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White Paper

Fundamentals of using an RF capture/replay analyzer in design verification

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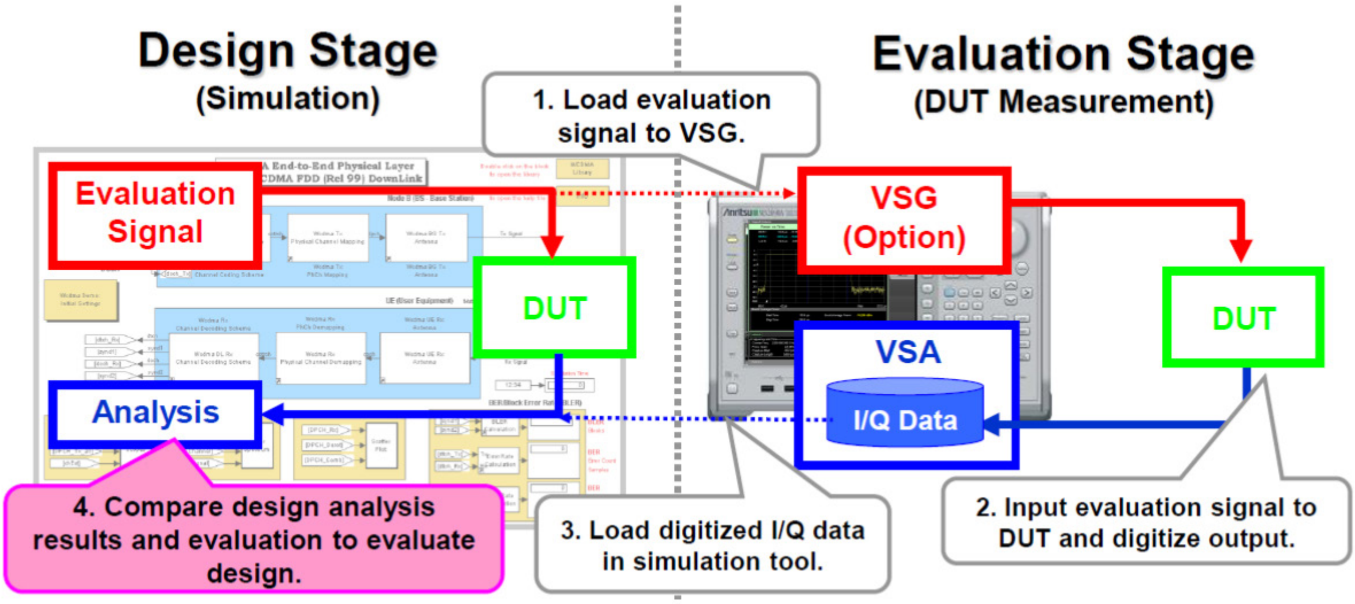
Technical trends in device and system characterization

Modern development techniques exploit computer modelling and simulation for improving the time and efficiency of developing new RF circuits. Of course the final proof of the modelling comes from measured results on a real world device developed according to the modelling techniques. Thus the integration of modelling with real world signal generation and analysis has become an important trend. This is the generate-analyze method where the required signal is first generated in a simulation and replayed out via a real signal generator, then the resulting signals from the device under test is captured by the signal analyzer and compared to the theoretical predications of the simulations.

Also of growing interest is the scenario where a very complex "real world" RF environment needs to be captured and replayed under repeatable laboratory conditions, for testing against different design parameters. This is the classical capture-replay method, where the signal analyzer is used to capture the real RF environment and then this is analysed to verify the required test characteristics are present in the captured signal. Once captured then, this signal is then replayed from the signal generator to recreate the real RF environment in the laboratory for testing and reference purposes. A typical application here is where harsh RF noise environments occur, as they are often very complex to simulate with enough statistical accuracy and real world capture is far more accurate.

