Fermi National Accelerator Laboratory

TM-1699

A Simplified, Improved Method for Making Amplifier Equivalent Noise Charge Measurements Using a New Generation Digitizing Oscilloscope

Tom Zimmerman
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

October 1990

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

A SIMPLIFIED, IMPROVED METHOD FOR MAKING AMPLIFIER EQUIVALENT NOISE CHARGE MEASUREMENTS USING A NEW GENERATION DIGITIZING OSCILLOSCOPE

Tom Zimmerman

October 1990

Abstract

Historically a variety of methods have been used to measure the equivalent noise charge (ENC) of amplifier/shaper systems for high energy physics. Some of these methods require several pieces of special test equipment and a fair amount of effort. The advent of digitizing oscilloscopes with statistics capabilities makes it possible to perform certain types of noise measurements accurately with very little effort. This paper describes the noise measurement method of a time invariant amplifier/shaper and of a time variant correlated sampling system, using a Tektronix DSA602 Digitizing Signal Analyzer.

The Noise Measurement Problem

All charge amplifier systems have a random output noise present which determines the lower limit of signal resolution and affects the accuracy at which a signal can be measured. This random noise can be due to several components, typically series and parallel white noise, and 1/f noise. The amplifier noise is usually referred to the input so that it can be quoted as an equivalent noise charge (ENC) and thus be directly compared to a charge input signal. The standard noise measurement method for a real amplifier system is to measure the RMS noise present at the output, and refer this to the input by dividing by the measured charge impulse gain of the amplifier. Depending on the type of system, one of several different methods is typically used to measure the output noise, such as true RMS voltmeter measurement, use of a multichannel analyzer with readout, or observing count rates out of a variable threshold comparator. However, these methods can be inaccurate and cumbersome, and a significant amount of time may be required to set up the equipment and take measurements.

An attractive solution to the noise measurement problem would be to apply a test input impulse, acquire and digitize the amplifier output signal and noise, then directly calculate ENC from the acquired data. Digitizing oscilloscopes would seem to offer a solution since they can digitize and store high bandwidth signals. However, standard digital scopes cannot directly calculate the RMS value of a random waveform. In addition, one or several data acquisition cycles would not yield enough data to calculate an accurate RMS noise value. A digital scope could be used in conjunction with a PC with a data analysis package to sample large amounts of data and then calculate the desired quantities. However, this could be more difficult and time consuming than the previously mentioned methods.

A simple alternative has recently become available with the introduction of digitizing oscilloscopes with statistics capabilities. At this writing, the Tektronix DSA600 series Digital Signal Analyzer is the only known scope with this capability, but other similar instruments will likely appear in the near future. The important features relevant to noise measurement are the ability to measure and display quantities such as RMS voltage and maximum voltage in a user specified portion of any (random or periodic) waveform acquired during a sweep, and the ability to store and do statistics on the results from a large number of sweeps. When a number of sweeps are stored, the average value and standard deviation of any measured quantity can be computed and displayed.

Noise Measurement of a Time Invariant Amplifier/Shaper System

In order to calculate ENC at a given input capacitance, the impulse gain of the system must be measured. In general this should be done first to insure that the amplifier is working properly and that a reasonable response is observed. The most accurate method of injecting an impulse is by introducing a fast (relative to the amplifier response) step to the amplifier input through an accurately known capacitance. A good choice for this capacitor is a 1% surface mount capacitor (10 pf is a reasonable available value). With a good layout, parasitic capacitance is negligible and the charge injected is thus accurately known. Additional capacitors of this type can be added from amplifier input to ground in order to increase the input capacitance, usually to simulate a given detector capacitance. The input step can be supplied by a signal generator which outputs a good square wave. The frequency should be set as high as is practical without disturbing the impulse response, in order to minimize oscilloscope measurement time.

