Configurable Signal Analysis

James Zhuge, Crystal Instruments, Santa Clara, California

Configurable signal analysis (CSA) is a new concept introduced and adopted by Crystal Instruments in its newest generation of dynamic signal analyzer systems including the CoCo-80. It allows the user to dynamically configure digital signal processing (DSP) functions so the data processing flow can be adjusted from application to application. The result is that a portable, handheld signal analyzer can be customized to include specialized, powerful functions while maintaining a very clean and simple user interface for day-to-day operations. CSA is a unique feature that is currently available only in products such as the CoCo-80/90 dynamic signal analyzer from Crystal Instruments.

Traditionally, dynamic measurement instruments could only realize fixed data analysis functions. These functions were configured by the manufacturer before the products were shipped to the user. While the user could change some of the parameters in the preset algorithms, they usually had little control over the data processing flow and the sequence of the applied math functions. With such a design philosophy, the user interface of dynamic measurement systems tended to grow more and more complicated as more and more functions were added to meet all the specialized needs of different users. Important customers had to wait for the next version for their special request to be adopted by the vendor, and small customers had little chance of getting their unique needs met if the function was not widely used.

The new CSA concept completely changes this paradigm. It is designed to keep the user interface very simple while letting users customize the analysis functions either on their own or with the assistance of Crystal Instruments support.

Contrary to the traditional approach, CSA is user customizable. With CSA, the user can flexibly apply various math operations to live data streams without changing the installed program. The processing algorithm is a combination of user-customizable math functions. Most of these algorithms are fairly simple, such as add, subtract, multiply and divide operations. Some others are very sophisticated, such as calculating frequency response functions (FRFs) between all the channels. Users can choose and apply the analysis functions that they like or combine them to meet particular needs. The user can also cascade these algorithms in sequence, combining several functions to generate a very advanced new function. With this approach, CoCo DSP systems are enabled with "unlimited" application functionality.

CSA is implemented by creating a "CSA script," which is like a computer program, except that the interface is graphical instead of traditional line code. The graphical interface makes developing the CSA script very simple and intuitive. CSA scripts are written in extended markup language (XML). A script body usually consists of version information, parameters used by CSA math modules and several CSA math modules.

Many traditional signal analyzers do provide "signal calculators" or "math functions" that the user can define. However, the concept of CSA is much more than this and has several advantages over these traditional signal math calculators:

- CSA applies not only to the block-based signals but also to continuous data streams. You can save and analyze the resulting data streams the same way you do the original input signals.
- CSA comes with algorithm-dependent parameter setup schemes. In the traditional signal math calculators, for example, it is difficult to associate analysis parameters to the algorithms. CSA allows the user to define analysis parameters so that you do not need to define these every time you use the function.
- The CSA configuration includes a user-interactive verification process. It downloads control logic code to DSP and tests the memory and computational resources to be used by the DSP. This ensures that the CSA script will function and that no logical errors are included in the script.

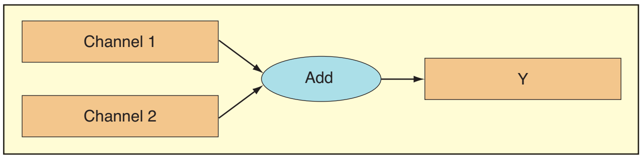


Figure 1. Example of math operation with two inputs and one output.

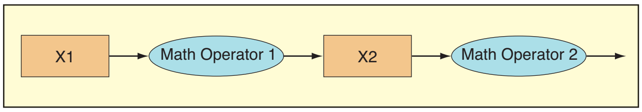


Figure 2. Cascaded math operators.

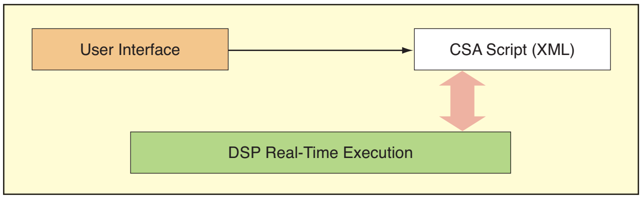


Figure 3. The CSA script is automatically interpreted by the software into DSP code.

