whenever the program is launched, all configurations present in this directory are automatically recognized. This means that configurations can be transferred to a second PC simply by copying the desired configuration files.

  All other program settings that are not part of a configuration, such as the layout of the user interface or the File Browser path, are automatically saved when exiting the program and then restored the next time the program is launched.

-  Delete
  The "Delete" button is available whenever no unsaved changes are present in the current configuration.

10. Configuration parameters
This area displays all of the parameters associated with a configuration. They define exactly how the jobs in the list will be converted. The elements are sorted hierarchically and can be hidden as needed to improve the display overview. To simplify the setting of parameters, the individual parameter groups in this area are color-coded to match the three analysis views (Metadata Analysis, IQ Analysis and Signal Processing) where the parameters are used.
See sections (2.4.2 to 2.4.4) for details.

The parameters listed in the "Files" group define the following:

- Structure: "Combined IQ (1 File)" or "Separate I/Q (2 Files)"

- Endianess: Interpret binary data as Little Endian or Big Endian. This setting applies to both metadata and I/Q sample values.

11. Software status messages
General program confirmations and errors are displayed here: For example, configuration was saved successfully, or job could not be added because the source file was to small (min. 1 kbyte).

12. Start conversion jobs
If this button is red, the job list is either empty or incomplete. Otherwise, it remains green and is used to start processing the job list. It can also be used to stop a conversion in progress.

2.4.2 Metadata Analysis

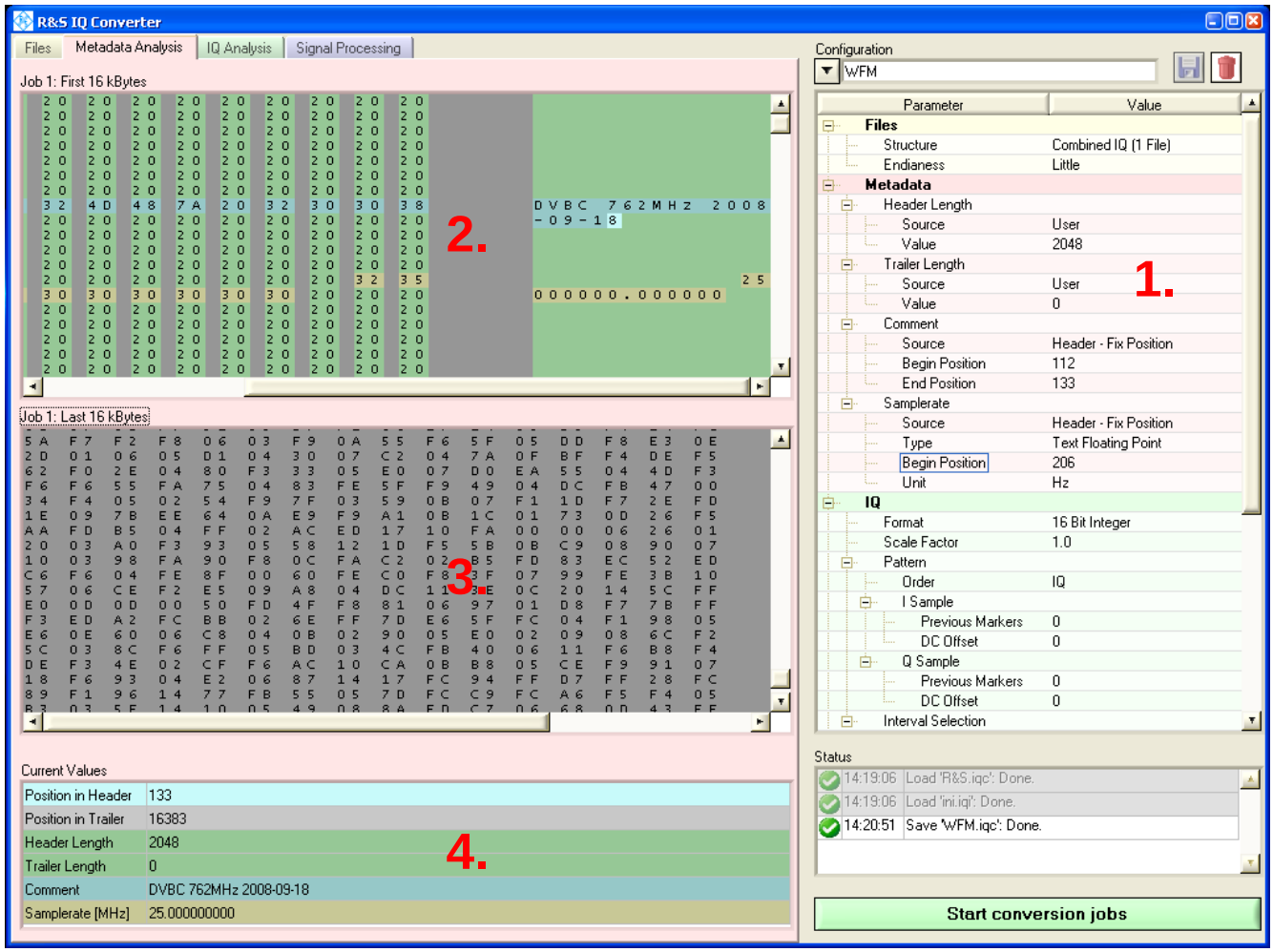


Fig. 4: Metadata Analysis view.

Like the other two analysis views, the information displayed in this view always applies to the first job in the job list. If there are no jobs in the job list, then no data will be displayed in this view.

1. Configuration parameters

- Header Length
  This entry is required so that parts of a header are not incorrectly interpreted as I/Q sample values. This length can be either fixed (Source: "User"; Value: length in bytes) or calculated dynamically (Source: "Header – End Pattern"). In the case of the latter, the header of each individual job is searched for this end pattern and, if found, the header length is configured accordingly. If a line feed is needed in a searchable pattern, use the character sequence "\n" (Carriage Return: "\r", Null: "\0"). To include the character "\", use "\\".

This configuration information can be found in the format description, if available, or alternatively in the header preview. For example, it is very easy to recognize the end of a header in text format. When uncertain, set the length manually at a conservatively high value. Although the first I/Q sample values in the file will not be converted, any glitches caused by header bytes being incorrectly read as sample values will be prevented.

- Trailer Length
  Analogous to Header Length.

- Comment
  The output file for the Rohde & Schwarz waveform generators also include a comment. This can be defined by the user (Source: User; Value: any text) or taken from the header/trailer (Source: Header or Trailer). If taken from the header/trailer, the comment is derived either from a fixed range (Source: Fix Position) or dynamically. In the case of the latter, the comment must be enclosed by a defined start and end pattern.

- Samplerate
  Like with the comment, the sample rate can be fixed or derived dynamically from the metadata. In contrast to the comment, however, the sample rate does not have to be present as text, but rather can also be a binary value (e.g., Type: 32 Bit Float). The sample rate unit cannot be determined automatically, and therefore must be entered separately in the "Unit" field.

Any time a parameter value is not valid, an error symbol will appear to the left of the invalid entry. As long as the associated field is not currently being edited, a tooltip is also available with a precise description of the error.

2. Header preview
Up to 16 kbyte of the source file header are displayed both hexadecimally (left) and as text (right). If separate files are used for I and Q, the I file is displayed here.

This view makes it easy to determine the length and format (binary / text) of a potential header. Any comment or sample rate information can also be identified here.

3. Trailer preview
Analogous to the header preview.

4. Current values from both previews
To check the defined configuration parameters, the header length, trailer length, comment and sample rate values for the first job are listed here as well as highlighted in color in the corresponding preview.

The current marker positions in the two previews are also displayed here. These markers make it possible to click a symbol within the preview and determine its position, or to enter a position and mark the corresponding character in the preview.

2.4.3 IQ Analysis

Fig. 5: IQ Analysis view.

Several of the control elements described here are either unavailable or have only limited availability when the I/Q sample values are provided as text instead of in binary form. These elements are identified with an asterisk **(*)**. This restriction is in place because the byte length of sample values expressed in text format can vary, thereby unacceptably slowing down navigation through large files.

To ensure that all functions can still be used, text-based I/Q waveforms should first be converted in full length into the binary Rohde & Schwarz format, then reopened for a second conversion process with all options.

1. Configuration parameters

- Format
  Defines how the program reads in the individual sample values. If a binary format is selected, the Endianess parameter under the Files section must also be set correctly. In addition, the header length must be precisely defined to the byte; otherwise, interpretation of sample values might start before or after the actual start of the sample value and therefore return incorrect results.

- Scale Factor
  This parameter is defined in (2.4.1 7d).
  Use this field to enter the scale factor manually. You can use the IQ Preview (5.) to determine the value, or the value can also be approximated automatically using (8.). It is recommended that "Auto Optimization" be enabled so that the optimum scale factor is determined and used for every job in the list during the conversion process, independent of the manually defined value. Although disabling "Auto Optimization" will cut the conversion time in half, the manually defined scale factor is then used for every job in the list, even if it is not the ideal value for that job.

