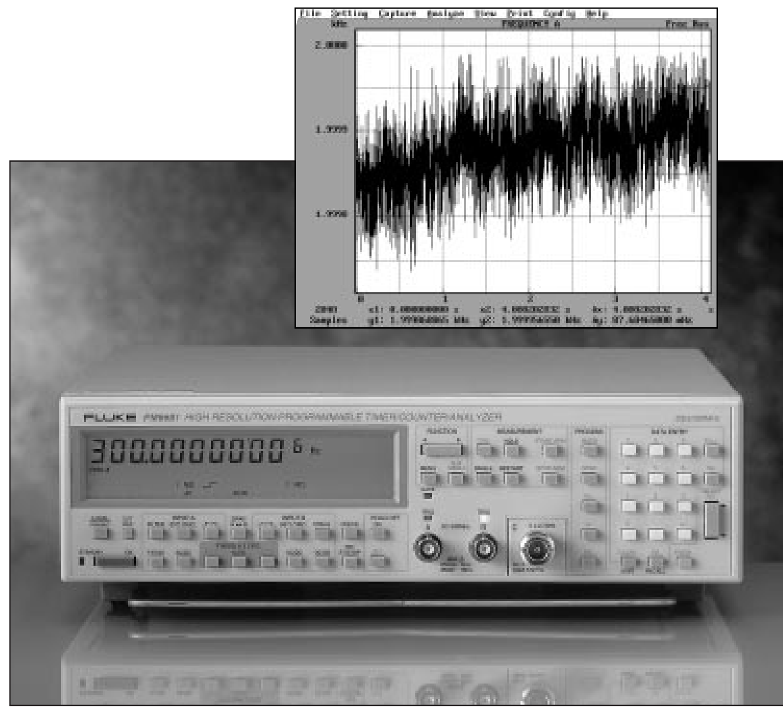
ABC of Time & Frequency Analysis

Application Note

PM6681 Timer/Counter/Analyzer with TimeView™ software

Background
Why are oscilloscopes such popular instruments? They do not measure voltages very accurately. Even the cheapest DVM can produce more accurate results when measuring static voltages. Yes, that's it: oscilloscopes let you view dynamic voltages, voltages that vary over time. This ability makes oscilloscopes ideally suited for viewing and analyzing most types of dynamic signals. And the absence of this dynamic signal view limits the applications of voltmeters to the checking and calibration of static signals.



Dynamic signal analysis of amplitude and frequency

Amplitude and frequency content are the two most important characteristics of any signal.

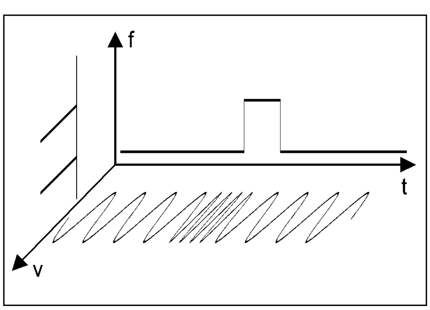


Fig. 1 A sinusodial signal with squarewave frequency modulation as shown on an oscilloscope (V vs. t), a spectrum analyzer (V vs. f) and a TFA (f vs. t). All these instruments are needed for a complete picture of the signal.

Oscilloscopes are used to analyze changes in amplitude, but not changes in frequency. The traditional measurement tool for analyzing the frequency content of a signal is the Spectrum Analyzer. This can find static (fixed) frequencies or give a statistical (averaged) picture of dynamic (changing) frequencies. To view frequencies which are changing, a third type of tool is needed: the Time & Frequency Analyzer (TFA), sometimes also called Modulation Domain Analyzer.

The three basic signal analysis tools.

To analyze all the dynamic characteristics of a signal, three basic tools are needed:

- Oscilloscope
- Spectrum or FFT Analyzer
- Time & Frequency Analyzer

An oscilloscope lets you view voltage variations over time, a Spectrum or FFT Analyzer lets you view voltage distribution over frequency, and a TFA lets you view frequency variation over time (see Fig. 1).
All three tools are needed for a complete signal analysis that covers all three axes: Voltage, Frequency and Time