The charge gain of an amplifier is usually quoted in output voltage per unit input charge, typically in mv/fc. The output voltage for an impulse input is taken as the baseline to peak voltage difference of the output response. To measure the response with a digital oscilloscope, the amplifier should drive a 50 ohm terminated scope input. A suitable coupling capacitor may be necessary at the amplifier output to prevent DC currents. In some cases a buffer may be necessary to drive 50 ohms. However, care should be taken since the buffer can add noise and affect frequency response. The bandwidth of the scope channel used should be set to the lowest value possible without affecting the observed amplifier response. It is best to trigger the scope with the input signal generator trigger output. To accurately measure the peak, the scope should be placed in averaging mode to effectively eliminate the random noise. The number of averages necessary for a stable response depends on the magnitude of the noise. The baseline to peak difference can be measured with cursors. Or, the peak-to-peak measurement function of the scope can be used, as shown in Figure 1.

If a reasonable response and gain are observed, the output noise voltage should then be measured. First, however, it is important to verify

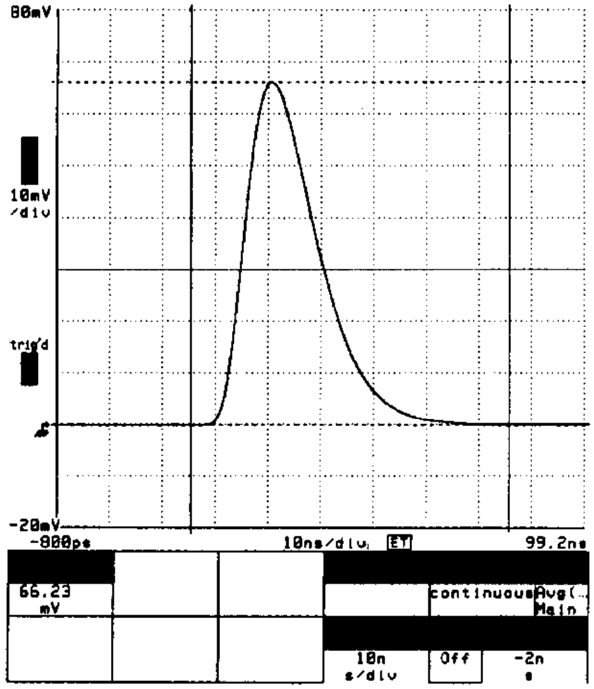

FIGURE 1. Impulse gain measurement.

that only the amplifier random noise is being measured. It is not uncommon for amplifiers to pick up external environmental noise. The easiest way to see if this is a problem is to leave the scope in averaging mode to eliminate the random noise, as for the gain measurement, and remove the input signal. The trigger should then be derived directly from the amplifier output scope trace, not from the signal generator. The scope vertical gain must be high enough so that triggering can be accomplished on the amplifier output noise. The trigger level should be set as high as is possible while maintaining consistent triggering. Any non-random periodic external noise should be readily apparent. If only amplifier random noise is present, this will average out to zero. The DSA602 has FFT capabilities, which can be used to quickly spot added noise energy at specific frequencies in the output noise spectral density. An example of the FFT output is shown in Figure 2. The FFT output was averaged to obtain a clean display. In this example, a 35 MHz signal pickup is the largest source of interference. The higher frequencies around 100 MHz are probably radio stations. The FFT can be a valuable aid in understanding what external noise sources are present.

External noise can be eliminated or greatly reduced by proper shielding and bypassing. A sometimes easy and effective solution is to simply put the amplifier inside a grounded metal box. Once external noise has been eliminated, the amplifier output noise can be measured. This requires a scope trigger which is not derived from the amplifier output. The easiest

