Application Note: CNT-91 + TimeView™

ABCs of Modulation Domain Analysis

Background

An instrument like an Oscilloscope lets you view voltage variations over time. A Spectrum Analyzer lets you view voltage variations over frequency. A Modulation Domain Analyzer (MDA) lets you view frequency variations over time. Figure 1 shows all three dimensions pictorially. To analyze all dynamic properties of a signal, all three of these tools are required:

- Oscilloscope (v vs. t)
- Spectrum Analyzer (v vs. f)
- Modulation Domain Analyzer (f vs. t)

While Oscilloscope and Spectrum Analyzer measurements are well-understood, Modulation Domain Analysis requires more explanation. This application note specifically addresses the use of a state-of-the-art frequency analyzer, such as the Pendulum CNT-91, along with TimeView™ software to obtain powerful modulation domain analysis.

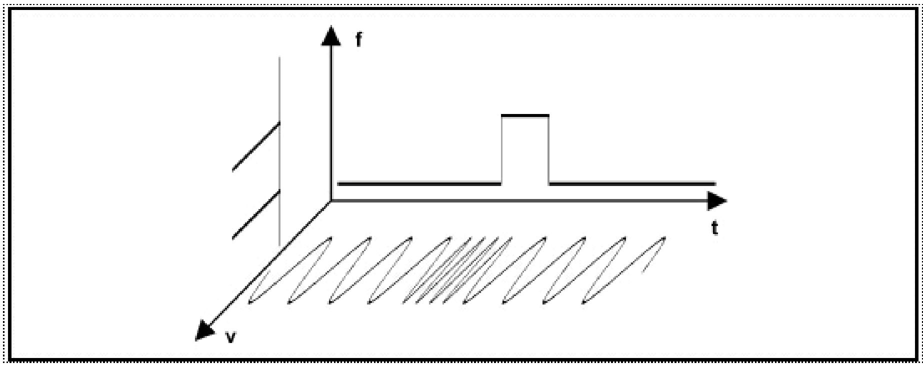


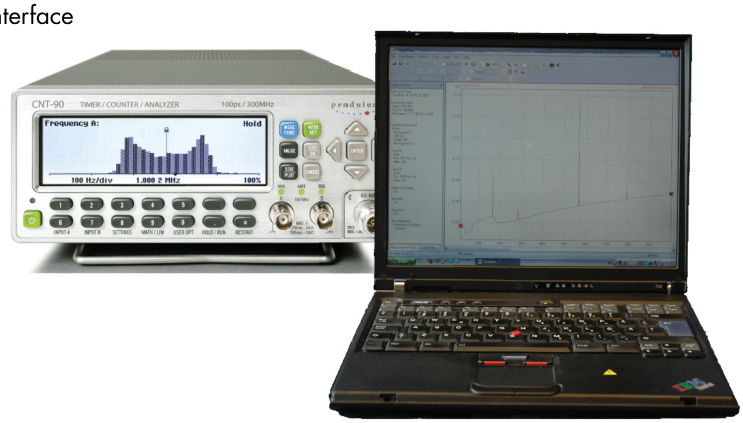
Figure 1. A sinewave signal with squarewave FM as shown on an oscilloscope (v vs. t), a spectrom analyzer (v vs. f) and a Modulation Domain Analyzer (f vs. t). These three instruments give a three dimensional view of the signal's properties.

CNT-91 + TimeView: An MDA Solution

The Pendulum MDA solution consists of three parts:

- **Fast sampling front end:** CNT-91 Frequency Analyzer
- **Interface:** Standard PC with GPIB or USB interface
- **TimeView control & analysis software** running on a Windows PC

TimeView is connected to the front end frequency analyzer through the PC interface. All settings and controls are accessed through the PC and stored as ASCII files that can be easily imported into various programs. Graphs can be printed on the PC's printer.



CNT-91 Frequency Analyzer

The CNT-91 operates on fourth generation frequency counter technology. It incorporates state-of-the-art techniques for improving measurement accuracy.

The CNT-91 uses a unique time stamping method that allows for continuous event counting – eliminating "dead time" between counts. The momentary contents of the counter are transferred to memory at regular, pacing intervals. The read out of the register content is synchronized to the input trigger, so it is the event trigger that is time stamped. Each stored time stamp is interpolated "on the fly" for improved resolution. The contents stored are thereafter processed.

The CNT-91 uses a Linear Regression Least Squares Line-Fitting Method to further improve measurement accuracy. The main advantage of linear regression is increased frequency resolution through the reduction of noise from the measurement process. The basic resolution of each timestamp is 35 picoseconds. The CNT-91 has 14 digits of display so resolution is not restricted.