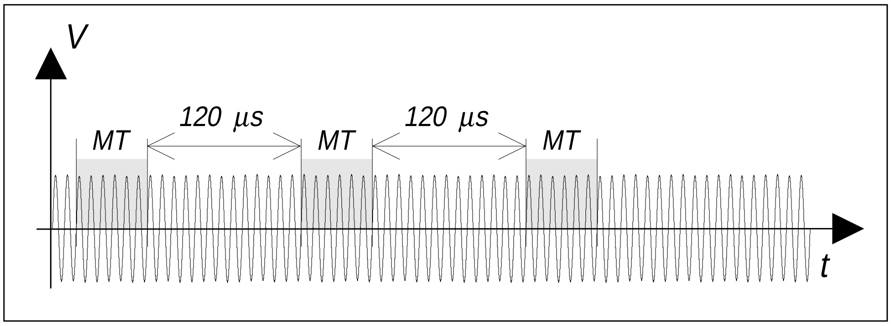


Fig. 2 Free-running frequency samples in a sinewave.

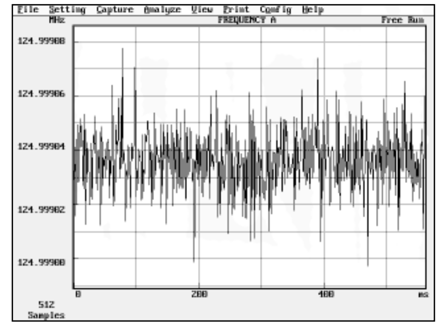


Fig. 3 Free-running frequency samples from a stable signal source. The diagram shows frequency vs. time.

TimeView™- a TFA solution

The TimeView Time & Frequency Analyzer from Fluke consists of three parts:

- Fast sampling front-end (PM 6681)
- Standard PC with GPIB interface
- TimeView control and analysis SW

The signal to be characterized is connected to the front-end input (PM 6681 timer/counter/-analyzer). All setting controls are made from the PC. Graphs can be printed on the PC printer, and settings and results are stored as ASCII files, that can easily be imported into various programs for detailed analysis (e.g. EXCEL spreadsheet).

Capturing single-shot events (free-run capture)

Single-shot events occur just once. Or the repetition rate may be so low that you only want to measure on one cycle (e.g. temperature cycling of oscillators). To characterize frequency variations over time, the PM 6681 front-end makes repeated frequency measurements that are stored in its internal memory.

Sample rate

There is a "dead-time" between measurements of 120µs (see Fig. 2). With a Measuring Time MT, the sample rate for each frequency measurement is:
Sample rate = 1/(MT+120 µs)
An MT of 100 µs (TimeView default value) means that TimeView will take frequency samples (0 ... 4.5 GHz), with 6-7 digits resolution, every 220 µs or approx. 4500 times/s.

Time-stamping

PM 6681 will "time-stamp" each measurement in a block., by means of a separate time-stamp clock (125 ns resolution). The time given by this clock is read and stored together with the start of all subsequent measurements.
When data capture is finished, the values and the corresponding time-stamps are transferred to the PC as a two-dimensional array, and TimeView handles the display and analysis. In this way TimeView knows both the actual measurement values and the time at which the measurement was made.
The time-stamping feature is especially important for non-continuous signals such as when measuring frequency in bursts, or the pulsewidth of random pulses.

Capturing repetitive events (repetitive sampling)

Even though free-running capture has a sample rate of well over 8000 values/s, this is not enough in some applications. Consider for example the measurement of the output settling time of a VCO or a synthesizer. Here you could expect settling times of a few microseconds. To measure this, you need to improve the time scale, so it corresponds to

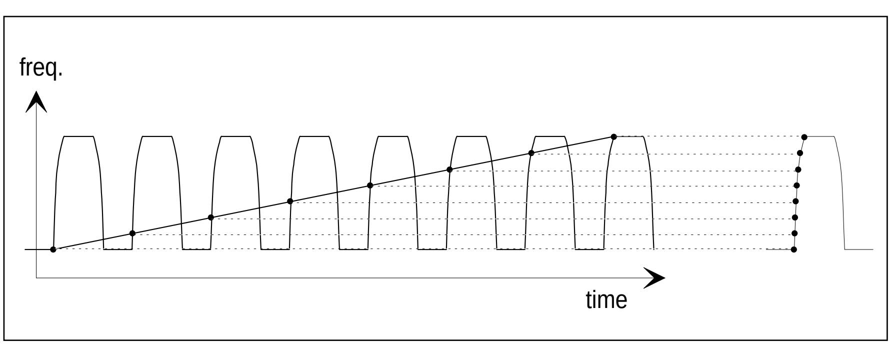


Fig. 4 Using repetitive sampling, many measurements are made at fairly long intervals and put together to show a fast frequency transition. Each measurement can be delayed down to 100 ns with respect to the previous measurement.