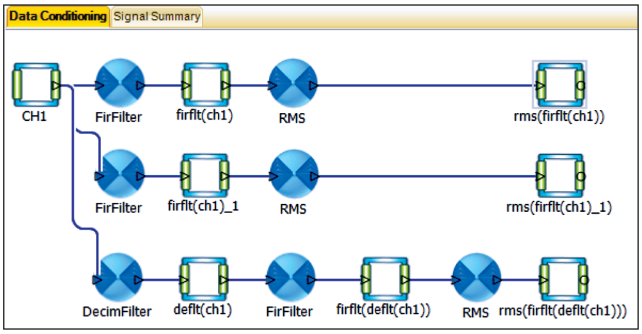


Figure 4 Block diagram of CSA of multiband filter.

CSA Implemented at the DSP Level

In the past, most signal analysis algorithms were based on data block processing. These data blocks were usually described as a matrix or a vector. This model creates a particular challenge when processing is required to apply to continuous data streams. Complicated control logic such as "while-if-then" loops had to be used. While manufacturers such as LabView from National Instruments and MATLAB® from MathWorks offer the capability to do this, it requires advanced programming skills, and the code was difficult to read and maintain. In CSA, the concept of *data blocks* is extended to what is called *data streams*. The stream describes a data buffer that has its content updated partially at one time. This model provides an easy way of handling the streaming data and enables engineers, system integrators or users to apply various mathematical functions to live data efficiently.

A data stream can be represented in a diagram using a square block to represent the stream object such as a real-time stream, an oval to represent a math operator and arrows to show the data flow. Figure 1 shows an example where two streams are the input to a math operator, and the output is a single stream. For example, this function could simply add Channel 1 TO Channel 2 to compute the output. Math operators can be cascaded (see Figure 2). For example, a time stream can first go through a band-pass filter, then an RMS detector to measure the energy over a particular frequency band.

The CSA script controls the math elements and input and output streams that are available. During run time, the software interprets the script and translates it into data flow and control logic as shown in Figure 3. While the user need only view the graphical interface that shows the CSA definition, the software automatically interprets the logic and generates the low-level code that is implemented on the DSP level. All this is performed behind the scenes, making implementation very simple for the user. The software also uses the CSA script to handle the stream allocation, de-allocation, math operation, priority, storage and display.

The DSP creates many threads of operation to look at the priority and conditions of each math operator. This is called event-driven operation. A math building block is executed when this math building block is at high priority and its input buffers are full. The execution sequence is managed by a specially developed task manager.

CSA Editor

Customization of a CSA script is done within the CSA editor that is integrated into the Crystal Instruments EDM (engineering data management) software. The CSA editor uses an intuitive drag-and-drop graphic language that makes configuring the CSA an easy-to-learn visual process.

In one example, the user may want to know the energy distributed in different frequency bands. With CSA, the data flow can be structured so that the signal coming from the native channel (Ch1) is split into multiple streams. A digital band-pass filter is applied to each stream. After the band-pass filter, an RMS estimator is applied. The user can then store the time streams coming out of each RMS estimator. The flowchart in the CSA editor is shown in Figure 4. Notice that the last path has a decimation filter (DecimFilter) before the FIR filter. This allows RMS calculation for low-frequency data over a long period.

This example shows that CSA allows the user unprecedented flexibility and unlimited variation of analysis algorithms. Of course, to produce effective analysis results with CSA, more experienced skills and knowledge of signal processing is required. This can be done by the end user, and CI engineers provide a paid service to do this task for customers. Two applications are described below that show the advantage of the CSA concept combined with the flexibility and portability of the CoCo-80 analyzer.