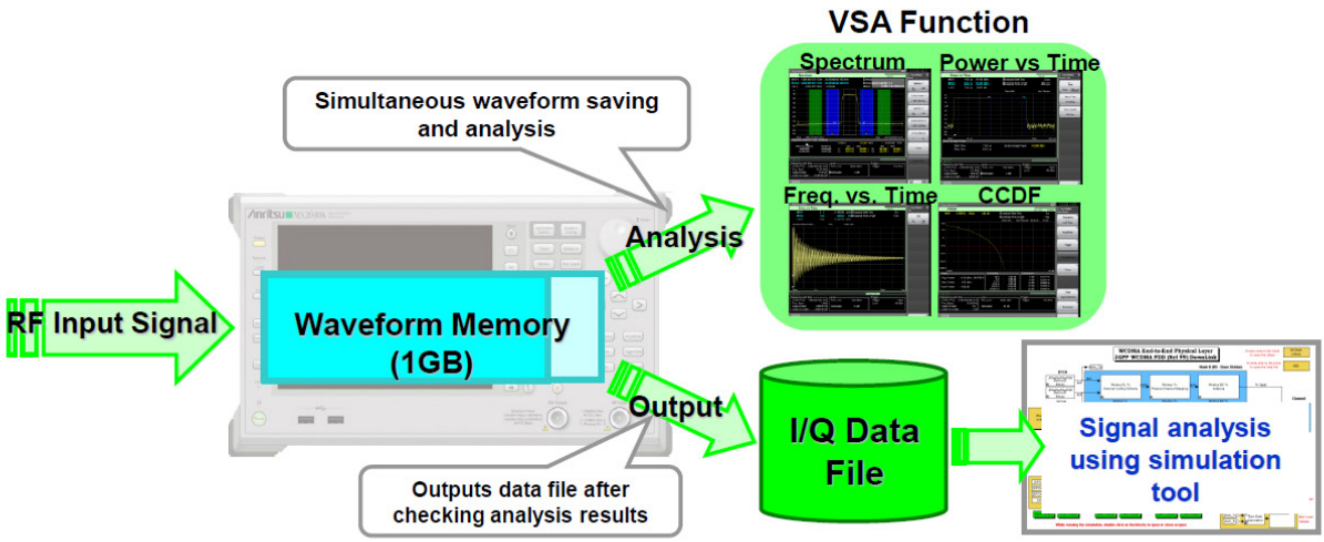


Principles and operation for signal capture/replay.

The first part of the system is the RF signal capture stage, with digital sampling capability and extraction into vector IQ file format for storage of the captured signal. The second part is the RF signal replay stage, with memory recall/replay and vector modulator to re-create the captured signal. The second part also has an RF output stage to output at the required frequency and power level.

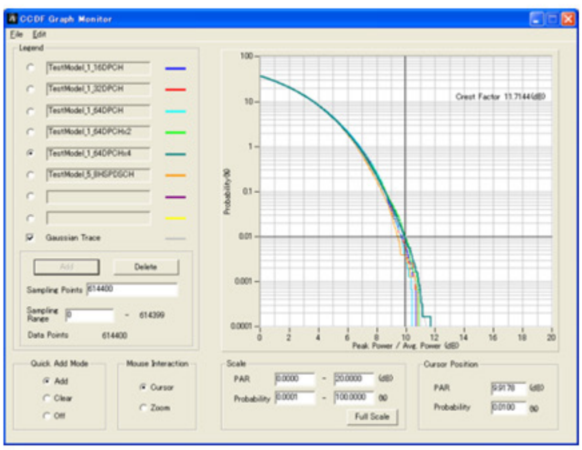
Available options to implement a system are based on either a custom solution developed specifically for the application, or a flexible solution based on generic instruments/modules. Custom system solutions are usually fixed/optimised in terms of RF sampling and RF output stages, and customised to the required frequency and power levels. Flexible solutions are normally using dynamic RF capture and RF output stages (frequency and power level). These are generally based on spectrum analyzer and vector signal generator, with standard instruments giving full flexibility in RF stages, using heterodyne mixers/oscillators and attenuators. The downside of standard instruments is of course they may not be optimised in RF capability to the required application.