Standard PC with GPIB or USB interface

TimeView is compatible with all models of Pendulum Frequency Analyzers including CNT-90, CNT-91 and CNT-90XL. The interface is connected via GPIB or USB. The system requires Microsoft Windows 2000, XP, Vista, or Windows 7.

USA | 1565 Jefferson Road, Suite 460 | Rochester, NY 14623 | +1.585.321.5800 | sales@spectracomcorp.com
FRANCE | 3 Avenue du Canada | 91974 Les Ulis, Cedex | +33 (0)1 64 53 39 80 | sales@spectracom.fr
UK | 6A Beechwood | Chineham Park | Basingstoke, Hants, RG24 8WA | +44 (0)1256 303630 | info@spectracom.co.uk

TimeView Control & Analysis Software

TimeView control & analysis software converts a Pendulum Frequency Analyzer into a high performance MDA with a frequency range of up to 20 GHz. The software leverages the zero dead time capabilities of the CNT-91 and enables such measurements as period back-to-back and Allan Deviation vs. time (t).

TimeView can also record and analyze slower variations (trends) in any time or frequency related parameter, such as:

- Phase
- Duty Cycle
- Pulse Width
- Rise/Fall Time

Capturing Single-Shot Events (free run capture)

Up to 1.85 million samples of measurement data can be taken as a single-shot data capture. To characterize frequency variations over time, the CNT-91 makes repeated frequency measurements that are stored in its internal memory together with the time stamp at a sample rate of up to 250,000 Samples/sec. Unlike traditional counters, the CNT-91 provides an array of data for TimeView with actual measurement values AND the point of time when the measurement was made. The time stamping feature is especially important when measuring non-continuous signals such as a frequency burst or the pulse width of random pulses.

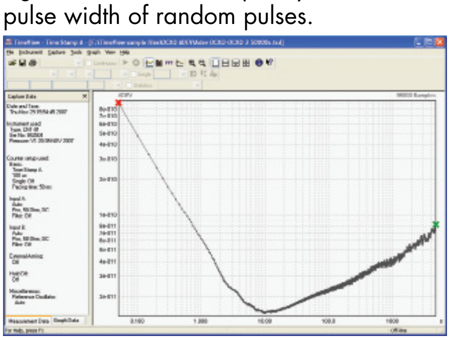


Figure 2. ADEV plot of a very stable oscillator.

Time Stamping Capture Mode

In the free-run mode, the CNT-91 front-end measures, processes and outputs formatted frequency (or period or other measurement function that selected) to TimeView. When in the time stamping mode, TimeView collects raw time stamping data and makes the final processing in the PC instead. TimeView collects N samples of time stamp data on channel A or B and presents the result graphically. Measured time stamp

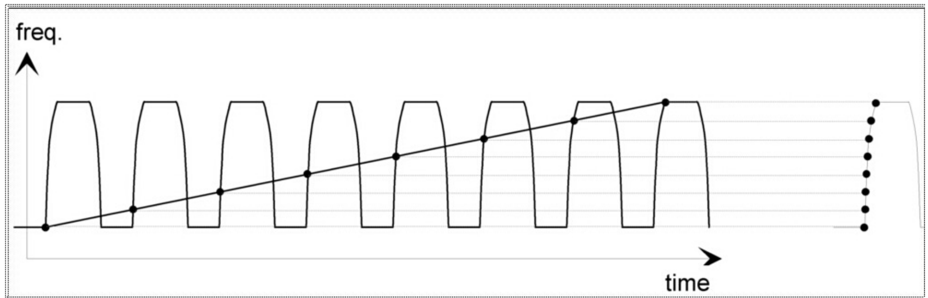


Figure 3. With repetitive sampling, many measurements are made at fairly long intervals and put together to show a fast frequency transition. Each measurement can be delayed down to 10 nsec with respect to the previous measurement.

data can be viewed in 7 different display modes, one of them being Allan Deviation (ADEV). Fig. 2 shows an ADEV graph of a stable oscillator.

Capturing Repetitive Events (Repetitive Sampling)

Free-run capture has a sample rate of over 250,000 Samples/sec. While this is enough for most applications, some demand higher rates. Consider the measurement of an output settling of a VCO or a synthesizer requiring greater precision. To measure this, you need to improve the time scale so it corresponds to millions of measurements/sec. TimeView does this with periodic repetitive events called "Repetitive Sampling." With this capture method, TimeView measures several times in subsequent cycles. Each measurement is somewhat delayed in the cycle with respect to the previous measurement. When enough samples are taken, these are put together to show a picture of the fast frequency transient. See Fig. 3.