- Pattern
  This set of parameters defines the pattern followed by the individual sample values in the source file. This will affect the position of the I and Q sample value (Order: IQ, QI). If the input waveform contains only the real part, and therefore does not include any Q sample values, then the Q components can automatically be set to zero or to be equal to I during the conversion (Order: I only – Q = 0; I only – Q = I). If the input signal contains markers in addition to the I and Q information, these parameters can be used to define how many markers are to be skipped before I or Q appear.

- DC Offset
  The I and Q channels can be assigned a DC component separately; for example, to return a signal that was shifted back to zero-mean as a result of a signed integer. This makes sense to do, even when just considering the scale factor (2.1.4).

- Interval Selection
  This set of parameters defines what part of the I/Q sample values from the source file(s) to convert. These parameters have two purposes. First, the converted waveform length should not exceed the storage capacity of the Rohde & Schwarz waveform generator (Maximum Length 32 / 64 / 128 / 256 / 512 / 1024 MegaSamples). Second, precisely selecting an interval so that the end matches seamlessly to the start is beneficial in preventing glitches in the spectrum during the endless replay. The views (5.) and (10.) make it easy to define the interval boundaries. If all sample values from the source are always to be converted, the Last Sample Type parameter should be set to "Auto Max Length". In this case, set the First Sample value to '1'.

2. Total I/Q samples used for the IQ Preview (5.)
Because the IQ Preview can display I and Q traces in the time domain as well as their common spectrum in the frequency domain, the valid range is from 8 to 8192. Smaller values are more suited to detailed analyses in the time domain. In contrast, the spectrum resolution increases with larger values.

3. (*)Cursor selection
Defines whether the cursor position in the IQ Preview (5.) defines the interval start or the interval end parameter. If the Interval Selection:Last Sample:Type is set to "Auto Max Length", only the interval start parameter can be set using the cursor.

4. (*)Display of the total number of I/Q sample values in the file(s)
This value is given an exact definition in the case of binary sample values. For text-based sample values, an interpolated value is provided for reference purposes.

5. IQ Preview
Displays how the software is currently interpreting the sample values from the source file(s). By changing various I/Q configuration parameter settings in this view, it is possible to find a matching combination quickly, even when dealing with initially unknown I/Q formats. A valid configuration can be recognized by the cohesive I and Q traces, as well as a channel spectrum that rises above the white noise.

Another function provided in this view is monitoring of the current scale factor. Two horizontal lines (at ±32676) identify the value range used by the Rohde & Schwarz waveform generators. Therefore, the I and Q traces should fully utilize this dynamic, but without exceeding it (2.4.1 7d).
If "Auto Optimization" is enabled for the scale factor, the optimum value is always used during the conversion, regardless of the defined scale factor value.

(*)Finally, simply click in the view to set the start or end of the interval to be converted, depending on the setting in (3.). This setting is particularly useful in conjunction with the Seamless loop feature (10.).

6. (*)Position of the IQ Preview within the file(s)
Use the slide control or the numeric field to select the starting position in the sample values for reading the information for the IQ Preview (5.). This makes it possible to view any portion of the I/Q source data, thereby facilitating the automatic definition of the scale factor (8.) and permitting the user to define the interval boundaries using the cursor.

7. Show / hide the traces in the IQ Preview (5.)
The traces available in the IQ Preview (5.) can be hidden or displayed independently of one another to ensure that the best overview is always available for every situation.

8. Automatic adjustment of the scale factor
Enable this function to adjust the scale factor automatically when scrolling through the source data using (6.). However, please note that when scrolling through large files, not all sample values are recorded, and the resulting recommended scale factor can in certain circumstances be too large. The results can, however, always be used as a guideline. To ensure that the optimum scale factor is always used in every job, enable the configuration parameter Scale Factor:Auto Optimization.

9. (*)Display the number of I/Q sample values in the selected conversion interval
This value varies based on the total number of sample values in the source file(s) (4.) in cases where only a partial range was selected for conversion.

10. (*)Seamless loop preview
This special I/Q waveform preview showing the transition from the end to the start of the interval makes it possible to identify the optimum interval boundaries with the least amount of discontinuity by incrementally moving the cursor in (5.).

11. (*)Show / hide the traces in the seamless loop preview (10.)
Analogous to (7.).

2.4.4 Signal Processing

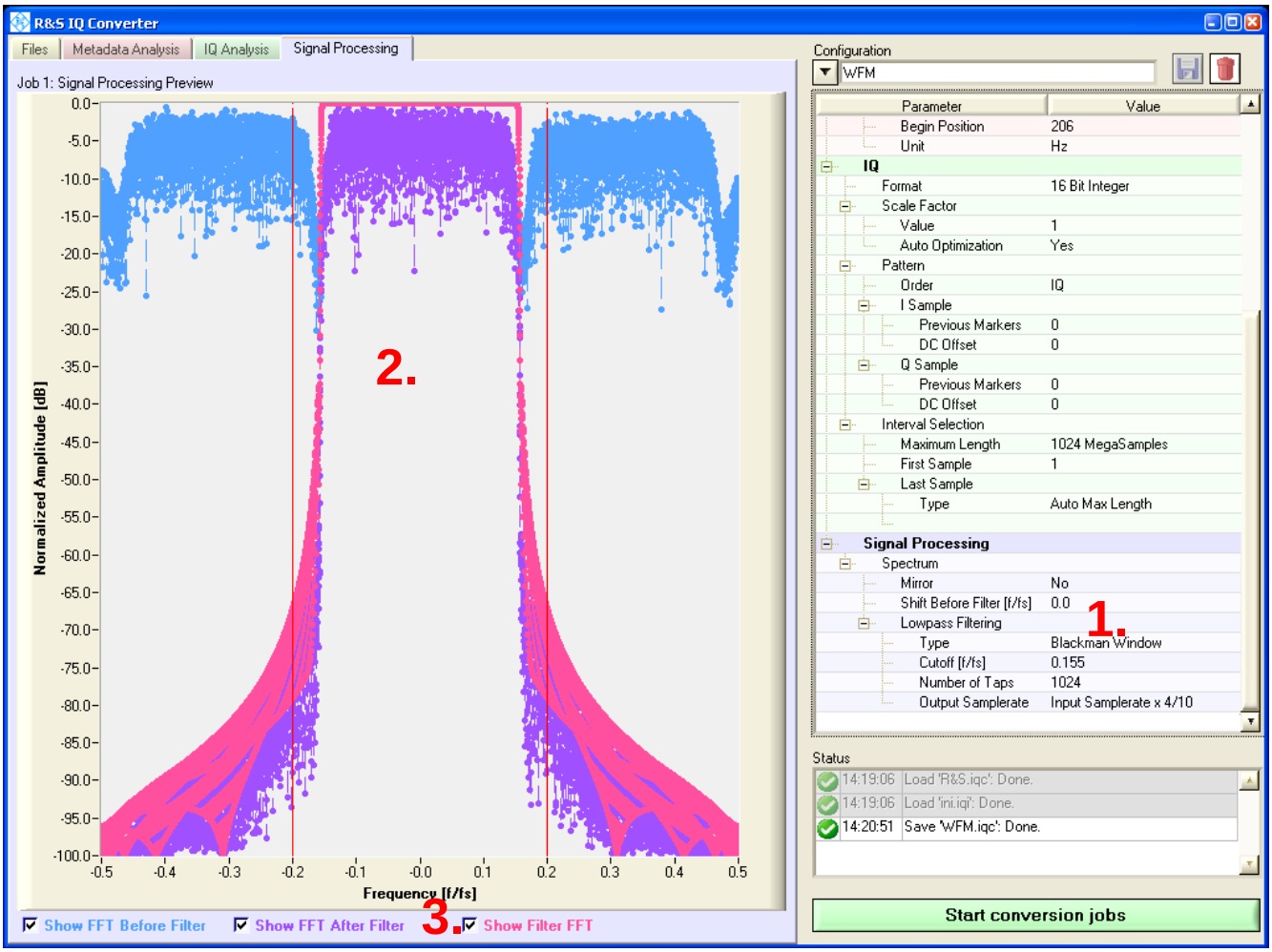


Fig. 6: Signal Processing view.

1. Configuration parameters

- Spectrum Mirror
  The I/Q data spectrum can be mirrored as needed. This corresponds to an inversion of the Q sample values.

- Spectrum selection
  Any segment of the I/Q spectrum can be shifted (Shift Before Filter [f/fs]) in order to position it symmetrically at the 0 Hz mark so that the remaining segments can then be suppressed using a lowpass filter (Type, Cutoff, Number of Taps). This is particularly useful when the input waveform includes multiple channels. An increase in the number of filter taps improves the filter quality and also increases the time required for the conversion.

- Sample rate reduction
  If the input spectrum is not fully utilized up to the Nyquist frequency, this is because the I/Q sample values have been generated at a higher sample frequency than necessary. Since higher sample frequencies require higher data rates and thus shorter runtimes, the software makes it possible to reduce the sample rate by means of resampling as part of the spectrum selection process described above.

2. Signal Processing Preview
The effects of the settings made in (1.) are visualized here:

- The turquoise trace illustrates the current spectrum from the IQ Preview after any mirroring and/or shifting.
- The lilac trace shows the effect of the selected lowpass filter on the turquoise spectrum.
- The pink trace corresponds to the frequency response of the lowpass filter.
- The red vertical lines show the new Nyquist frequencies based on the selected output sample rate. With the exception of these, the lilac trace should not contain any other significant components, as these would be added to the selected spectrum as an interfering alias.