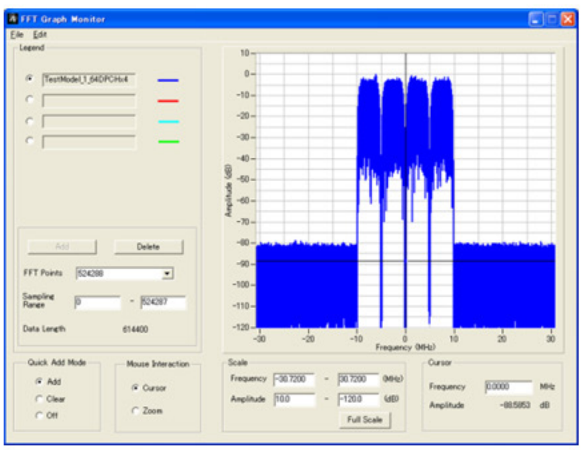
The basic concept of signal capture with a spectrum analyzer is to use the flexibility of the RF front end to provide a highly configurable RF capture capability, and to combine this with the digitising and vector IQ sampling capability that is used in a modern vector signal analyzer. The vector IQ sampling captures both the phase and amplitude information of the signal. The analyzer then needs an additional capture-storage stage that allows the data to be stored in a suitable permanent medium (e.g. internal hard drive, external server etc). Finally, the analyzer may also have the appropriate signal analysis software that allows the captured data to be analysed and specific characteristics measured on captured signals (e.g. occupied bandwidth, spurious emissions, EVM/frequency error), and this may support both the analysis of the current captured data, and also the analysis of previously captured/stored data that is replayed back to the analyzer for post-processing.



The basic concept of the signal replay is based around the Arbitrary Waveform Generator (AWG) technology. This uses a digital memory to store a vector IQ waveform, and then the waveform is replayed from memory into a vector modulator that creates the waveform in a "real world" analogue format. With the data being in vector IQ format, then both the phase and amplitude of the signal are re-created accurately. The recreated analogue signal is then passed to the RF front end that outputs the signal at the required RF frequency and power level for the application. Vector signal generators usually have a very flexible RF front end to support a wide range of frequency/power levels.

The vector signal generator may also provide software with the capability to analyse the vector IQ data using Fourier analysis, showing CCDF, FFT and Time domain view of sampled/created waveforms. This allows the user to understand key parameters such as crest factor and PAPR, to optimise the setting of the RF parameters to match the waveform. In addition, the waveform can usually be output from the IQ vector modulator as a baseband IQ signal (without conversion to RF), and usually has an IQ analogue input that allows real time IQ baseband data streams to be directly applied to the RF front end.





Understanding the key specifications, and limitations of different solutions.

(1) Time length of Capture on SA and Re-create on SG

This is the fundamental memory size restriction, in terms of size of file that can be stored or replayed. A key factor here is that the type of memory used must be fast enough to allow storage or retrieval of data fast enough for the maximum sampling rate. Normally this requires high speed solid state memory, and network or mechanical disk are not usually able to meet the required rates. The time length possible for the system is a function of the memory size and the sampling rate used, sampling rate being dependent on the bandwidth of the signal being captured. The A/D-converted digital IF signal is resolved into the I-Q components (In-phase/Quadrature-phase) after waveform correction, etc., and is stored in memory following various procedures such as decimation, floating point data processing, etc.