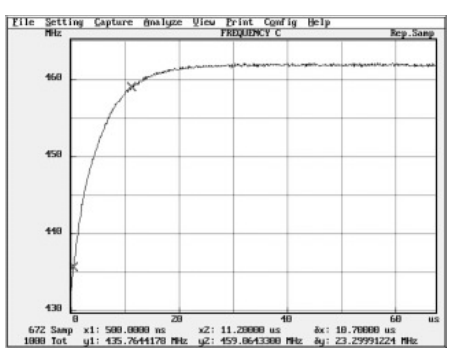


Figure 4. Repetitive Sampling of a fast changing frequency output from a UHF VCO.

The delay between subsequent measurements can be set down to 10 nsec steps. This corresponds to a virtual sampling rate of 100 MSamples/sec. As with a digital oscilloscope, there must be an external synchronization signal or a unique trigger point available somewhere in the system. An example is shown in Fig. 4, where the frequency response of a VCO is shown. The VCO is controlled via a repetitive pulse with a fast rise time. The input voltage toggles between two levels (high/low voltage) and consequently the output frequency should switch between two frequency values (high/low). The actual frequency response (f vs. t) is recorded via TimeView's repetitive sampling. In the graph, cursor measurements show that the frequency swing is approximately 29 MHz (from 433 to 462 MHz) and the rise time between cursor positions is 10.7 usec.

Viewing Frequencies That Vary With Time

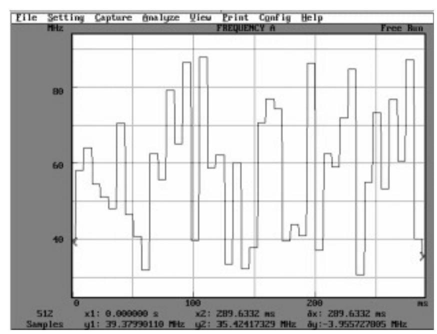


Figure 5. Frequency hopping (e.g. military frequency agile communications).

There are a variety of frequency sources available to designers. Some are very stable and others vary, such as those found in frequency hopping communications. In Fig. 5, a military frequency agile communication carrier is shown with pseudorandom frequency changes every 7 msec. The purpose of this rapid change of carrier frequency is to deter outside listeners. Another example is the frequency hopping in spread spectrum communications, such as in noisy industrial environments and wireless LANs. Here the purpose is to provide secure communications with less interference.

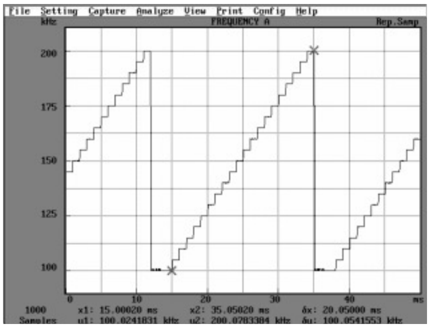


Figure 6. A frequency sweep made by a digital synthesized generator.

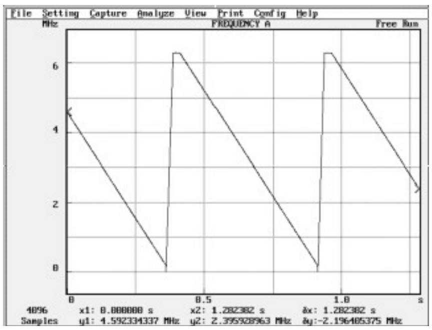


Figure 7. A frequency sweep made by an analog generator.

Other examples of varying frequency signals are those were the frequency is swept, such as in consumer electronics equipment and in very high frequency chirp radars. Fig. 6 shows an example of a frequency sweep from 100 to 200 KHz made by a Function Generator. This generator uses digital techniques to synthesize the output frequency, resulting in 20 discreet steps during the sweep period. An analog sweep generator would give a straight line instead (Fig. 7).

Because of the need to see f vs. t, the visualization of frequencies that change over time can only be made by an MDA, not an oscilloscope or a spectrum analyzer.

Measuring Jitter and Frequency Noise

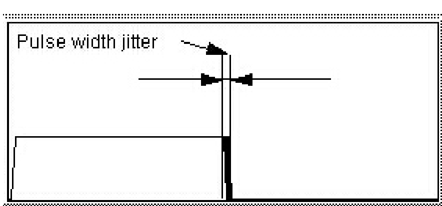


Figure 8. Jitter can be viewed on an oscilloscope as a fuzzy edge, but not quantified.