3. Show / hide the traces in the Signal Processing Preview (2.)
The traces available in the Signal Processing Preview (2.) can be hidden or displayed independently of one another to ensure that the best overview is always available for every situation.

3 R&S IQ Stream Extractor

Even though R&S IQ Converter program can process a number of different input file formats, packet-oriented I/Q data is not directly supported. That type of file must be preprocessed as shown here:

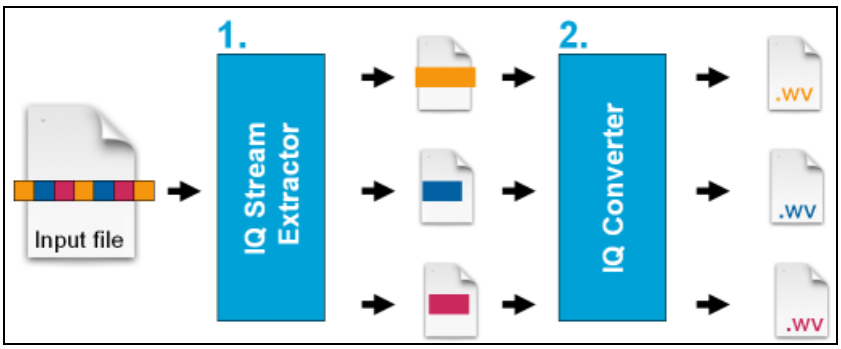


Fig. 7: R&S IQ Stream Extractor and R&S IQ Converter in combination.

R&S IQ Stream Extractor takes the independent I/Q streams from an input file of nearly any structure and splits them into separate output files, while removing the packet header (1.) so that the individual signals can then be processed with R&S IQ Converter (2.).

3.1 Overview

R&S IQ Stream Extractor is similar to R&S IQ Converter in that the system requirements, download conditions, installation and operating concept are identical.

In the Files view, one or more source files are added to the extraction job list, the matching configuration is either activated or created, and then processing is started by clicking the "Start extraction jobs" button.

The difference lies in the configuration parameters and the associated analysis view, which in this case define the packet structure. To successfully process any given I/Q streaming format, R&S IQ Stream Extractor must be able to obtain six main attributes for each and every packet:

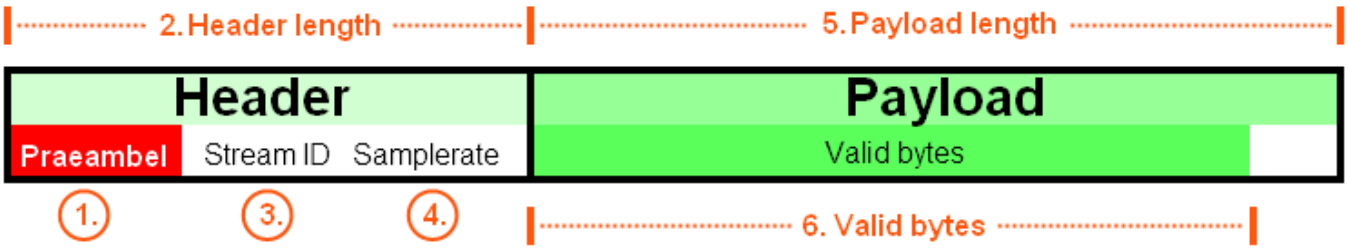


Fig. 8: R&S IQ Stream Extractor focuses on six main attributes per packet.

The preamble is a static pattern comprising one or more bytes that signals the start of a new packet. The remaining five attributes define the packet length and contents, and

can be either statically defined or extracted from each packet header. If these attributes are extracted from the header, their values may not be directly available. For example, if the header contains its own length and the total length of the packet, then the length of the payload is implicitly known, but the difference must still be calculated to obtain the actual value. This is why R&S IQ Stream Extractor supports up to five variables, as well as mathematical expressions. Each of these variables can be assigned a specific item of information from the header in one of these binary formats (Little Endian or Big Endian):

- Floating point (32 bit / 64 bit)
- Integer (8 / 16 / 32 / 64 bit, signed or unsigned)

Even bit-level status logging is available, because a user-defined data format, consisting of bitmask and bitshift, is supported. For example, a 13-bit stream ID contained in one word (two bytes) can be read out as follows:

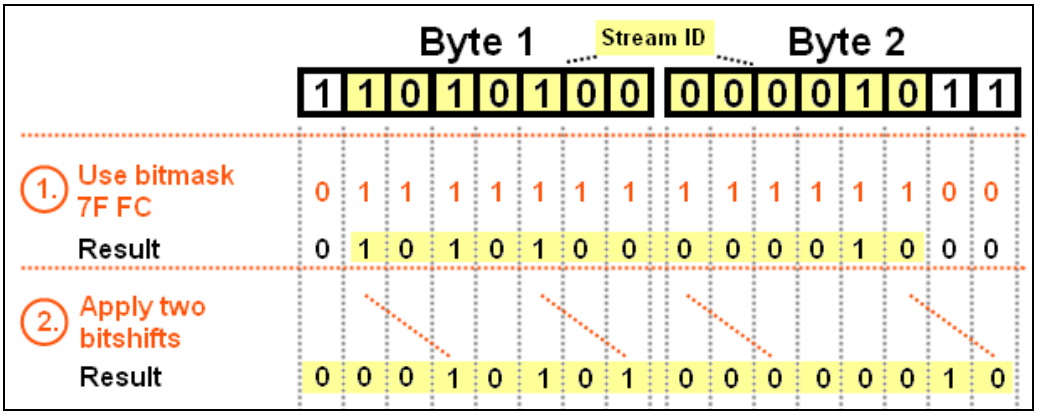


Fig. 9: Example of bit-level extraction of the "stream ID" header information.

First, the bits in question are selected bytewise using hexadecimal bitmask:s "7F" selects the lower seven bits of the first byte, and "FC" selects the six upper bits of the second byte. These hexadecimal identifiers can be easily determined using the Microsoft®Windows calculator:

- Navigate to View > Scientific
- Select binary mode ("Bin") and enter a binary number, for example "1111 1100"
- Select hexadecimal mode ("Hex") and "FC" will appear

In the second step, a double bitshift ensures that the "stream ID" value starts at bit significance 1. Without this step, the interpreted value would be too large by a factor of 4 (2^2).

After the information from the header has been assigned to the variables, the required packet attributes ("Header Length", "Stream ID", etc.) can be defined by means of mathematical expressions, such as "A+C-24".

3.2 Packet Analysis

This analysis view reads up to 256 kbyte from the first file in the job list to simplify creation of a configuration that matches the input streaming format:

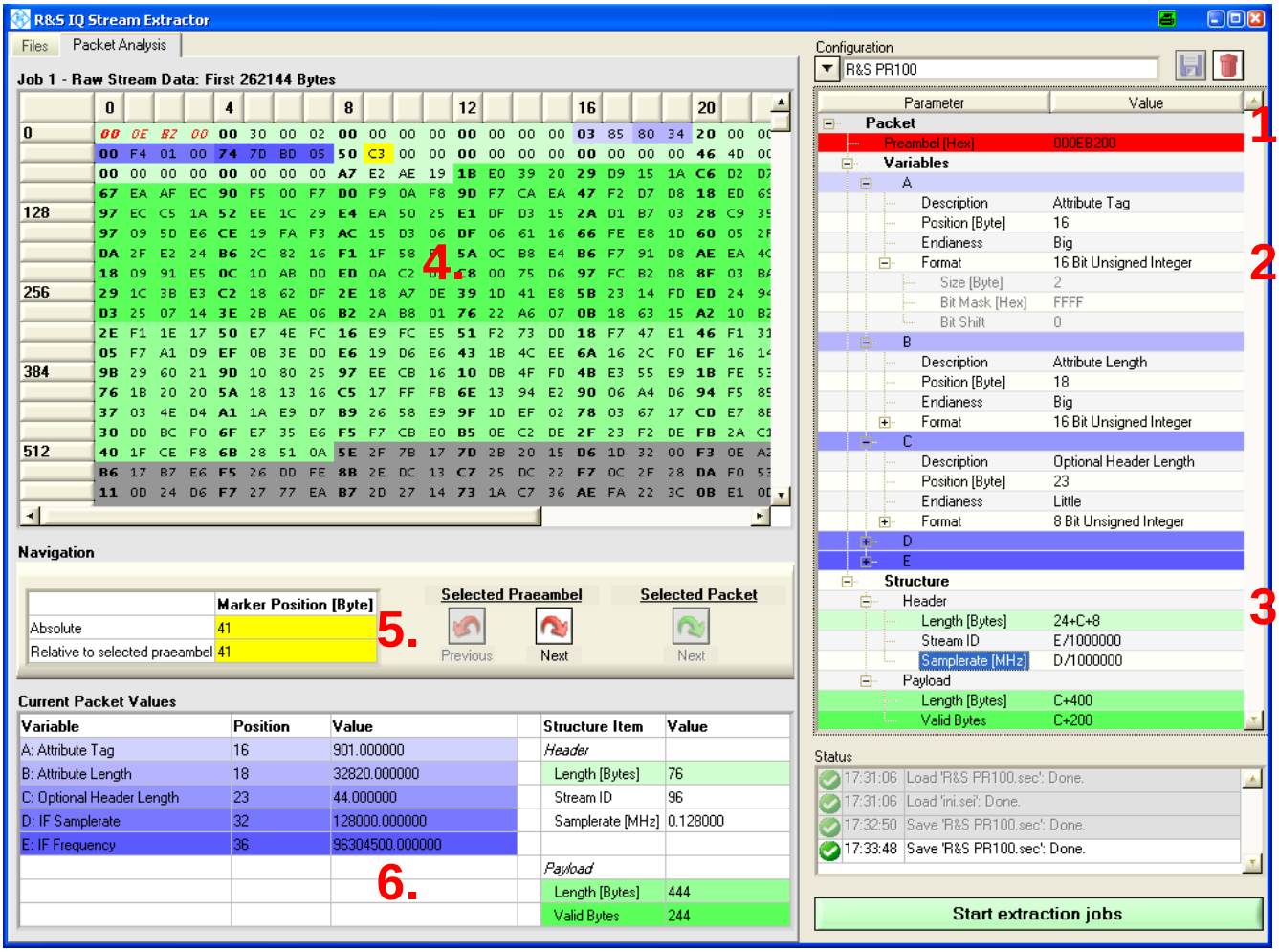


Fig. 10: Packet Analysis view.

1. Preamble

This hexadecimal byte pattern is the most important parameter in the configuration because it defines the possible start positions for a packet. In the binary preview (4.), all found preambles are highlighted in red. Only one of these is displayed in italics, since it represents the start of the packet currently being analyzed. This selection can be changed by clicking on another preamble within the preview (4.) or by using the navigation bar (5.).

2. Variables
Up to five variables ('A' to 'E') can be used to extract the information required to calculate the packet attributes from the packet header. This requires the following settings:

- Description
  This user-defined text field provides an explanation of the value assigned to the variable. Although an entry is not required, it does make it easier to interpret view (6.).

- Position [Byte]
  This value defines the start position in the header for extracting the information for the variable. This mathematical expression can also contain preceding variables (i.e., the position of variable 'C' can be defined by variables 'A' to 'B', but not by 'C' to 'E'). In this way, information at variable positions in the header can still be extracted.

- Endianess
  Defines whether the binary format described below is to be read using "Little Endian" or "Big Endian".

- Format
  Defines how the header bytes selected for the variables are to be interpreted. Select "User Defined" to perform this bit-level analysis using bitmask and bitshift.

If not all variables are required, the position information for the lower variables should be left blank in the configuration list. All input can be verified in views (4.) and (6.), because this is where all resulting variable positions and values are displayed automatically for the currently selected preamble.

3. Packet attributes
The mathematical expressions for defining the five central packet attributes based on constants and/or variables are assigned here:

- "Header Length" – for identifying the start of the payload
- "Stream ID" – for separating payload of various streams
- "Samplerate" – for use by R&S IQ Converter
- "Payload Length" – for identifying the end of the packet
- "Valid Bytes" – for identifying the end of the payload

This input can likewise be verified by checking the resulting values in views (4.) and (6.).

4. Binary preview
This analysis view displays up to 256 kbyte at the start of the first file in the job list. Color-coded displays allow the entered configuration parameters to be verified:

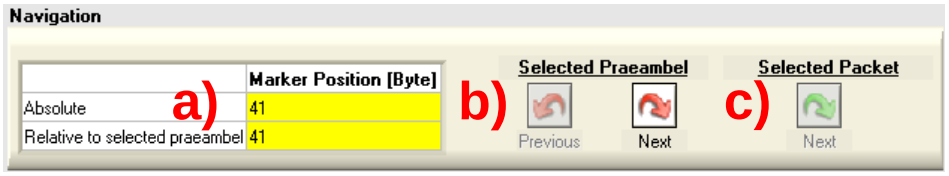
- **Red lettering**
  Highlights all preambles in the data stream. The one representing the start of the currently selected packet is also displayed in italics. Not every preamble has to be at the start of a new packet; depending on the streaming format, this byte pattern can also appear within the payload. If the currently selected (i.e., italic) preamble is not the start of a packet, all variable values will be calculated incorrectly because the position definition will not fall at the anticipated header bytes.

- **Yellow background**
  This marker determines the position of a specific byte in the preview. It can be set simply by clicking any byte that is not part of the preamble pattern. The position then is displayed within the navigation bar (5.) absolute and also relative to the selected preamble (i.e., packet start).

- **Green background**
  Three different shades of green identify the current values of the packet attributes "Header Length", "Payload Length" and "Valid Bytes".

- **Blue background**
  Five different shades of blue identify the header bytes extracted from the individual variables.

5. Navigation bar



a) Displays the marker positions described in (4.).

b) While view (4.) permits graphical selection of the active preamble, this can also be done using these two buttons.

c) This button is an important indicator for the accuracy of the configuration parameters. This button is enabled only if another preamble follows the currently selected packet (calculated by adding "Header Length" and "Payload Length" to the current preamble position. All preambles within the payload can then be skipped and the data of the next packet analyzed immediately.

6. Calculated values in the current packet
For the packet defined by the currently selected preamble, these tables display all resulting variable and packet attributes values used to verify the configuration.

4 Application Example

The R&S PR100 is a portable receiver that can record FM radio channels as I/Q waveform files:

Fig. 11: R&S PR100.

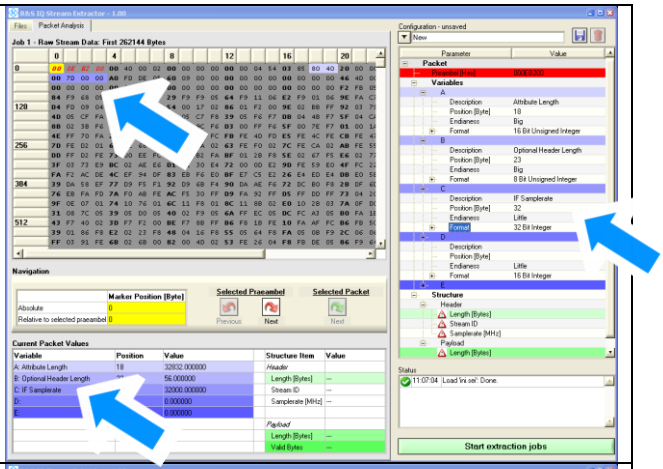
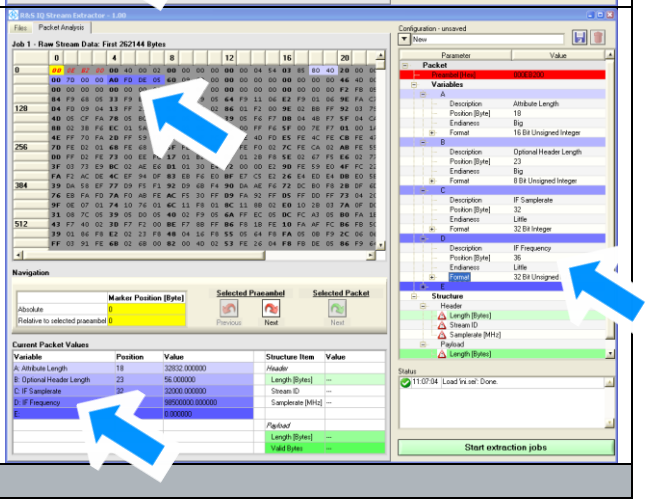
The R&S PR100 file format does not correspond to that of the described R&S SFU, R&S SFE and R&S SFE100 signal generators, and it is also packet-oriented. This file format therefore provides an excellent example of an R&S IQ Stream Extractor and R&S IQ Converter application. The file "R&S_(R)_PR100_StreamExample_V100.riq" used in this example can be downloaded free of charge from the download page of this application note in order to reproduce the steps outlined here. The download includes several minutes of an FM radio channel in which the receive frequency changes multiple times.