MD80 Aircraft Engine Vibration Monitoring

In the application shown in Figure 5, an aircraft engine test requires RPM and vibration measurements at different locations on the engine. In addition, the test requires that a velocity sensor be used. The instrument will convert the signal into displacement, apply a high-pass filter at a cutoff frequency of 40 Hz, and record the peak-peak time history over a period at predefined RPM rates.

This type of test can be easily configured using CSA technology as shown in Figure 6. In the CSA editor, three math operators are applied to the raw data Channel 1 – integration, IIR filter and peak-peak detection. The output is the peak-peak time history.

The math operators can have preset parameters to simplify running the test and keep the operator from accidentally changing the required parameters. Or the parameters can be set so that they can be modified on the CoCo hardware at run time.

Since the high-pass filter will always have a cut-off frequency at 40 Hz, for example, it can be defined as a fixed value in the CSA editor. The filter type, shape, and filter orders can be defined as shown in Figure 7a. The user cannot change this value on the CoCo hardware in the field.

After the CSA is designed, it can be downloaded to the CoCo-80 analyzer, where the user will only see the few parameters required for this specific measurement. This design makes using the hardware in the field very simple even though the analysis that is being performed can be very advanced. A sample of measurement is shown in Figure 7b.

Construction Noise and Vibration Monitoring

In this application, the CoCo-80 analyzer running a CSA script remotely monitors noise and vibration at a construction site. The sensor monitoring and signal processing is very specific for this test and requires customized analysis functions. In the past, this would have required a high-end system or customization by the analyzer manufacturer, but CSA can be easily implemented by the end user.

Figure 5. Aircraft engine test setup.

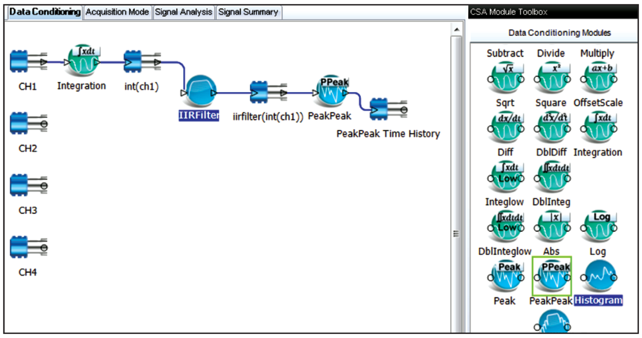


Figure 6. CSA editor with aircraft test including integration, IIR filter and peak-peak detection.

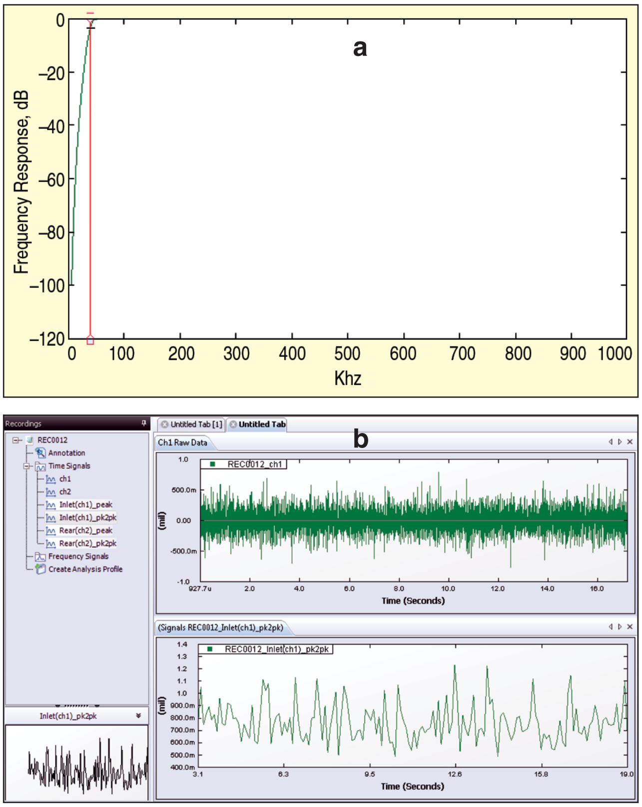


Figure 7. Filter parameter interface configured on a PC as part of the CSA configuration.