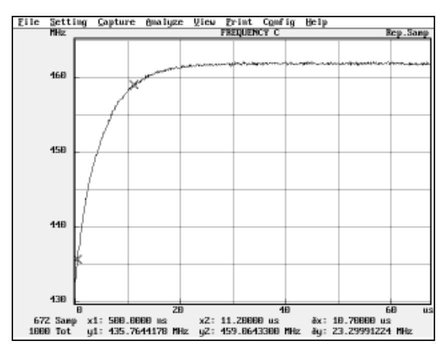


Fig. 5 Repetitive sampling of a fast-changing frequency output from a UHF VCO.

millions of measurements/s. TimeView does this on periodic repetitive events, in a way called repetitive sampling.
With this capture method, TimeView measures not once but 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. 4).
The delay between subsequent measurements can be set in steps down to 100 ns. This corresponds to a virtual sampling rate of 10 MS/s. As with repetitive sampling in a DSO, there must be either an external synchronization signal or a unique trigger point somewhere in the signal.

An example is given in Fig. 5, which shows the frequency response of a VCO. The VCO is controlled via a repetitive pulse with a fast risetime. The input voltage toggles between two levels (high/low), and consequently the output frequency should switch between two frequency values (high/low frequency). The actual frequency response (f vs. t) is recorded by TimeView's repetitive sampling. In the graph, cursor measurements show that the frequency swing is approx. 29 MHz (from 433 to 462 MHz) and the "risetime" between cursor positions is 10.7 µs.

Viewing frequencies that vary with time

There is a great variety of frequency sources. In some, the frequency is rock-stable, while in others the output frequency varies strongly. Examples of varying frequencies are found in frequency hopping communication. Fig. 6 shows a military frequency agile communication carrier, with

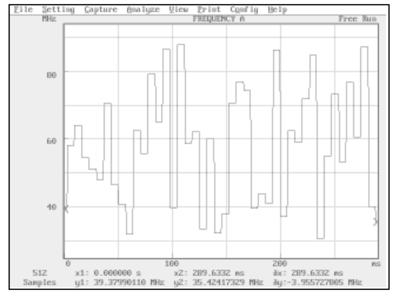


Fig. 6 An example of the use of frequency hopping is in military frequency agile communication.

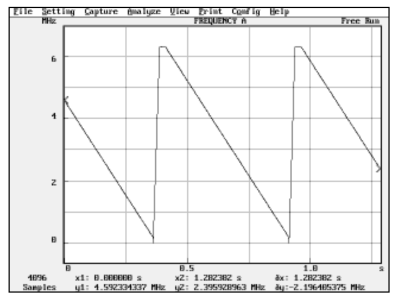


Fig. 8 A frequency sweep made by an analog generator.

pseudorandom frequency changes every 7 ms. The purpose of this rapid change of carrier frequency is of course to prevent "the enemy" from listening.
Another example is the frequency hopping in spread-spectrum communication, found for example in noisy industrial environments or in wireless LANs. Here, the purpose is to provide better-quality communication with less interruptions.
Yet other examples of varying frequency are various frequency sweep signals. These are found in LF audio testing of consumer electronics equipment, as well as in very high-frequency radar "chirps".

Fig. 7 shows an example of a frequency sweep from 100 to 200 kHz, made by a modern function generator. This generator uses digital technology to synthesize the output frequency. This is why the frequency is changing in 20 discrete steps during the sweep period. An old-fashioned analog sweep generator would give a straight line instead, as shown in Fig. 8.

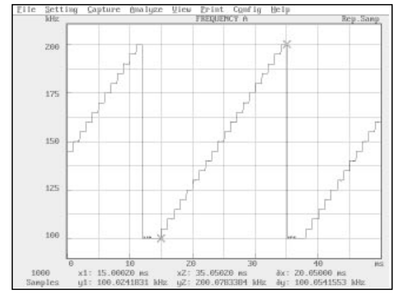


Fig. 7 A frequency sweep made by a digital synthesized generator.