Rather than capturing signal amplitude (scalar waveform sample), resolving into I-Q data and storage saves the signal phase data as vectors to enable Fourier analysis after digital modulation. The cumulative time range (capture time) can be saved to memory as data counts (samples) allocated by capture period (sampling rate). In an actual signal analyzer, the standard memory capacity is typically 1 Gbyte, supporting a maximum data storage capacity of about 100 M samples per measurement. The sampling rate is limited by the frequency span of an FFT analysis, but in a signal analyzer the sampling rate is selected automatically by setting the analysis frequency span. Consequently, there is no necessity to calculate required sampling rate when it is set automatically. The maximum capture time and maximum sample counts are decided at the same time as the sampling rate, but usually rather than capturing the maximum sample count, the optimum sample count is set for the measurement conditions.

Figure below lists the sampling rates for the set frequency span and the relationship between the maximum capture time and maximum sample count.

Freq Span	Sample Rate	Capture Time	Max Sample Count
1kHz	2kHz	2000s	4M
10kHz	20kHz	2000s	40M
100kHz	200kHz	500s	100M
1MHz	2MHz	50s	100M
10MHz	20MHz	5s	100M
31.25MHz	50MHz	2s	100M

(2) Analysis bandwidth/Frequency Span

The analysis bandwidth must be set correctly with respect to the maximum bandwidth of signal to be captured [according to standard sampling theory] for accurate capture/replay. Wider bandwidth requires more memory to store the same capture length, and so bandwidth and capture time are both directly traded off within the constraint of the available memory size. Of course the frequency span of the generator must match or exceed the span of the analyzer, to ensure accurate replay of signals. The read data is FFT (Fast Fourier Transform) processed to generate the spectrum for the relevant time range. Similarly, processing with other parameters can also generate other signal displays, such as Power vs Time, etc.

The spectrum obtained by FFT processing is a sequence of amplitude values for discrete frequency points. In addition, the frequency span obtained by FFT depends on the sampling frequency while the frequency gap between discrete frequency points (frequency resolution) is inversely proportional to the number of data points (sample count). Consequently, the data used for FFT is digitized at the sampling rate that satisfies the frequency span for spectrum display while also assuring a sample count supporting the frequency resolution. Put another way, the data for FFT must be digitized using the "sampling frequency" and "sample count" that achieves the expected "frequency span (frequency range)" and "resolution" at spectrum display. Incidentally, in a spectrum analyzer, the frequency resolution is evaluated as the RBW (Resolution Bandwidth); the time required for measurement, or the sweep time, is determined by the RBW and frequency span.

A signal analyzer emulates the usability of a spectrum analyzer and uses the same concept of RBW as a spectrum analyzer to improve the consistency of data measured using a spectrum analyzer. To start with, the sampling rate and data length required for FFT processing supporting the frequency span and RBW settings are set automatically. Additionally, the RBW corresponding to the frequency span can be set automatically. At this time, in the same way as a spectrum analyzer, the measurement time increases because the number of calculations increases as the RBW becomes smaller (frequency resolution increases). An FFT processes the time range to be analysed as one continuous time period and performs the same continuous process on the signals before and after (the time range to be sampled). As a result, a difference in the values near both sides of the analysis time range (i.e just before or after the analysed sample) causes an error in which the spectrum appears to widen, etc. To prevent this, the signal analyzer uses the standard method of performing a window function processing using a Gaussian window. This modifies the data value before and after the required sample time to provide a smooth data set, but of course this requires there to be data before and after the analysis time range. As a result, the data length used for the analysis calculations (I-Q data length) becomes longer than the target analysis time (width). This also happens with non-FFT analysis (trace) modes, For example, Power vs Time plots require data before and after the analysis time length to perform processing for the detection and moving average, and for the spectrogram window function and detection. The length of the required before and after data differs with the trace type and the marker measurement result read accuracy setting (Marker Result). Usually, the minimum data length required to capture the results as quickly as possible is set automatically, taking account of the size of the windowing data that I required.