When the CoCo is connected with a wireless modem, it communicates with the user through a secure internet connection. This simple integrated solution is far more cost-effective than

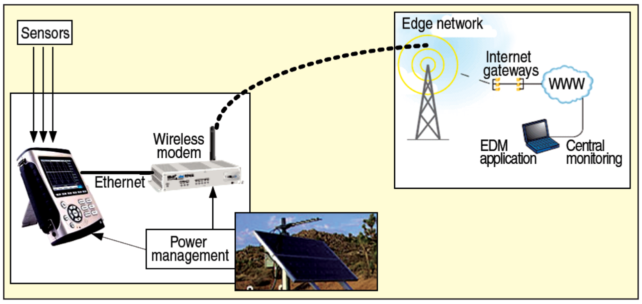


Figure 8. Remote construction sound and vibration monitoring setup.

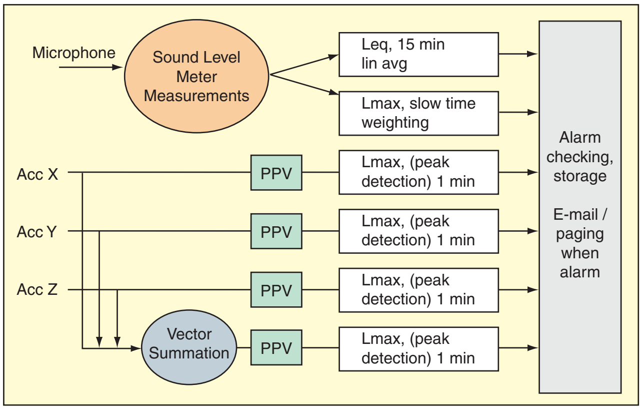


Figure 9. Input channel measurement block diagram.

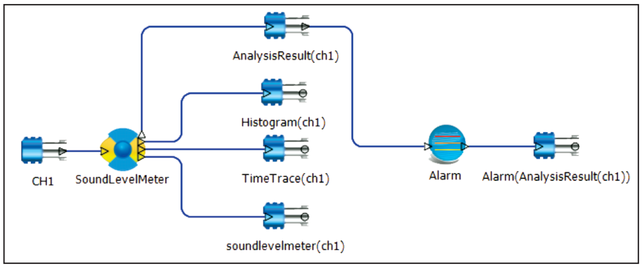


Figure 10. Microphone channel CSA script.

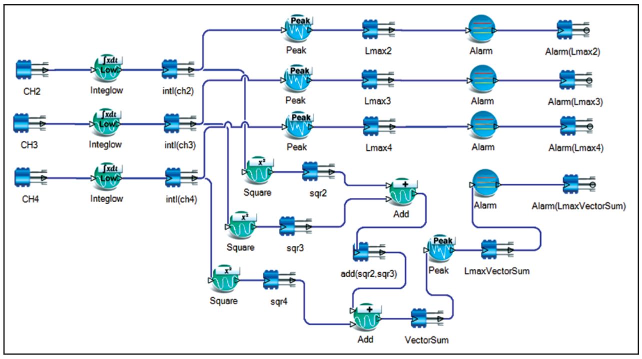


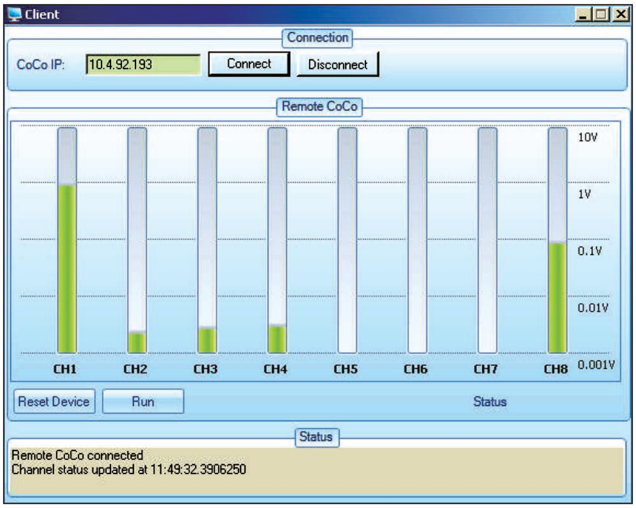
Figure 11. CSA script for accelerometer channels.

