KEITHLEY

Application Note Series

Number 601

Peak Detection with the Model 2001 DMM

Introduction

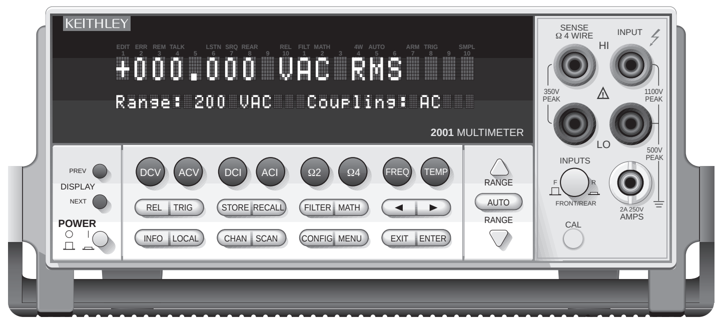
Keithley Instruments' Model 2001 Digital Multimeter offers a variety of functions not available in any other DMM. These unique functions include DCV peak spikes, ACV peak and ACV crest factor measurements. This application note is intended to provide users with a basic understanding of the operation, capabilities, and limitations of these functions.

In many applications, the Model 2001's peak detection capabilities make it possible to use it in place of an oscilloscope, allowing significant cost savings and simpler measurement setups. These capabilities include:

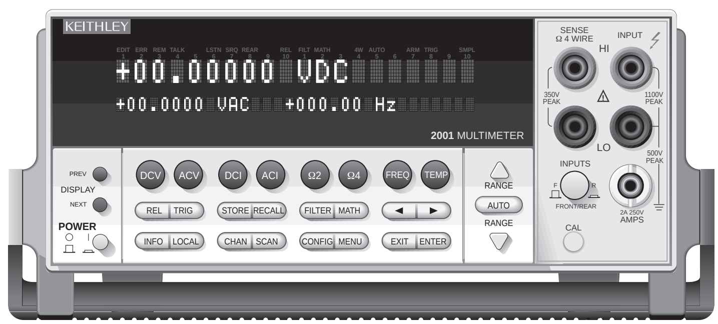
- Capturing voltage transients with pulse widths as short as 1µs. There's no need for an expensive digital sampling oscilloscope (DSO).
- Measuring the peaks of AC waveforms up to 1MHz.
- Measuring and displaying maximum and minimum signal levels simultaneously.
- Measuring the crest factor (peak/rms) of an AC waveform directly. This makes it easy to derate the accuracy of rms measurements properly, if applicable, or to characterize a waveform without the need to view it. For example, the duty cycle of a pulse train can be calculated directly from its crest factor value.

Although the Model 2001 offers a number of peak measurement functions, it has only one peak detector. The instrument's front panel controls allow users to change the configuration of the circuitry that precedes the peak detector to switch from one peak measurement function to another. The most appropriate circuitry configuration for a particular measurement will depend on the characteristics of the input signal.

Model 2001 in Primary display mode.



Model 2001 in Multiple display mode.



Model 2001 Display Modes

In the primary display mode, the top line displays information such as readings, units, and channel number (if scanning), as well as the type of measurement being performed (if needed for clarification). The bottom line in this mode will display information on the measurement range (if fixed), ACV and ACI coupling, frequency coupling and terminals, and temperature sensors. To switch the Model 2001 into the multiple display mode, simply press the NEXT or PREVious DISPLAY keys (found in the lower left corner of the front panel). Each measurement function has its own set of multiple displays. To scroll through the multiple displays available for each measurement function, repeatedly press and release the NEXT DISPLAY key. To scroll through the displays in reverse order, repeatedly press and release the PREVious DISPLAY key. To return to the default reading display, press and hold either key. In the multiple display mode, the Model 2001 can display the readings of up to three separate measurements at once. However, even though the readings are displayed simultaneously, the instrument makes these measurements sequentially.