In today's digital telecommunications systems, it becomes essential to maintain control over system jitter. Jitter is a cycle to cycle variation of a periodic event (period, pulse width or time interval variations). It can be random or deterministic in nature, meaning it can occur randomly in the system or predictably on a repetitive basis. Examples include periodic variations of a computer clock oscillator or clock-to-data jitter in a communications system. Jitter can sometimes be detected on oscilloscopes (v vs. t), seen as fuzzy edges of a pulse (Fig. 8).

To measure jitter, you need to make many single pulse width measurements and statistically process the samples to arrive at a max, min and standard deviation values from the samples. The delta Δ(max-min) is called the peak-to-peak jitter, but normally the most important measure is the rms-jitter (standard deviation).

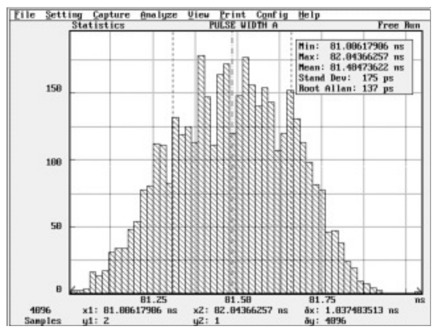


Figure 9. Random jitter gives a Gaussian distribution.

An oscilloscope can indicate peak-to-peak jitter but not rms-jitter, whereas TimeView can accurately calculate both types of jitter and the distribution of the actual measurements in a distribution histogram. Such a histogram may help to reveal the "nature of jitter". Random jitter gives a Gaussian distribution of jitter. See Fig. 9.

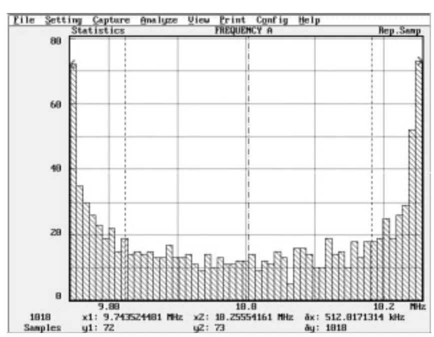


Figure 10. Jitter caused by sinusoidal frequency modulation gives a "bathtub" distribution.

Jitter caused by a sine modulation gives a histogram that looks like a bathtub. See Fig.10.

Jitter caused by a square wave modulation on the other hand, gives a histogram with two distinct bars at the maximum and minimum respectively. See Fig. 11.

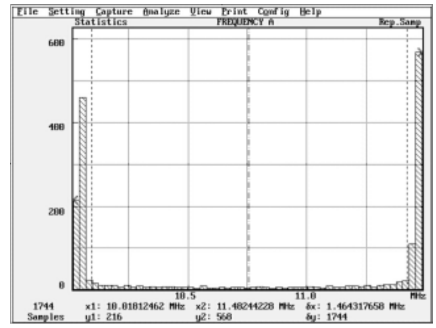


Figure 11. Jitter caused by a square wave frequency modulation gives a 2 bar distribution.

Frequency Modulation

A frequency modulated (FM) signal is difficult to characterize with a normal oscilloscope. The frequency varies and thus the period is changing as well. It's almost impossible to acquire a stable triggering source and to figure out the nature of the modulating signal is guesswork at best.

TimeView can characterize FM easily because an MDA displays frequency that varies over time. A representation of a frequency modulated carrier in a frequency vs. time graph is shown in Fig.12.

From Fig. 12, you can quickly conclude that the carrier is approximately 10 MHz, having a frequency deviation of approximately 2% (0.2 MHz). By looking at the time axis, you see that the modulation is periodic and sinusoidal, having a frequency of approximately 50 KHz (20 usec modulation cycle). At one glance, we have an indication of all three important frequencies in an FM signal as follows:

1) Carrier Frequency (f_c)
2) Frequency Deviation (f_d)
3) Modulation Frequency (f_m)

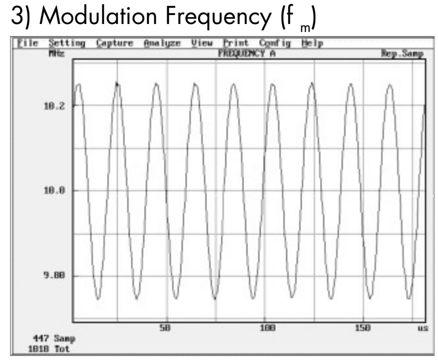


Figure 12. FM shown in the modulation domain. The modulation signal shape is revealed.