PC-based solutions. The complete remote monitoring system is illustrated in Figure 8.

A remote monitoring system must be designed to accept a remote reset command. Any computerized system can hang up due to unexpected software glitches. Although rarely used, this function is necessary if the operator is a long distance from the monitoring system.

Two software methods are available to monitor the CoCo-80 remotely. One is a dedicated user interface based on the EDM software. The EDM is a Microsoft Windows application that can be installed and launched on a PC. A special option can be enabled in the software so it can be connected to one or multiple CoCo-80s remotely by using static IP address identification.

The second method goes one step further, using Internet technology. The EDM software can act as a website portal and post



CoCo IP: 10.4.92.193

Remote CoCo connected
Channel status updated at 11:49:32.3906250

Figure 12. Sound level meter display which is viewed remotely on a PC.

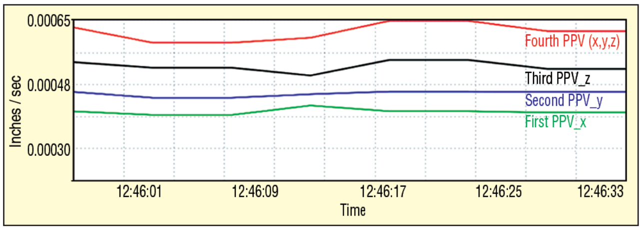


Figure 13. Live display of measurements viewed on a web browser.

data graphs to a dedicated website address. This method allows users to view live data from the CoCo on the Internet anywhere in the world.

Signal analysis and processing for this application is very specific. It includes the following requirements:

- Microphone hourly energy mean noise levels (L_{eq}), maximum noise level (L_{max}) and a histogram
- Triaxial accelerometer peak particle velocity (PPV) with L_{max} 1 minute periods for X, Y and Z and also the vector sum of the three channels.

The general measurement block diagram for this measurement is illustrated in Figure 9. Although the analysis includes very specific requirements, it can easily be implemented on the CoCo-80 analyzer using CSA. A CoCo with four IEPE input channels will be used for each monitoring device.

Channel 1 on the analyzer is connected to a microphone, and the CSA script for this channel is shown in Figure 10. The sound-level-meter block includes several calculations including A-weighting in the time domain, L_{eq}, with 15-minute averaging and an L_{max} using slow time averaging. These calculations are all performed in the sound-level-meter block, and the results are included in the analysis result (Ch1) signal. This signal is then connected to an alarm block, which is configured to compare the results with a predefined limit and send an e-mail or page a cell phone if the alarm level is exceeded. The other signals – histogram, time trace and sound level meter – represent live signals that can be viewed on the CoCo or remotely during run time.

Channels 2, 3 and 4 on the analyzer are connected to the X, Y and Z channels of a tri-axis accelerometer. The CSA script for Channels 2 through 4 is shown in Figure 11. First, each signal is integrated to compute velocity from the digitized acceleration signal. Next, the three vibration signals are squared and added to compute a vector sum. Finally, peak analysis is applied to all channels. By configuring the time duration of the peak calculation to one minute, a 1 minute L_{max} calculation is the result. Finally an alarm block is added to compare the L_{max} to a limit and send an e-mail or page in case the signal exceeds the alarm. The same peak and alarm blocks are added to all three channels and the vector sum signal.