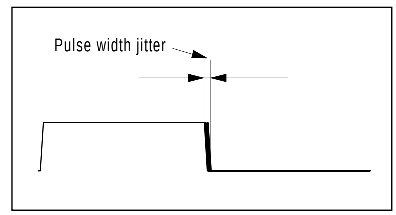


Fig. 9 Jitter can sometimes be detected, but not measured, using an oscilloscope.

Needless to say, the visualization of frequencies that change over time can only be made by a TFA, and not by an oscilloscope or a spectrum analyzer.

Measuring jitter and frequency noise

In today’s computer and digital telecommunications systems, it is more essential than ever before to keep system jitter under control. But what is jitter?
Jitter is the cycle-to-cycle variations of a periodic event; be it period, pulsewidth or time interval variations. Examples are period variations of a computer clock oscillator or clock-to-data jitter in a communications system. A large amount of jitter can sometimes be detected on analog scopes, and is seen for example as a fuzzy edge of a pulse (see Fig. 9).
To measure the jitter, you need to do a lot of single pulsewidth measurements, and statistically process the samples to get the max., min. and standard deviation values from the samples. The ∆(max.-min.) is called the peak-to-peak jitter, but normally the most important measure is the RMS jitter (standard deviation).

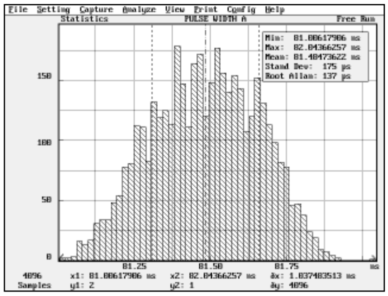


Fig. 10 Random jitter gives a Gaussian distribution.

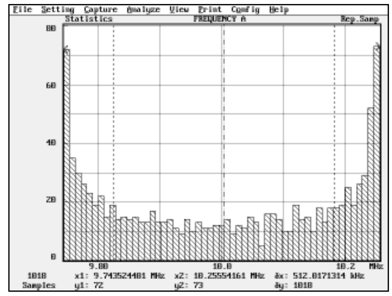


Fig. 11 Jitter caused by sinusodial frequency modulation gives a distribution like a "bathtub".

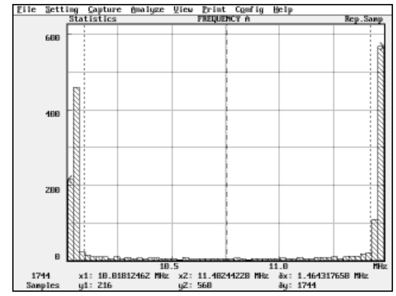


Fig. 12 Jitter caused by a squarewave frequency modulation gives a "2-bar" distribution.

An oscilloscope can indicate peak-to-peak jitter but never RMS jitter, whereas TimeView can accurately calculate both types of jitter, and can also display the distribution of the actual measurements in a distribution histogram. Such a histogram may help to reveal the "nature of jitter". A random jitter gives a Gaussian distribution, like the example shown in Fig. 10.
Jitter caused by a sine modulation gives a histogram that looks like a bathtub, as in Fig. 11.

Jitter caused by a squarewave modulation, on the other hand, gives a histogram with two distinct bars at the maximum or minimum values (see Fig. 12).

Measuring frequency modulation

A frequency modulated (FM) signal is difficult to characterize with a normal oscilloscope. The frequency varies, and therefore the period is also changing. You cannot get stable triggering, and figuring out the nature of the signal turns into guesswork. TimeView and other TFAs can characterize FM easily. Simply because a TFA displays frequency that varies over time, and that is exactly what FM is all about.
A representation of a frequency modulated carrier in a frequency vs. time graph is shown in Fig. 13.
From Fig. 13, you can quickly conclude that the carrier is approx. 10 MHz, with a frequency deviation of approx. 2% (0.2 MHz). By looking at the time axis, you can see that the modulation is periodic and sinusoidal, with a frequency of approx. 50 kHz µ20 (s modulation cycle). So, at one quick glance, we have an indication of all three important frequencies in an FM signal:

- Carrier frequency f_c
- Frequency deviation f_{dev}
- Modulation frequency f_{mod}