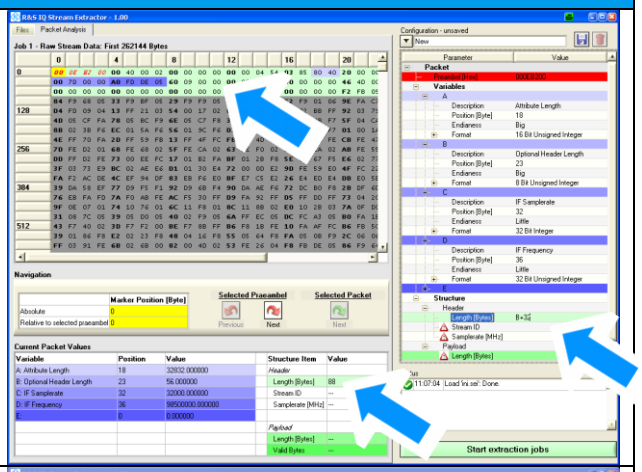
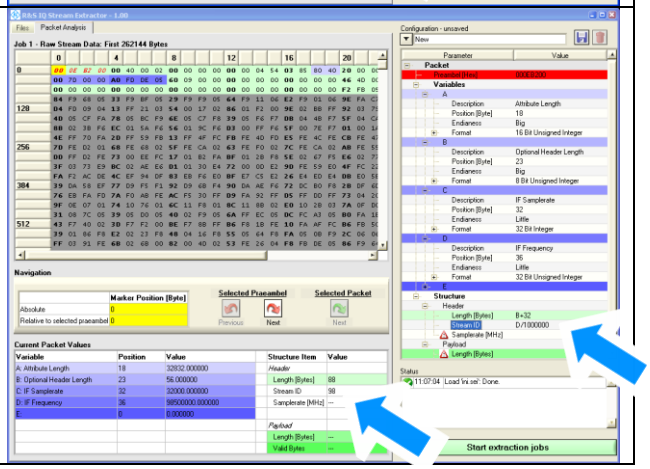
4.1 R&S IQ Stream Extractor

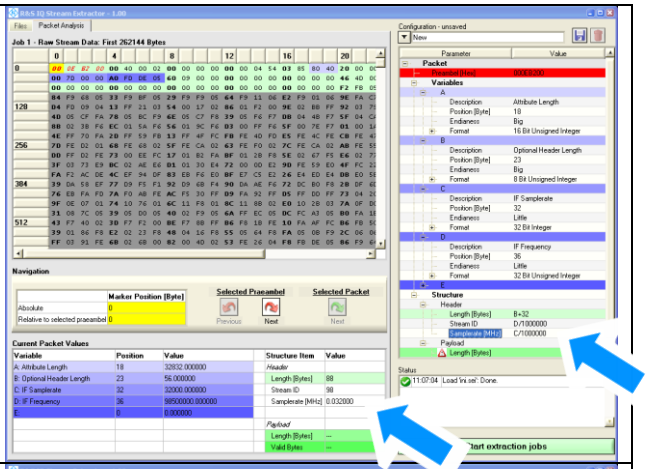
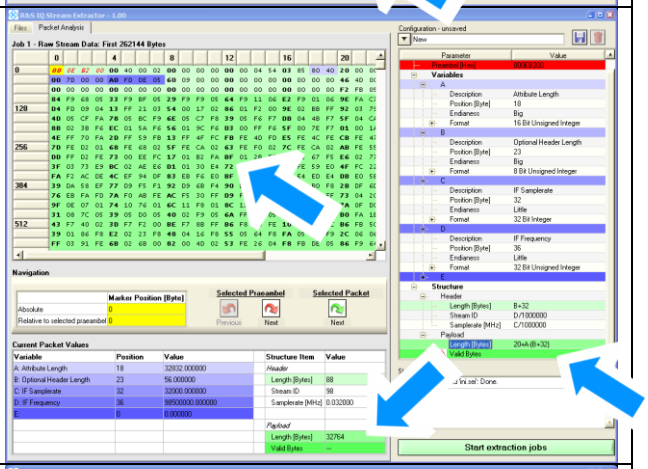
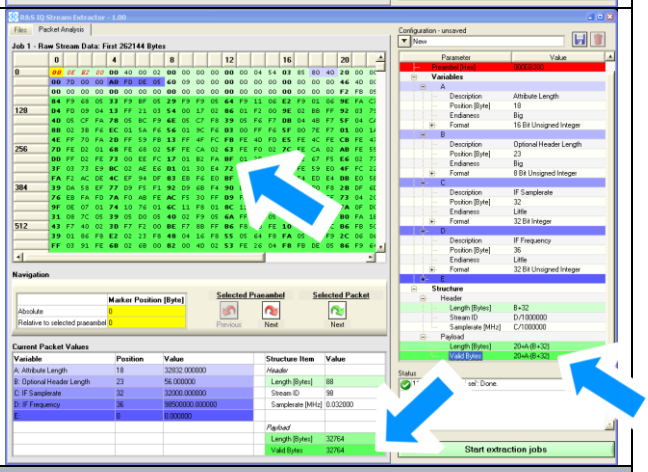
1	**Because the I/Q sample values from the R&S PR100 to be converted are available in packet-oriented form, R&S IQ Stream Extractor is launched first for preprocessing:**	
1a	Start R&S IQ Stream Extractor.	

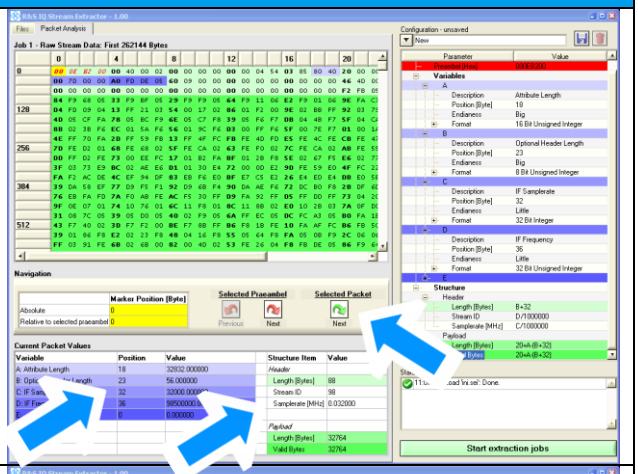
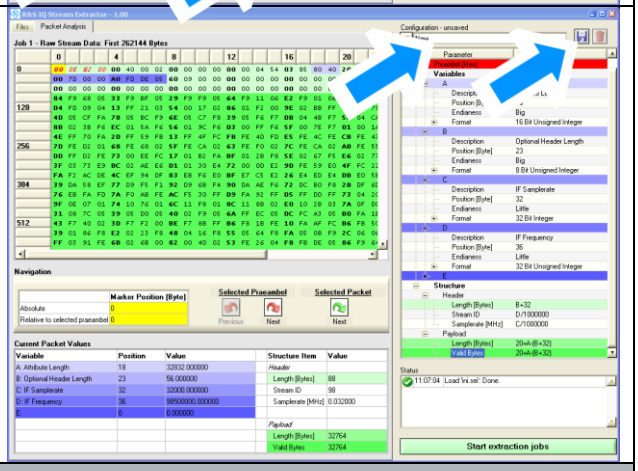
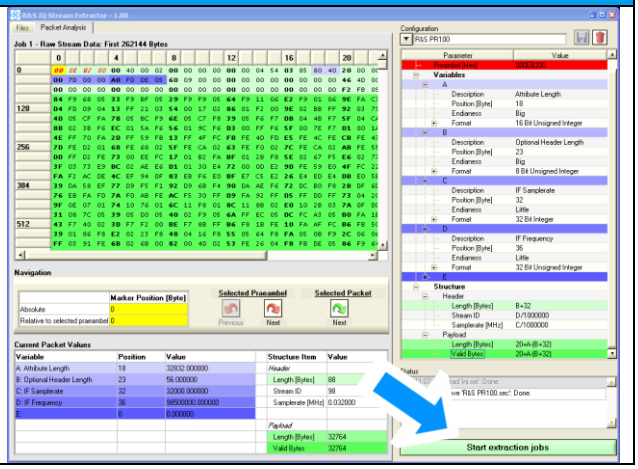
2	**Initially, the R&S PR100 streaming format is not known to R&S IQ Stream Extractor. Therefore, a configuration file must be created that describes the correct data processing for the program. For future conversions, the configuration file matching this input format is simply selected.** **To simplify creation of the configuration, the "R&S_(R)_PR100_StreamExample_V100.riq" file to be converted is added to the extraction list. The Packet Analysis view then become available based on the first entry in the list:**
2a	In the integrated File Browser, select "R&S_(R)_PR100_StreamExample_V100.riq".
2b	Double-click the file to add it to the job list.
2c	Click the "Packet Analysis" tab in the upper left-hand corner to switch to the Packet Analysis view.

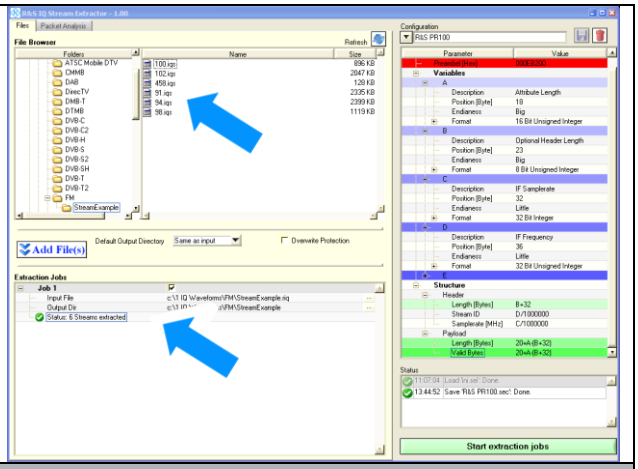
3	**Refer to the R&S PR100 manual for the description of the streaming format:** • **Preamble pattern: 000EB200** • **"Attribute Length" header information is associated with the total packet length** • **"Optional Header Length" header information supplies the header length** • **"IF Samplerate" header information corresponds to the I/Q sample rate** • **"IF Frequency" header information can serve as the stream ID** **=> Each of these available values should now be assigned a variable The format and position of these values are taken from their description in the manual**
3a	Set the "Preamble" configuration parameter to "000EB200". Note how the specified preamble pattern is automatically highlighted in red in the preview.
3b	Configuration of variable A: • Description = "Attribute Length" • Position = "18" • Endianess = "Big" • Format = "16 Bit Unsigned Integer" The specified variable position and length are automatically highlighted in light blue in the preview. The table below also displays the description and the current variable value "32832".
3c	Configuration of variable B: • Description = "Optional Header Length" • Position = "23" • Endianess = "Big" • Format = "8 Bit Unsigned Integer" The previews are updated again and display "56" as the current value.