Both microphone and accelerometer measurements are processed simultaneously, allowing all the test requirements to be met on a single CoCo device. Note that with most traditional signal

CoCo-80/90 Dynamic Signal Analyzer

CoCo-80/90 is a multichannel, portable, data recorder, dynamic signal analyzer and vibration data collector. It is ideal for a wide range of industries, including machine conditioning monitoring, automotive, aviation, aerospace, electronics and military that demand easy, quick and accurate data recording and real-time processing in the field. CoCo-80 is equipped with two, four or eight input channels and accurately measures and records both dynamic and static signals on each channel simultaneously. The mass flash memory records eight channels of streaming signals simultaneously up to 102.4 kHz while simultaneously computing real-time time and frequency-based functions. An embedded signal source channel provides various signal output waveforms that are synchronized with the input sampling rate.

CoCo-90 is equipped with an additional eight channels (total of 16 input channels) and accurately measures and records both dynamic and static signals. The mass flash memory can record up to 16 channels of streaming signals simultaneously up to 51.2 kHz while simultaneously computing real-time time and frequency-based functions.

The CoCo-80/90 system is equipped with two USB ports, 100-baseT Ethernet, SD-card interface, audio input/output, a 5.7-inch color LCD display and a keypad.

Twenty-four-bit A/D converter, DSP technology and a patented hardware design offers dozens of data processing functions and more than 130 dB dynamic range in measurement, 10 times higher than competitive products. This allows the capture of signals as high as 10 volts and as low as a few micro-volts in the same test without changing settings. The CoCo-80 software stores and organizes the data in the popular ASAM-ODS standard. This data standard provides ultimate flexibility and version compatibility. Data may also be exchanged with other data formats such as UFF, BUFF and user-defined ASCII format.

When CoCo is connected to the wireless modem, it becomes a remote monitoring system. With the inclusion of a solar power source, a CoCo monitoring solution can be installed almost anywhere.

The CoCo vibration data collector mode is a specialized user interface designed to be used in the vibration and machine condition monitoring industry. It includes route setup and measurement tools, standard vibration data collection measurements such as rms, true-rms, overall-rms, peak and also waveform, spectrum and demodulation measurements.

analyzers, such a customized measurement would require either a very high-end, high-cost system or custom DSP programming by the manufacturer. Only Crystal Instruments' CSA puts this level of customization in the hands of the end user with such a small portable device.

During run time, the status can be viewed remotely on a PC running the EDM software. Figure 12 shows a screen capture of the EDM PC host software viewed on a remote PC 100 miles from the test site. Alarm limits are set to each of the signals being monitored. When a signal exceeds the alarm, an e-mail is automatically sent to a designated address.

In addition to viewing the status remotely, data can be automatically posted to a web site directly from the CoCo hardware. Figure 13 shows the live update display shown on the website monitoring the CoCo inputs. From time to time, the user can download the signal files from the CoCo to the PC. A simple interface is developed based on the EDM platform. The user can operate the CoCo unit remotely through the control panel.

Summary

The new CSA technology from Crystal Instruments has the advantage that it provides both simplicity and flexibility to the dynamic analysis system. Traditional analyzers have the disadvantage in that increasing functionality increases the complexity of instrument operation. Manufacturers continue to add features and functions to the software over time, but the result lowers product simplicity. In use, specific applications always require specific operations. These operations are usually repetitive and simple but may not be available on any generic signal analyzer. The concept of CSA allows users to customize their applications, allowing parameter setup and operation to be tailored to a specific measurement.

Simplicity is very important, especially in a hand-held device with limited user interfaces. Unlike an instrument controlled with a PC interface, a handheld instrument usually is equipped with a limited keypad and access space and is designed for field use, which requires quick and direct operation. CSA enables multiple functions on the same hardware platform without sacrificing simplicity of operation.

Another advantage of using CSA technology is that it provides powerful functions for expert users while maintaining a simple interface for use by technicians. This allows the use of the same instruments to conduct both simple and advanced tasks. In a typical working environment, the managers or senior engineers may have the capacity to set up the instrument, while the operators are only allowed to conduct routine tasks. CSA makes this possible with one hand-held portable device.

The author can be reached at: jzhuge@go-ci.com.