(3) Dynamic range (ADC, RF performance)

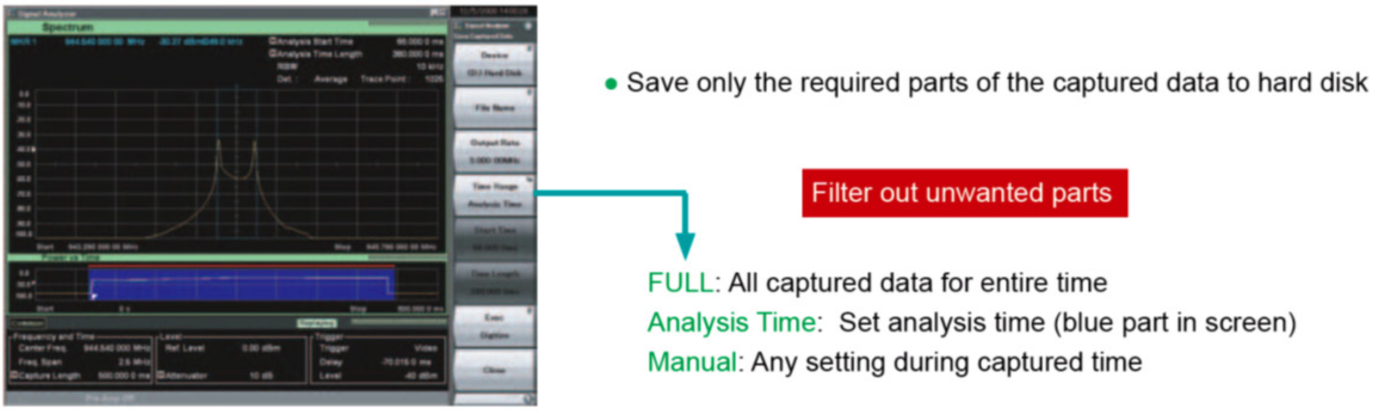
The dynamic range capability determines the level accuracy to which the signal is captured and replayed. On both the capture and replay sides it is primarily limited by the accuracy of the analogue-digital conversion process (ADC or DAC). It is then further affected by the accuracy/stability of the RF stages (level accuracy and stability from RF converters, amplifiers and attenuators). In an actual analyzer, an attenuator (signal attenuator) and preamplifier in the input section assure the correct measured signal level is input to the analyzer, either amplifying or attenuating the signal as appropriate to match the desired input signal power range. At frequency conversion, although it is possible to obtain the IF signal using a single conversion, in measuring instruments, the final IF signal is obtained using multiple frequency conversions rather than a single conversion. This gives better linearity and stability across a wide range of frequencies. In addition, if the frequency of the signal to be measured is higher than the instrument maximum signal frequency, sometimes a frequency converter is used at the input stage to down-convert to the instrument measurement frequency. The signal path until frequency conversion is the same in a signal analyzer and spectrum analyzer, and the items to consider are the same. Noise and non-linearity generated in the analogue section from input to IF conversion is added to the measured value and is part of an analyzer's basic performance. Consequently, high-level analogue circuit technology is essential when handling very small high-frequency signals.