DCV Peak Spikes

Operational Overview

The DCV peak spikes function can be used to capture voltage transients on a DC signal and measure the maximum and minimum levels of an input signal. There are two peak spikes measurement modes. In the Positive-Peak mode, the input signal is passed directly to the peak detector, so the most positive value is captured as the peak. In the Negative-Peak mode, the input signal is inverted before being sampled by the peak detector. In this case, the most negative value is captured as the peak.

Display

DCV peak spikes measurements can be displayed in two ways: as a primary display of AC VOLTS[1] (by selecting the AC-TYPE to be either POSITIVE-PEAK or NEGATIVE-PEAK) or as part of multiple displays of DC VOLTS. While the operation of the peak spikes function is the same in each display mode, the function control and displayed information are slightly different.

DCV peak spikes measurement in primary display mode: The primary display mode should be used when the peak spikes measurement is the only parameter of interest to the user. Both positive-peak and negative-peak measurements are available via the primary display of AC VOLTS. To access this measurement function, press CONFIGure and ACV. Use the ◄ ► cursor button to highlight AC-TYPE from the menu options that appear on the lower line, then press ENTER. Then, use the ◄ ► cursor and ENTER again to select either POSITIVE-PEAK or NEGATIVE-PEAK.

The primary display mode not only allows the user to control the resolution, filtering and coupling of the measurement, but also provides greater measurement integrity. This improved integrity is due to the fact that the unit is measuring only peak spikes, rather than measuring multiple functions sequentially. In cases where the transient being measured is a non-repetitive event, it is essential to use the primary display mode.

Another advantage of using the primary display mode is the ability to set the length of "peak window." A peak window is the amount of time a signal is sampled before a reading is displayed. A parameter control menu will appear automatically once either POSITIVE-PEAK or NEGATIVE-PEAK is selected. This menu allows the user to set the peak window anywhere from 0.1 to 9.9 seconds. This window must be set carefully to ensure an accurate reading when measuring non-repetitive transients. At the end of each sample period, the peak detector is reset while the reading is being calculated. Consequently, during this reset operation (which takes approximately 30ms), the input is not being monitored. However, by using the peak window properly, users can prevent measurement problems. Since the generation of transient spikes is controllable in most applications, the user should simply set the unit for a long peak window. As long as the spike occurs within that window, it will be captured. This subject will be discussed in greater detail in the Applications section.

DCV peak spikes in multiple display mode: There are three multiple displays of DC VOLTS that include peak spikes measurements. These multiple displays are ideal for the user who wishes to perform more than one function at a time, such as monitoring the noise on a DC voltage while simultaneously measuring the voltage. However, there are some limitations to keep in mind when making peak spikes measurements in the multiple display mode:

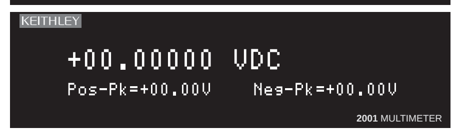
- The length of the peak window is preset at 100ms and cannot be changed by the user.
- The range of the peak measurement is determined by the range set for DC VOLTS.
- The resolution is fixed at 3½ digits.
- No filter is used.
- The coupling is fixed at AC+DC.

Figure 1: DCV Peak Spikes in Multiple Display Mode

Figure 1A: Positive peak spikes and highest value

Figure 1B: Negative peak spikes and lowest value

Figure 1C: Positive and negative peak spikes



The first multiple peak spikes display (Figure 1A) shows positive-peak and the highest peak since reset. To reset the highest peak value, press the DCV button. The second multiple display (Figure 1B) shows negative-peak and the lowest peak since reset. The third display (Figure 1C) measures positive-peak and negative-peak, which represent the maximum and minimum levels of the input signal. This display is ideal for measuring the peak-to-peak value of an AC waveform. To access these displays, after pressing the DCV button, simply press NEXT DISPLAY repeatedly until the desired display appears.