3d	Configuration of variable C: • Description = "IF Samplerate" • Position = "32" • Endianess = "Little" • Format = "32 Bit Integer" The previews are updated again and display "32000" as the current value.	
3e	Configuration of variable D: • Description = "IF Frequency" • Position = "36" • Endianess = "Little" • Format = "32 Bit Unsigned Integer" The previews are updated again and display "98500000" as the current value.	

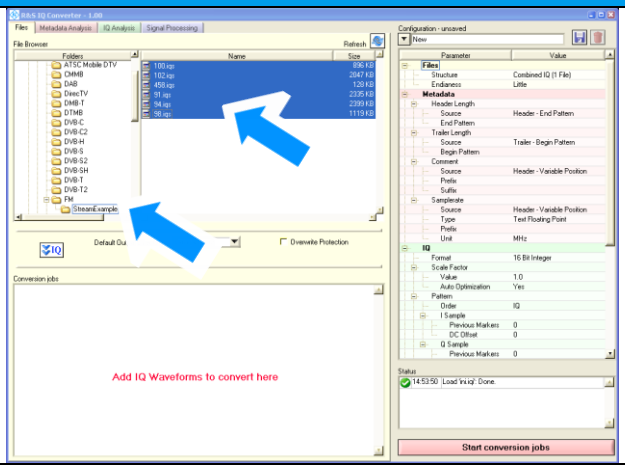
4	**The values calculated on the basis of the four variables do not directly match the packet attributes required by the program. Therefore, mathematical expressions must be derived:** • **"Header Length" can be calculated from the information provided in variable B ("Optional Header Length"). This is because the format description in the manual indicates that only a constant offset of 32 needs to be added. The calculation formula is therefore "B+32".** • **"Stream ID" is linked directly to variable D ("IF Frequency") because a change in the R&S PR100 receive frequency implies a new I/Q data stream. To improve readability, the value is converted from Hz to MHz ("D/1000000").** • **"Samplerate [MHz]" is calculated on the basis of variable C ("IF Samplerate"). Because variable C is also in Hz, it is similarly divided by 1000000 ("C/1000000").** • **"Payload Length" is governed primarily by variable A ("Attribute Length"): Adding the offset of 20 provides the total packet length. From this, only the header length (B+32) still needs to be subtracted: "A+20-(B+32)".** • **For the R&S PR100, "Valid bytes" always corresponds to "Payload Length": "A+20-(B+32)".**
4a	For "Header Length", enter the formula "B+32". The previews are updated again and display "88" as the current value.	
4b	For "Header Stream ID", enter the formula "D/1000000". This returns the current value "98".	

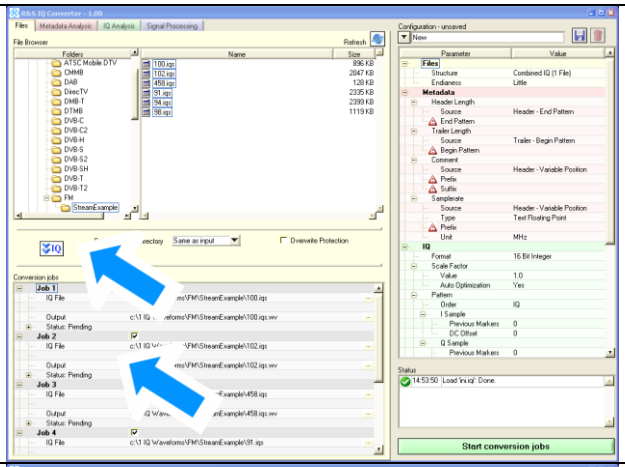
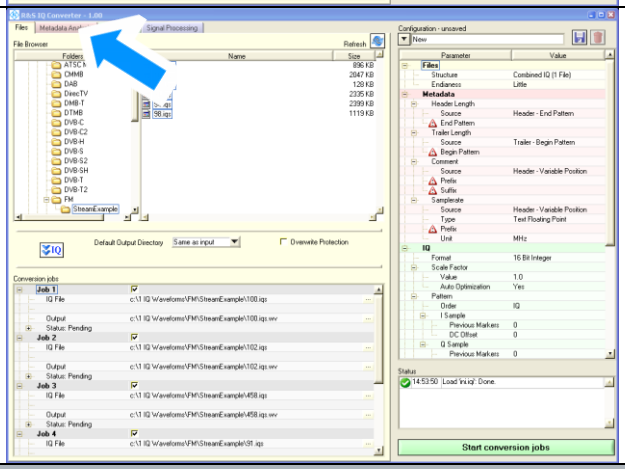
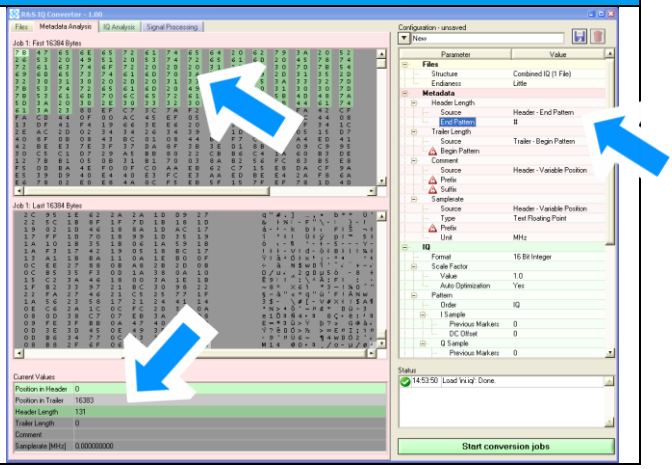
4c	For "Header Samplerate", enter the formula "C/1000000". This returns the current value "0.032".	
4d	For "Payload Length", enter the formula "A+20-(B+32)". The previews are updated again and display "32764" as the current value.	
4e	For "Valid bytes", enter the formula "A+20-(B+32)". The previews are updated again and display "32764" as the current value.	

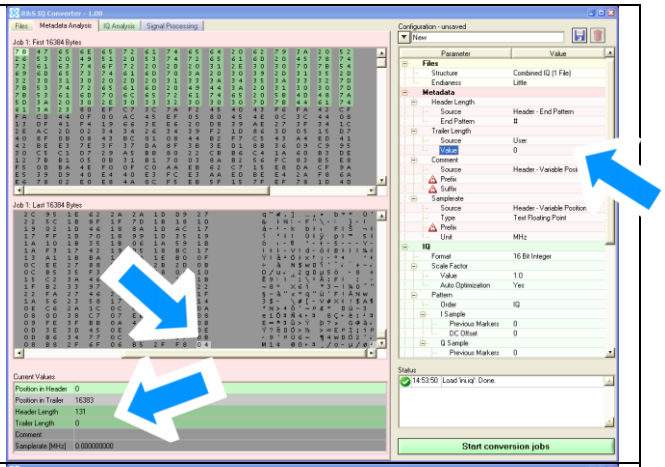
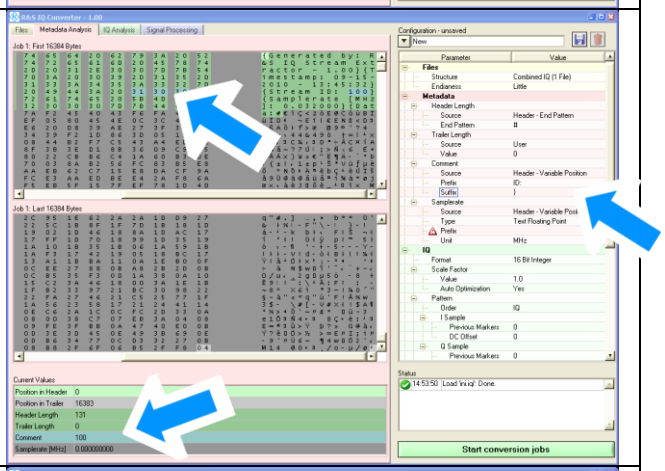
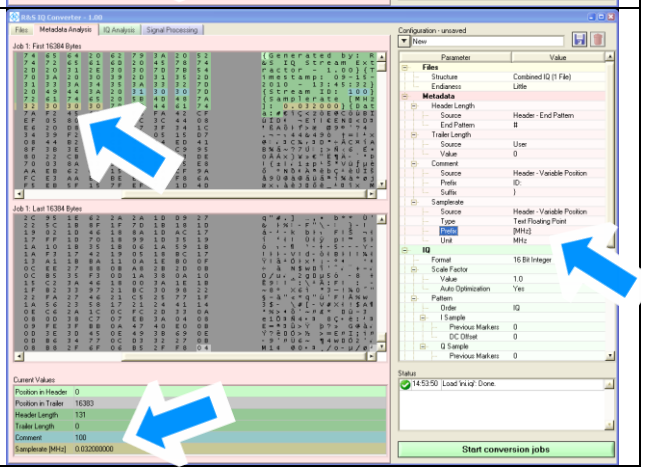
5	**After all configuration parameters have been entered, check to ensure that R&S IQ Stream Extractor is correctly interpreting the input file. The verified configuration is then named and saved.**
5a	If the packet structure is interpreted successfully, the "Selected Packet – Next" button in the navigation bar is enabled. Click the button, then check the lower table view (Current Packet Values) to verify that the values of the variables and their derived attributes have been correctly determined for the subsequent packets.
	