FFT- Analysis

To analyze the modulation in more detail, you can use the built in FFT-function. When applied on the signal in Fig. 12 (frequency

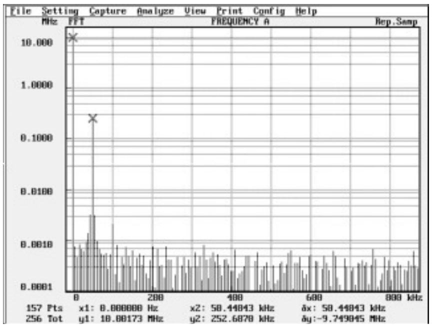


Figure 13. FFT processing of the modulation domain graph shows carrier, modulation frequency and deviation.

vs. time), it will produce the graph shown in Fig. 13, which is frequency vs. frequency.

Just as a “normal” FFT operation on a voltage vs. time graph will show the spectral contents of the original signal, the FFT graph shows the spectral contents of the frequency vs. time graph.

In Fig.13, the found modulation frequencies are shown along the X-axis just as in a normal FFT of voltage vs. time. Along the Y-axis we find the carrier and the frequency deviations from the carrier caused by modulation. There are also two cursors shaped as “X.” The left cursor (x1 in the graph) tells us that the carrier is 10 MHz. The right cursor (x2) shows the modulation frequency is 50 KHz causing a deviation of the carrier of 250 KHz.

Distribution Histogram

The statistical distribution histogram can give valuable information about the modulation scheme, see Fig. 14. From the shape of the distribution histogram, we can conclude that the modulation is sinusoidal (bath tub). We can also read the maximum frequency deviations as well the carrier frequency (mean frequency over N modulation cycles).

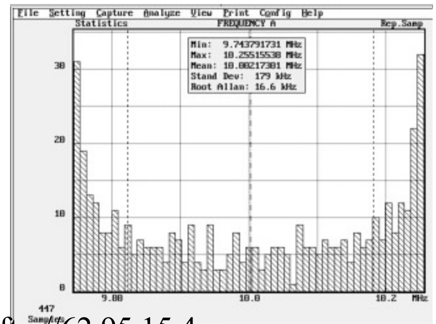


Figure 14. The distribution histogram shows frequency deviation and indicates sinusoidal modulation.

Finding Very Small Unwanted Modulation Sources

TimeView is an excellent tool for frequency stability analysis, and an ideal complement to a spectrum analyzer, whose strength is amplitude stability analysis. Furthermore, TimeView can be used for troubleshooting designs in order to track sources of noise or interference.

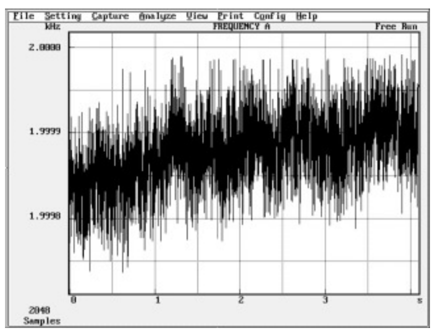


Figure 15. Frequency vs. time output of a pulse generator.

As an example, refer to Fig. 15 which shows the output frequency of a pulse generator with jitter. After further investigation using TimeView, we conclude that the jitter is random in nature (Fig. 16). Performing an FFT of the signal shows a dominant 100 Hz modulation source, i.e. the power supply causing FM noise on the output signal (Fig. 17).

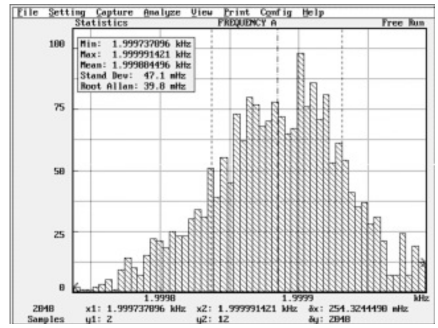


Figure 16. The histogram of frequency vs. time data indicates random noise.

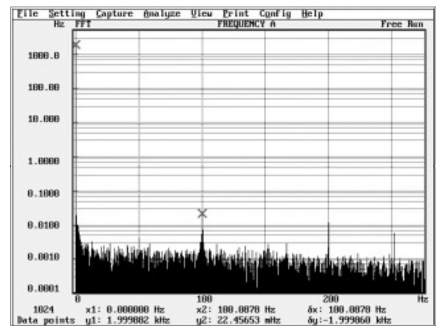


Figure 17. FFT- processing of the modulation domain graph shows the power supply contributed noise with a 100 Hz modulation.

Summary

The combination of a Frequency Analyzer, PC and TimeView software is a powerful, and cost-effective modulation domain analysis tool designed for:

- Showing dynamic frequency variations over time (frequency scope)
- Analyzing noise and jitter
- Analyzing modulation