Autoranging, Coupling and Filtering

As mentioned earlier, measuring peak spikes in the primary display mode offers users the flexibility of specifying the measurement resolution and of using autoranging, as well as the ability to choose the input coupling (AC+DC or AC only) and filtering desired. However, special care is needed to maintain measurement integrity. For instance, using autoranging will produce inaccurate results if the input signal is a non-repetitive event. The following example illustrates this limitation: If the autoranging function is enabled and a baseline input of 100mV is present, the Model 2001 will choose the 200mV range to measure

[1] Note: The DCV peak spikes measurement is accessed via the AC VOLTS function key in the primary display mode because all peak measurements are performed through the Model 2001's AC circuitry.

this signal. However, if a 10V, 100μs input pulse occurs, it will create an overflow on the 200mV range and cause the Model 2001 to switch upwards to its highest range to take a reading. However, by the time this range switch is completed, the 10V spike will have passed and only 100mV will be present. The unit will display 100mV, then subsequently switch back to the 200mV range. However, *the value of the spike itself is never displayed*. In this case, to get a proper measurement, the user should select the 20V range.

Similar care must be used when applying filters. Generally, filtering is recommended with any of the peak functions. However, this rule-of-thumb does not hold true for one-shot, non-recurring events. Consider an application where the 20V range is selected to measure the input signal described in the previous paragraph, and filtering is enabled. If a 10-reading digital filter is used, then each measurement will have a weight of 1/10 in the displayed reading. The occurrence of the 10V spike would then yield in a filtered reading of (10 + 9(0.1))/10 = 1.09V, which is clearly incorrect. However, if the input signal is repetitive, filtering can be helpful in reducing reading noise.

The selection of the input coupling is also important. When the Model 2001 is AC coupled, a DC blocking capacitor is placed in series with the input, followed by a resistor to ground. This circuit forms a high-pass filter that attenuates low frequency signals. To achieve maximum accuracy, AC+DC coupling should be used for input signals of frequencies less than 200Hz. It is also critical to use AC+DC coupling for square wave inputs, because the input C-R forms a differentiator circuit and will yield falsely inflated peak measurements. This behavior is exactly like that of an AC coupled oscilloscope. In general, the use of AC+DC coupling is recommended whenever possible.

ACV Peak

Operational Overview

This function can be used to measure the peak magnitude of an AC waveform. In this configuration, the input signal is rectified before it is captured by the peak detector. Therefore, the peak captured will be the maximum deviation from zero volts. Due to the rectification, peak values up to 400% of range can be captured, so for example, the 2V range can capture a peak of 8V. However, the rectification process will introduce a small amount of noise into the processed waveform, making it difficult to measure the peak of signals that are very small when compared to the measurement range. Consequently, ACV peak is not specified for peak inputs that are less than 10% of range. While peaks of less than 20mV (in other words, 10% of the 200mV range) are not specified for ACV peak, they can be measured accurately with the DCV peak spikes function.

Display

ACV peak measurements are available via the primary display of AC VOLTS (by selecting PEAK as the AC-TYPE) or as a multiple display of AC VOLTS in conjunction with the rms and average values. While the operation of the peak function is the same in either display mode, two segments of the function control are different: resolution and filter.

ACV peak measurement in primary display mode: When employing the primary display mode, the user can set the peak resolution anywhere from 3½ to 7½ digits. However, selecting a resolution greater than 3½ digits will not yield additional information, as these levels of resolution are below the noise floor of the measurement. Using the factory default setting of AUTO automatically sets the resolution to 3½ digits. Primary display mode also allows the user to control the digital filter. For input signals of stable magnitude, the filter should be used to produce a more stable reading. However, the filter must be turned off to display non-repetitive peaks. Using the factory default setting of AUTO filter automatically enables a 10-reading averaging filter. Note: The information and recommendations concerning resolution and filtering also apply to DCV peak spikes measurements in the primary display mode.

ACV peak measurement in multiple display mode: The advantage of using this display mode is that it shows three ACV measurements (rms, average and peak) simultaneously. With these measurements, the type of AC waveform can often be determined without the need for an oscilloscope. However, there are two disadvantages to using multiple display mode when making peak measurements. The first disadvantage is due to the fact that each of the functions is performed in sequence, even though the readings are displayed simultaneously. That means the Model 2001 is measuring parameters other than peaks during most of the measurement time. Therefore, peaks that occur while the other functions are being performed simply aren't captured. The second disadvantage of this display mode is that the peak readings cannot be filtered, and the resolution is fixed at 3½ digits.