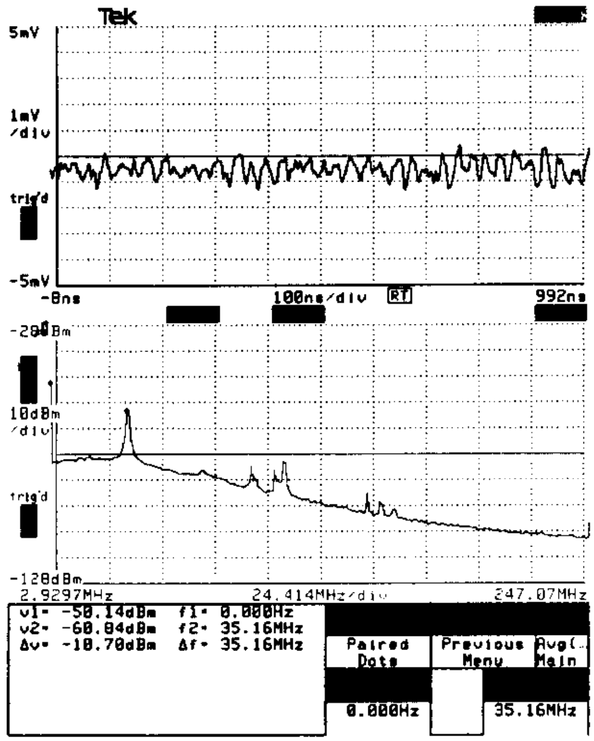

FIGURE 2. FFT of amplifier output noise.

way to achieve this is to use the signal generator trigger output to trigger the scope, as was done for the gain measurement. (However, no signal should be applied to the amplifier). The RMS measurement function should be invoked to measure the output noise. The measurement function can be set to operate over one signal period, or over a specified zone of the scope display. Since noise is aperiodic, zone measurement must be selected. For this noise measurement, the whole zone (0-100% of the screen) should be selected. A numeric result will be displayed for each sweep. By turning on the statistics function and setting the number of events to several thousand, a large amount of sweep data will be accumulated. Displayed will be the average, min, max, and standard deviation for the complete set of RMS values recorded. The average is the RMS output noise voltage of the amplifier.

If the magnitude of the amplifier output noise is low enough, the input noise of the scope may become a non-negligible portion of the measured result. In this case, a more accurate amplifier output noise result may be found by disconnecting the amplifier from the scope, performing another noise measurement, and subtracting in quadrature this result from the previous measured result.

Noise Measurement of a Correlated Sampling System

Integrated circuits for high energy physics which perform correlated sampling are becoming commonplace, since this is relatively easy to do in CMOS technology. These circuits essentially sample the output level of a charge integrator before and after the signal arrival time, and then store the difference as a voltage on a capacitor for subsequent readout. Usually many channels are on one chip, and the readout is multiplexed onto one analog output bus. Since the integrator has some output noise, the sampled result will have some uncertainty related to the magnitude of the noise. In other words, for a given charge input, the output will be a DC level which is proportional to that charge, but with some uncertainty. Therefore repeated acquisition and readout cycles will produce a distribution (most likely Gaussian) of output levels. The ENC of the system can be found by measuring the charge gain and the output noise.

The charge gain measurement method for a correlated sampler is very similar to the time invariant amplifier measurement method. Averaging should be used to eliminate noise. The test channel output level should be measured for no charge input, and again for a known charge input. Cursors can be used to measure the output voltage change, as shown in Figure 3. The gain is simply the output level difference divided by the input charge.