Four key hints and tips to optimize measurement capability

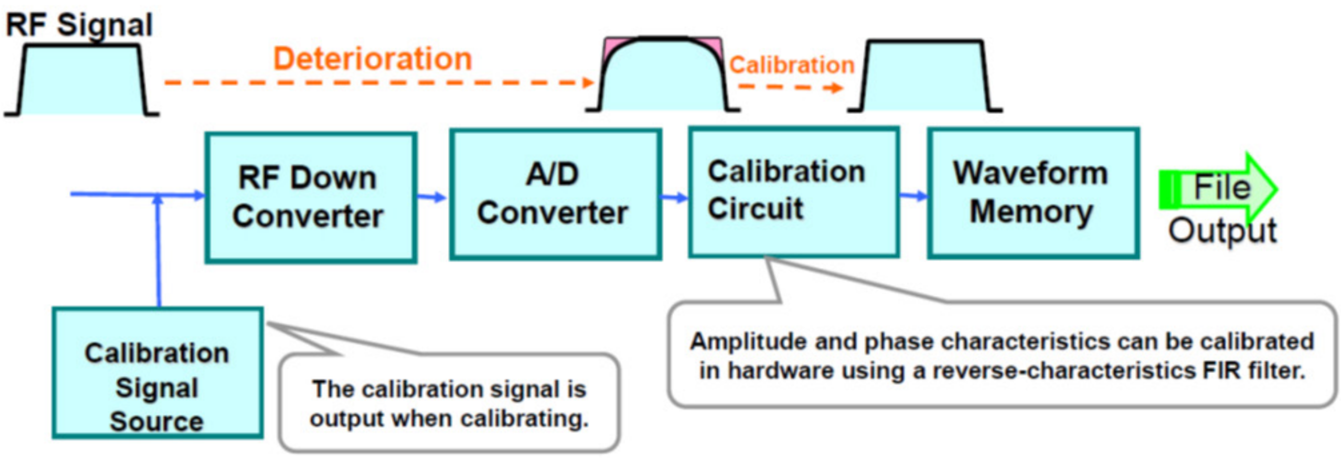
File storage and conversion process should be matched to the type of data to be captured. If the data is a short burst (i.e. fitting the sample rate / capture time chart above) then internal memory can be used for storage, and this will usually be fully integrated with the conversion process to IQ data format. If a longer time capture is required, then an analyzer with a high speed external data streaming capability is required, to ensure the data can be saved onto an external drive (e.g. 1Tbyte S-ATA drive, 64GB external RAM drive). For this solution, the physical hardware port of the captured data (e.g. 10GbE Ethernet port) should be compatible with the drive storage interface.

Sampling rate matching for accurate replay. As noted above, the sample rate can be set automatically with a signal analyzer, to match the bandwidth settings of the instrument. If this mode is used then normally the signal will be properly sampled. If the bandwidth or sampling rate is set manually, then caution should be taken to ensure the sampling rate is matched to the frequency span of the required signal. Also, if the input signal contains higher frequencies than those intended for sampling, then without correct anti-aliasing filters then these can produce "artefacts" in the sampled signal that are false data coming from the higher frequencies. The use of an FFT based vector signal analyzer usually accounts for this, and should be the preferred solution.

Noise application for the capture "random" signals and filter the result to replay desired components can be very difficult. If a basic modelling or simulation tool is used to create a complex real world noise or interference environment, it can be a very difficult task (and sometimes impossible) to create a noise like signal that is complex and representative enough to use for finding possible problems with sensitive receiver circuits. In this case, it is recommended to use an RF capture process as described above to capture a sample of real word noise in the relevant environment. This can then be replayed in the lab and used for testing, having a more representative signal than a basic modelling tool can provide. Using the frequency selective filtering of a signal analyzer RF front end, it is then possible to isolate and save specific noise components (frequencies) of particular interest for specific tests.



Calibration of the RF signal capture circuits is essential for accurate data. It goes without saying that errors in the RF capture circuits will directly lead to errors in the captured data record, and hence the replayed signal or data analysis. So it is essential that the RF capture circuits have an effective calibration circuit. Many standard spectrum analyzers have a 50 MHz reference signal that is applied to the RF down converter and then measured after the A/D converter, and errors can be corrected. Although this does give good general drift stability, it does not provide accurate calibration across the frequency band that is being sampled, and errors due to the bandwidth and frequency variation versus the 50MHz reference will be incurred in the measured data. The Anritsu MS2830A and MS2690A series use a unique "full band" calibration circuit that characterises the down converter and AD converter across full band (to 4 or 6 GHz) and then applies a correction in real time to the actual data by using a reverse FIR (Finite Impulse Response) filter. This effectively cancels out all errors in the RF circuits and ADC, to produce a clean and corrected set of sample data.



Specifications are subject to change without notice.

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