Peak Window

Regardless of the display mode used, the ACV peak measurement function has a fixed peak window of 100ms. Since this function is intended to measure repetitive AC waveforms, this should not pose any serious limitations. If a longer peak window is required, switch the AC-TYPE to POSITIVE-PEAK or NEGATIVE-PEAK.

Autoranging, Coupling and Filtering

The recommendations offered for DCV peak spikes measurements in regard to autoranging, coupling and filtering are also applicable to ACV peak measurements.

ACV Crest Factor

Overview

The crest factor of an AC waveform is the ratio of its peak value to its rms value and specifies the dynamic range of a true rms instrument. For example, a sine wave has a crest factor value of 1.414, while a square wave has a value of 1.

In order to make high accuracy AC rms measurements, always consider the crest factor of the input signal, because the accuracy of many rms measuring units is adversely affected by high crest factor values. However, while most high accuracy AC instruments include a crest factor derating in their specifications, the Model 2001 is the only meter that will also compute the crest factor so that the user can employ the proper derating for a particular application. Crest factor measurement can also be a powerful tool for analyzing a pulse train waveform, because the duty cycle of the waveform can be found directly from its crest factor according to the following equation:

$$\eta = (1/CF^2) \cdot 100$$

where η is the duty cycle expressed as a percentage.

Operation and Display

The crest factor calculation is available as a multiple display of AC VOLTS in conjunction with ACV rms and frequency (Hz) measurements. The Model 2001 calculates the crest factor by taking an ACV peak measurement and dividing it by the rms value. While the instrument is capable of displaying crest factor values up to 9.99, rms measurements are not specified for crest factor values greater than 5.

Coupling and Filtering

From a measurement standpoint, a crest factor measurement is the same operation as an ACV peak measurement. Therefore, the same coupling recommendations apply to both these types of measurements. If filtering is enabled, while the filter will have no effect on the peak measurement, the rms value will be filtered. This may produce inaccurate crest factor readings if there is a large change in the input signal, because the filtered readings will take more time to settle. Note that this behavior will only occur if an AVERAGING type filter is selected. To eliminate this problem, select the advanced filter, because a large input transient will reset this type of filter.

Typical Applications

Single-sided non-repetitive transient capture

Figure 2 illustrates a single-sided non-repetitive transient waveform. The key to capturing a non-repetitive event like this one is setting the peak window parameter properly. The only display mode that offers this option is the primary display mode for DCV peak spikes. Follow these steps to set up the instrument for the measurement:

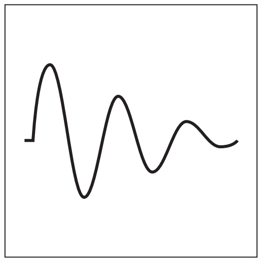
Figure 2: Single-Sided Non-Repetitive Transient Waveform

1. Select the ACV function (primary display mode).
2. Select a measurement range based on the expected value of the transient. Do not use autoranging.
3. To access the configuration menus, press the CONFIGure key.
4. Select VOLTS from the UNITS menu.
5. Select AC+DC or AC from the COUPLING menu.
6. Select POSITIVE-PEAK or NEGATIVE-PEAK from the AC-TYPE menu.
7. Specify a peak window that's long enough to guarantee the signal will be sampled. The size of window required will depend on how precisely in time the transient can be generated. If the occurrence of the transient is unpredictable, the longest peak window possible should be used to maximize the probability of capturing the spike.
8. Configure the unit for one of the user-controllable TRIGGER measure sources, such as MANUAL (by pressing the front panel trigger button), EXTERNAL (a trigger signal from another instrument or a signal from the experiment itself), TRIGLINK (a signal transmitted via the Model 2001's Trigger-Link line), GPIB (signals over the IEEE-488 lines), etc. Any of these sources will allow the user to initiate the measurement.
9. Trigger the Model 2001, then generate the transient. At the end of the peak window, a reading will be displayed.
10. If necessary, adjust the range to display the greatest resolution without generating an overflow reading.