5b	Enter the configuration name R&S PR100" in the text field at the upper right-hand corner, then click the button with the diskette icon to save the configuration.
	
6	**Because the R&S PR100 input file "R&S_(R)_PR100_StreamExample_V100.riq" is present in the job list and a matching configuration is enabled, the actual extraction can now take place:**
6a	Click the "Start extraction jobs" button at the lower right.
	

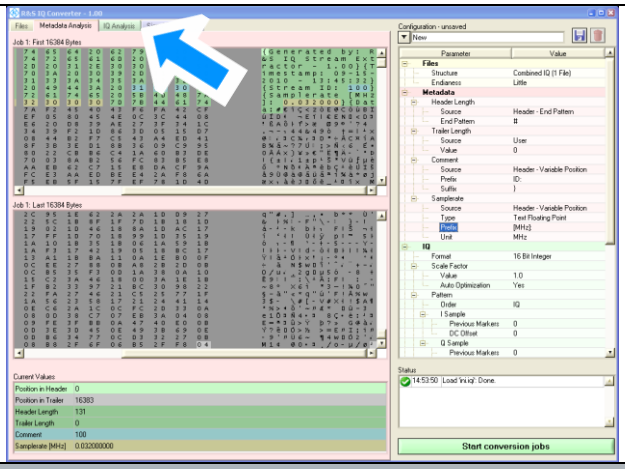
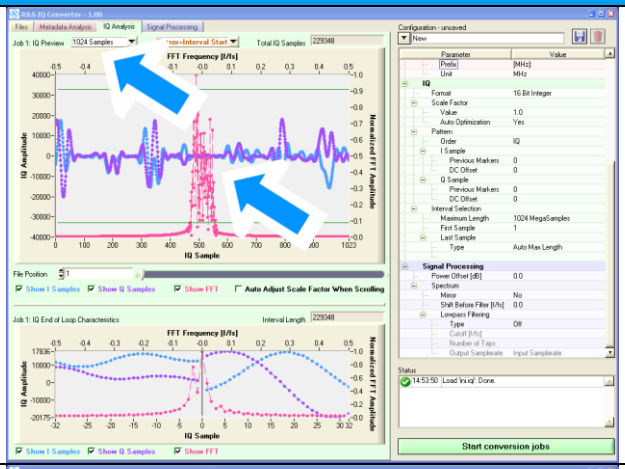
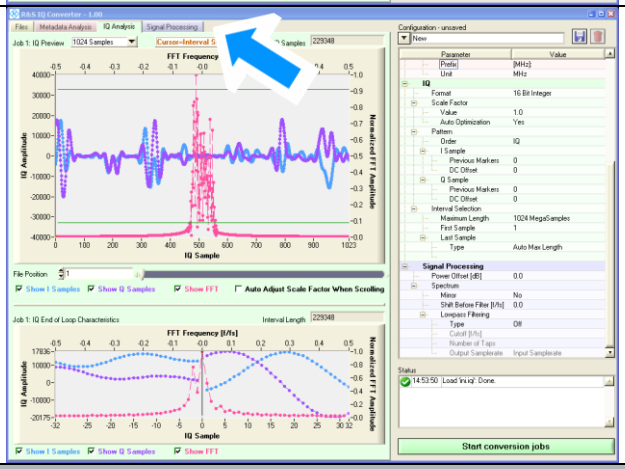
6b	After the extraction is completed, the status line for this entry in the job list indicates that six streams have been successfully extracted. The File Browser contains a new folder with the name of the input file ("\R&S_(R)_PR100_StreamExample_V100.riq\"), which in turn contains the six files, each named after the stream ID: • 100.iqs • 102.iqs • 458.iqs • 91.iqs • 94.iqs • 98.iqs	

4.2 R&S IQ Converter

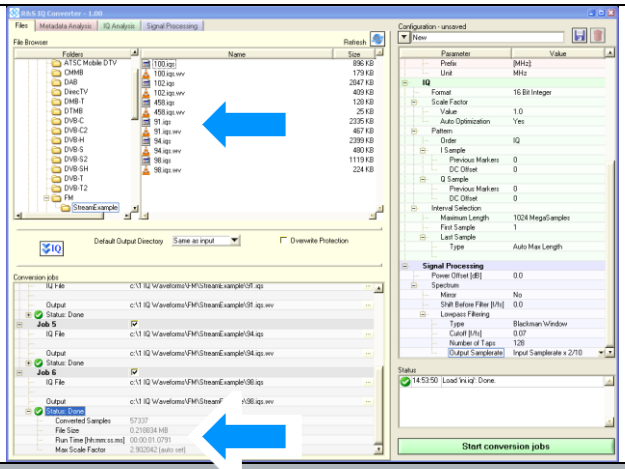
1	**Because R&S IQ Stream Extractor has split the individually recorded FM radio channels from the R&S PR100 into separate I/Q waveform files without a packet structure, R&S IQ Converter can be used to perform the actual conversion into the proprietary format for the R&S SFU, R&S SFE and R&S SFE100 signal generators.**	
1a	Start R&S IQ Converter.	
2	**Initially, the input format is not known to R&S IQ Converter. Therefore, a configuration file must be created that describes the correct data processing for the program. For future conversions, the configuration file matching this input format is simply selected.** **To simplify creation of the configuration, the files to be converted ("100.iqs" to "98.iqs") are added to the extraction list. The analysis views then become available based on the first entry in the list:**	
2a	In the integrated File Browser, select all files in the "\R&S_(R)_PR100_StreamExample_V100.riq\" folder.	

2b	Click the "Add IQ" button to add the selected files to the job list.	
2c	Click the "Metadata Analysis" tab in the upper left-hand corner to switch to the Metadata Analysis view.	
3	**The first configuration parameters to be defined tell the software how to handle the metadata; i.e., the header and trailer of the input files. In this case, this structure was generated by R&S IQ Stream Extractor. The header and trailer preview in R&S IQ Converter make the necessary settings easily recognizable:** • **"Header Length": This text header has a variable length and ends at "#"** • **"Trailer Length": No trailer is present** • **"Comment": The stream ID in the header can be used as the comment** • **"Samplerate": Is listed in the header text and can be extracted**	
3a	Configuration of "Header Length": • Source = "Header – End Pattern" Specifies that the mandatory value "Header Length" is defined based on the "End Pattern" information in the "Header" source. • End Pattern = "#" The resulting header length is then automatically highlighted in green in the preview. In the table at the bottom of the screen, the current value "131" is also displayed.	

3b	Configuration of "Trailer Length": • Source = "User" In contrast to the preceding header length configuration, no trailer is present here and information regarding its length can be extracted. Therefore, this value must be defined by the user. • Value = "0" This is also seen in the previews.	
3c	Configuration of "Comment": • Source = " Header – Variable Position" • Prefix = "ID: " • Suffix = "}" Analogous to the dynamic calculation of the header length, this configuration extracts the header text "Stream ID" as the comment. In both previews, the correct extraction of the comment can then be verified.	
3d	Configuration of "Samplerate": • Source = " Header – Variable Position" • Type = "Text Floating Point" • Prefix = "[MHz]: " • Unit = "MHz" Analogous to extraction of the comment.	

3f	Click the "IQ Analysis" tab in the upper left-hand corner to change to the IQ Analysis view.	
4	**The I/Q parameters are easily configured because the I/Q format of the R&S PR100 exactly matches the default settings in R&S IQ Converter. By increasing the number of sample values displayed in the preview, the level of detail for the displayed signal spectrum is increased.**	
4a	Set "IQ Samples for Preview" to "1024". In the IQ Preview, the correct interpretation of the I/Q sample values is seen in both the time domain and the frequency domain.	
4b	Click the "Signal Processing" tab in the upper left-hand corner to change to the Signal Processing view.	

5	**The signal processing functions are optional for the conversion process. However, because the frequency display in the IQ Preview already shows an unnecessarily memory-intensive oversampling, it makes sense to reduce the sample rate by using an appropriately dimensioned lowpass filter. This completes the configuration, which can now be saved:**
5a	Configuration of Lowpass Filtering: • Type = "Blackman Window" • Cutoff [f/fs] = "0.07" • Number of Taps = "128" • Output Samplerate = "Input Samplerate x 2/10)" These values can also be determined experimentally thanks to the detailed preview.
5b	Enter the configuration name "R&S PR100 - FM filtered" in the text field at the upper right-hand corner, then click the button with the diskette icon to save the configuration.
6	**Because the files to be converted are present in the job list and a matching configuration is enabled, the actual processing can now start:**
6a	Click the "Start conversion jobs" button at the lower right.