FFT analysis

To analyze the modulation in more detail, you can use the built-in FFT function. When applied to the “frequency vs. time” signal shown in Fig. 13, the result will be a “frequency vs. frequency” graph as shown in Fig. 14.
Just as a "normal" FFT operation on a voltage vs. time graph will show the spectral content of the original signal, the FFT graph shows the spectral content of the frequency vs. time graph. Fig. 14 shows the revealed modulation frequencies along the X axis, just as in a "normal" FFT on voltage vs. time. Along the Y axis we find the carrier and the frequency deviations from the carrier caused by modulation.
In Fig. 14 you find two cursors, shaped as an "X". The left cursor tells us that the carrier is 10 MHz. The right cursor shows that the modulation frequency is 50 kHz, causing a deviation of the carrier of 250 kHz.
The statistical distribution histogram can also give valuable information about the modulation (see Fig. 15). From the shape of the distribution histogram, we can conclude that the modulation is sinusodial (bathtub shape). We can also read the maximum frequency deviations, as well as the carrier frequency (average frequency over an integral number of modulation cycles).
Finding very small unwanted

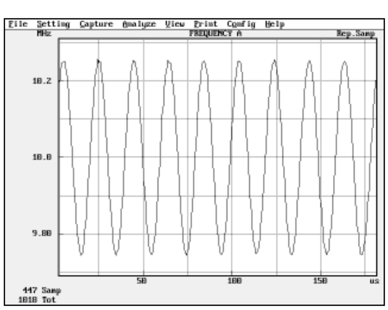


Fig. 13 FM as shown in a frequency vs. time graph: the "Frequencyscope".

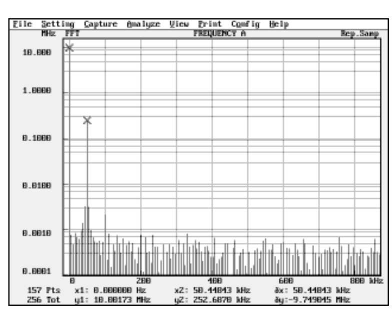


Fig. 14 The FFT function reveals carrier, modulation frequency and deviation.

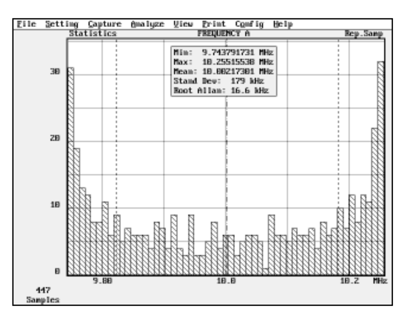


Fig. 15 The histogram of frequency vs. time data shows that the modulating signal is sinusodial.

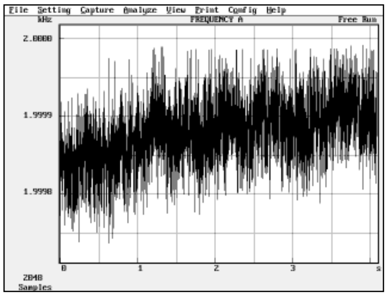


Fig. 16 Frequency vs. time from a pulse generator.

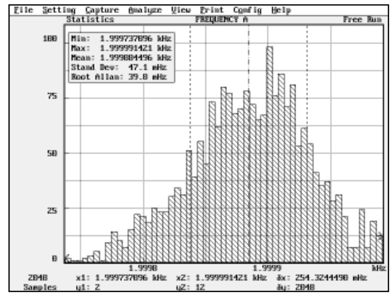


Fig. 17 The histogram of frequency vs. time data indicates random noise.

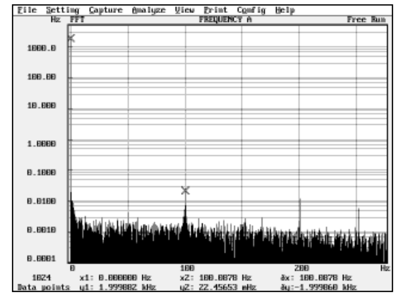


Fig. 18 The FFT of frequency vs. time data shows that a 100 Hz modulation source is causing the noise.

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 down the causes of noise or interference.
Look at Fig. 16, which shows the output frequency from a pulse generator, with a certain amount of jitter. The jitter appears to be of a random nature (see the distribution histogram in Fig. 17).
Fig. 18 shows that there is a dominant 100 Hz modulation source, i.e. the power supply is causing FM on the output signal.

Summary
TimeView is a tool designed for:

- *Showing dynamic frequency variations (“Frequency scope”)*
- *Analyzing noise and jitter*
- *Analyzing modulation*
- *Recording and documenting*

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