Double-sided non-repetitive transient capture

An example of a double-sided non-repetitive transient waveform is shown in Figure 3. In this application, the operation of the Model 2001 is the same as in the single-sided non-repetitive transient capture, except that both POSITIVE-PEAK and NEGATIVE-PEAK must be used individually to characterize both extremes of the transient.

Figure 3: Double-Sided Non-Repetitive Transient Waveform



Power supply testing

Figure 4A illustrates a typical waveform seen in power supply testing. In this case, the peaks to be captured are double-sided and repetitive. There are two peak capture modes that are suitable for this application.

Figure 4A: Typical Waveform in Power Supply Testing

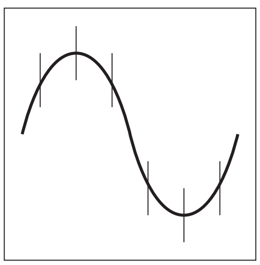


Figure 4B: Multiple Display Showing DCV, Positive-Peak and Negative Peak

The multiple display of DCV that shows both positive-peak and negative-peak simultaneously can be used if it would be advantageous to monitor the DC voltage, as well as the maximum and minimum transient values. To use this mode, press the NEXT DISPLAY button repeatedly while the DCV function is enabled until the multiple display shown in Figure 4B appears. The disadvantage of using this mode is that small transients will not be displayed with much resolution.

To gain more information about the transients, use the primary display mode of DCV peak spikes. Follow these steps:

1. Select the ACV function (primary display mode).
2. Enable autoranging by pressing the AUTO button if the AUTO annunciator is not already lit.
3. To access the configuration menus, press the CONFIGure key.
4. Select VOLTS from the UNITS menu.
5. Select AC from the COUPLING menu.
6. Select POSITIVE-PEAK from the AC-TYPE menu.
7. Enter the length of the peak window desired. This parameter is not usually important if the signal is repetitive. However, a smaller window will result in a higher reading rate. These steps will display the most positive transient.
8. To find the most negative transient, repeat the procedure, starting from Step #6, but select NEGATIVE-PEAK, rather than POSITIVE-PEAK.
9. If the magnitude of the largest transient is the parameter of interest, use the ACV peak function by selecting PEAK under the AC-TYPE menu in Step #6. Keep in mind that this mode rectifies the input signal before feeding it to the peak detector, and that the peak window will be fixed at 100ms.

Pulse train duty cycle characterization

Figure 5A: Typical Pulse Train Waveform

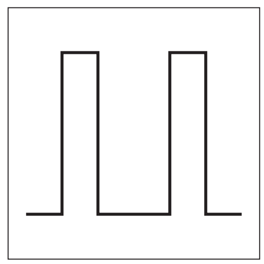


Figure 5B: Multiple Display Showing ACV rms, Frequency and Crest Factor

Figure 5A illustrates a typical pulse train waveform. In this application, the Model 2001's crest factor computation capability is used to determine the duty cycle of a pulse train. This technique is valid only for unipolar pulse trains, i.e. those that originate from a zero DC bias level. To characterize this type of waveform, follow these steps:

1. Select the ACV function.
2. Enable autoranging by pressing the AUTO button if the AUTO annunciator is not already lit.
3. To access the configuration menus, press the CONFIGure key.
4. Select VOLTS from the UNITS menu.
5. Select AC+DC from the COUPLING menu.
6. Press the NEXT DISPLAY button until the multiple display showing ACV rms, frequency, and crest factor appears (See Figure 5B).
7. Use the following formula to compute the duty cycle (η):
   $\eta = (1/CF^2) \cdot 100$

For More Information

While this application note addresses the control and general use of the most common peak measurement functions for the Model 2001, it cannot cover all possible measurement situations. For additional assistance, please call the Keithley Applications Department at 1-800-348-3735.

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