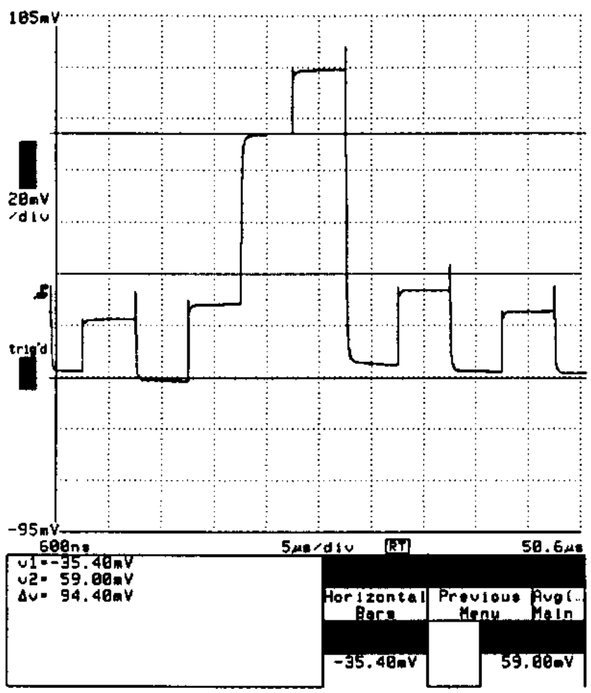

FIGURE 3. Correlated sampler gain measurement.

The RMS output noise can be found by measuring the standard deviation of the output level distribution for a large number of acquisition and readout cycles. This type of noise measurement requires a different method than that used for the time invariant amplifier. An RMS noise measurement of any given output level is not desired (since it is ideally just a noise free DC level), but rather a statistical compilation of a large number of output level values. To measure the output voltage, the measurement parameter should be set to max voltage (or min, or mid, since they should all be the same), during the time that the tested channel output is displayed. Zone measurement should be used, as opposed to periodic, since a measurement is desired at a specific time. Only the region of the readout which corresponds to the channel to be measured should be displayed on the screen. This can be accomplished by using a time base window function, or by triggering the scope at the appropriate time during the readout. For best results, the measurement zone should be constrained to a small portion of that channel's readout time (1% of the screen works well), in an area where the voltage has stabilized. To do this, the left and right measurement limits need to be changed from their defaults of 0% and 100% of the screen. This is shown in Figure 4.

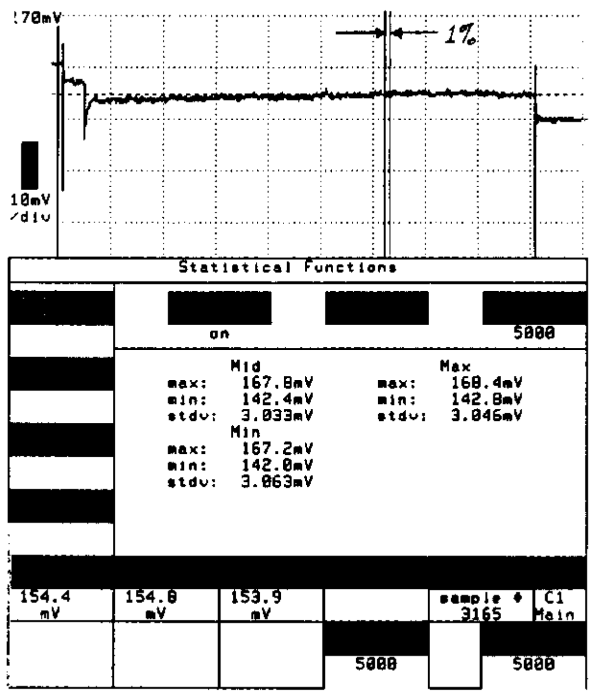

FIGURE 4. Correlated sampler noise measurement.

The statistics option should then be invoked, and the number of samples set high enough to give stable results (typically set to several thousand). If the measurement is done properly, the standard deviations of max, min, and mid voltage measurements will be nearly identical. The measured standard deviation is the RMS output noise. The ENC of this system is then calculated by dividing the output noise by the charge gain.

Conclusion

The techniques described here greatly simplify amplifier equivalent noise charge measurement, and represent a significant savings in time and effort when compared to existing methods. Fast discriminators, pulse counters, and sensitive manual adjustments are eliminated for time invariant system noise measurement. For correlated sampling systems, pulse height analyzers and the associated manual measurement of standard deviation are no longer required. One general purpose instrument can be used to make all amplifier gain and noise measurements. In addition, typical problems such as external noise pickup are easily identified, resulting in more accurate measurements.