6b	After all conversions have been completed, the results are displayed in the File Browser: • 100.iqs.wv • 102.iqs.wv • 458.iqs.wv • 91.iqs.wv • 94.iqs.wv • 98.iqs.wv The selected filtering and associated sample rate reduced the space requirements by 80 %.	

The converted I/Q waveform files can now be replayed using the ARB function offered by the R&S SFU, R&S SFE and R&S SFE100 signal generators:

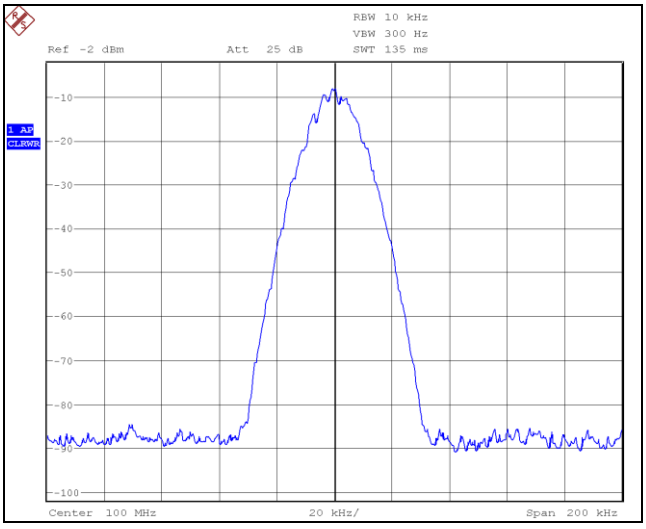


Fig. 12: Spectrum of "100.iqs.wv" waveform after reconstruction by the R&S SFU.

5 Frequently Asked Questions

5.1 General

Why are no floppy/network drives displayed in the File Browser?
For reasons of performance, the I/Q waveform files should be stored locally.

Why is my USB stick not displayed in the File Browser?
USB sticks inserted while the program is running are not recognized. Exit the program and launch it again.

How can I remove a conversion job from the list?
Click the checkbox to the right of the job number:

Where can I get software updates and example configurations?
Refer to chapter 7 for further information.

I created several configurations. How can I use these on other PCs?
Every configuration is saved in the installation directory in a separate file under its configuration name. Simply copy these files to the installation directory on the other PC. When the program is launched, all configurations stored in this location are recognized.

A configuration entry is marked as incorrect. Why isn't there a context-sensitive tooltip providing an explanation?
The context-sensitive tooltip appears only when the field isn't being edited. Press the "Enter" key to exit the input mode for that field.

5.2 R&S IQ Converter

5.2.1 Analysis

Why can't I find an I/Q waveform in the file, even though I tried all I/Q format options?
If more than one byte is used for each sample value in the I/Q waveform, then the selected header length as well as the selected I/Q format will make a difference. Increase the header length in 1 byte increments until the start of the I/Q data range matches the start of a sample value.

I have a file with I/Q sample values in text format. Why can't I use some of the program functions?
Unfortunately, these types of files cannot be navigated efficiently and cleanly at the same time. It is therefore recommended that you first convert the file to the binary Rohde & Schwarz format with less functionality, and then reopen the results with all remaining functions available, including the I/Q interval selection function.

How do I activate the "Interval Stop" cursor?
This is available only for binary I/Q formats. Set the IQ:Interval Selection:Last Sample to "User" and then select the "Interval Stop" cursor above the IQ Preview graph. Please note that the cursor becomes transparent when passed over invalid positions.

Why is the displayed stopband attenuation lower when I increase the number of taps for the lowpass filter?
A higher number of taps leads to an increased stopband attenuation. If this is not displayed correctly, the number of I/Q sample values used for the preview will be lower than the number of taps. To correct the display, select at least 1024 sample values in the IQ Analysis view:

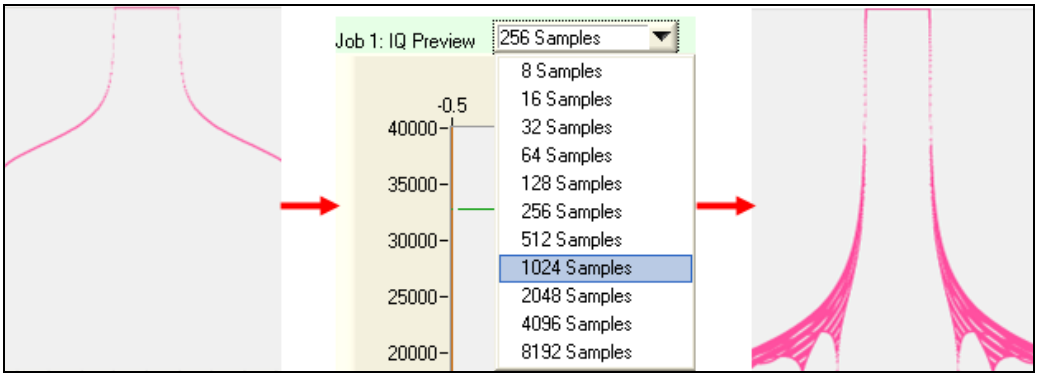


Fig. 13: Effect of the number of I/Q samples used for preview on the filter display.

5.2.2 Conversion

Why doesn't the conversion work?
This can have a number of different causes:

- The current configuration doesn't match the input file. To obtain details, go to the job list and delete all entries above this job so that the problematic file is first in the list to be analyzed. View the tooltips for the invalid configuration parameters to resolve the problem.

- An output file with the same name already exists, and overwrite protection is active. Deactivate write protection.

- The scale factor was defined manually and is too small or too large. Use the recommended scale factor, or activate the IQ:Scale Factor:Auto Optimization function.

Why do extra glitches appear in the spectrum when the I/Q waveform is played?
If the waveform generator reaches the end of the waveform during playback, the playback will automatically continue at the start of the I/Q waveform. If the sample values at the start of the I/Q waveform don't follow the signal trace described by the end of the I/Q waveform, the discontinuity will cause glitches in the spectrum. Optimize using the Seamless Loop preview in the IQ View.

Why does the conversion take so long?
Two conversion settings will affect the conversion speed significantly:

1. If IQ:Scale Factor:Auto Optimization is enabled, the conversion will take twice as long because the optimum scale factor is additionally being calculated on the basis of all sample values. If the value range for the I/Q waveform is already known, the optimum scale factor can be set manually, thus cutting the conversion time in half.

2. If a lowpass filter was enabled for channel selection, the conversion time will increase in direct proportion to the number of selected filter taps. This means that a filtering with 100 taps will take approximately one-tenth the time of 1000 taps – even though it will be at the cost of the filter quality.

Why were fewer I/Q sample values written than were selected for conversion?
If a lowpass filter was enabled in combination with the resampling function, the number of I/Q sample values will be reduced by the resampling factor.

Can the conversion results also be played back on other R&S signal generators?
This is possible with the following instruments, although there is also dedicated software available [2]:

- R&S®SMU200A
- R&S®SMJ100A
- R&S®SMATE200A
- R&S®AFQ100A
- R&S®AFQ100B
- R&S®SMBV100A

However in doing so, the following limitations apply:

- For some instruments, their ARB’s full digital bandwidth of up to 600 MHz cannot be used, due to the R&S IQ Converter’s sample rate limitation to 100 MHz.

6 References

[1] "Generating Interference Signals Using the R&S SFU-K37 Option" Application Note 7BM50_1E, Rohde & Schwarz

[2] "Importing Data in ARB, Custom Digital Modulation and RF List Mode" Application Note 1GP62_2E, Rohde & Schwarz

7 Additional Information

Our application notes are regularly revised and updated. Check for any changes at http://www.rohde-schwarz.com ➔ Downloads ➔ Application Notes ➔ 7BM79. Here you will also find software updates and example configuration files.

Please send any comments and suggestions about this application note to Broadcasting-TM-Applications@rohde-schwarz.com.

8 Ordering Information

Designation	Type	Order No.
R&S BTC		
Broadcast Test Center	R&S BTC	2114.3000.02
Arbitrary Waveform Generator	R&S BTC-K35	2114.3700.02
R&S CLG		
Cable Load Generator	R&S CLG	2116.9170.02
R&S SLG		
Satellite Load Generator	R&S SLG	2116.9193.02
R&S SFU		
Broadcast Test System	R&S SFU	2110.2500.02
ARB Generator	R&S SFU-K35	2110.7601.02
Memory Extension 1	R&S SFU-B3	2110.7447.02
R&S SFE		
Broadcast Tester	R&S SFE	2112.4300.02
ARB Waveform Generator	R&S SFE-K35	2113.4932.02
Memory Expansion	R&S SFE-B3	2112.4500.02
R&S SFE100		
Test Transmitter, Model .02 or Model .03	R&S SFE100	2112.4100.XX
ARB Waveform Generator	R&S SFE100-K35	2113.4926.02
Memory Extension	R&S SFE100-B3	2112.4400.02

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