SIGNAL RECOVERY

Boxcar Averager Specification Comparison

TECHNICAL NOTE
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Introduction

This Technical Note compares key specifications of the **SIGNAL RECOVERY** model 4121B Boxcar Averager with those of the SRS SR250 Gated Integrator. The following sections discuss some key specification differences in detail, which are then summarized at the end of the document.

Time Response

An amplifier followed by a sampling gate and an integrator make up what is known as a *gated integrator* or *boxcar averager*. The time response of the amplifier (t_{Amp}) and sampling gate (t_{Gate}) determine the time resolution of the instrument (t_{GI}). To a first approximation, the time response of an amplifier is 0.35 divided by its 3 dB bandwidth ($t = 0.35/f_{-3dB}$). The overall time response is calculated by summing the squares of the individual responses and then taking the square root ($t_{GI}^2 = t_{Amp}^2 + t_{Gate}^2$). To achieve the best performance/cost ratio, the time response of the amplifier must be just fast enough so that it adds very little to the response time of the gating circuit. Design it with a much faster response and the cost increases with only marginal improvement in resolution. Design it with a slower response and the effort and cost put into the gate design is wasted, giving poorer resolution.

The gatewidth of the **SIGNAL RECOVERY** model 4121B is 1.5 ns, with an amplifier bandwidth of 400 MHz, giving a response time of 0.875 ns. Hence the overall response is **1.7 ns**. The SR250 is specified with sampling gate response time of 2 ns, which by itself, is meaningless. Its input amplifier has a 3 dB bandwidth of only 100 MHz, giving a 3.5 ns response time and limiting its true time resolution to **4.0 ns**.

Amplitude Response and Stability of the Sampling Gate

An important measure of a sampling gate's stability is how its amplitude response changes as a function of its width. The model 4121B gate's amplitude response is stable over its entire range of widths. On the model SR250, we have measured a drop in the response of 30% when the gatewidth is reduced from 100 ns to 10 ns, and an additional drop of 29% when it is reduced further, from 10 ns to 2 ns. This is an overall drop of 50%, not only affecting stability but also significantly reducing the input sensitivity specification at short gatewidths. Table 1, discussed in the next section, makes this clear.

Input Sensitivity

The term *sensitivity* is often thought of as the input voltage (or current) required to produce a full-scale output. Hence when comparing sensitivity specifications expressed simply in terms of input signal level, it is important that the full-scale output is the same, which is the case with the 4121B and SR250. Alternatively, instrument gain can be calculated (normally quoted in reciprocal units of millivolts of input per volt of output) to eliminate the need to take the full-scale output voltage into account.

Table 1 below gives the sensitivity characteristics of the model 4121B. From this it can be seen that the **model 4121B is five times more sensitive than the SR250** at short gatewidths.

	Model 4121B at all gatewidths	SRS SR250 at > 100ns gatewidths	SRS SR250 at 10 ns gatewidth	SRS SR250 at 2 ns gatewidth
Input Sensitivity	20 mV	50 mV	71.2 mV	100 mV
1/Gain	2 mV per Volt	5 mV per Volt	7.12 mV per Volt	10 mV per Volt

Table 1, Instrument Sensitivity and 1/Gain Comparison

Input Impedance

The model 4121B offers input impedances of 1 MΩ or 50 Ω via two separate connectors. The 50 Ω input amplifier is DC coupled and gives a true 50 Ω impedance, giving both high bandwidth and excellent voltage standing-wave-ratio (VSWR). VSWR indicates how much of the input pulse reflects from the input amplifier, back into the input cable, with a perfect figure implying that the amplifier completely absorbs the signal presented to it. In this case there is no reflection back towards the source that might cause distortion or an erroneous signal to appear.

Some experiments need a high input impedance, but in these cases the signal bandwidth will be limited by the input time constant, which is given by the product of the cable capacitance and the input impedance. Such experiments can use the 4121B's 1 MΩ input, which is connected to a unity gain buffer amplifier. The bandwidth of this amplifier is lower than that of the 50 Ω input amplifier, but this is not a restriction since the bandwidth will in this case be limited by the input time constant.

The SR250, on the other hand, has only one input amplifier with a 1 MΩ input impedance, restricting the signal bandwidth. This also means that when a 50 Ω input is required then the user must fit an external coaxial terminator.

Hence the 4121B gives the user the option of using a true 50 Ω input when maximum bandwidth is required (typically for the narrowest input signals and short gatewidths), while still offering a 1 MΩ input when this is needed. The SR250, on the other hand, only offers a 1 MΩ input that has limited bandwidth.

Trigger Rate

The repetition rate of lasers and other signal sources is constantly rising. As a result, the maximum trigger rate of boxcar averagers is increasingly important, since it determines whether the required data can be collected in the time available. For example, assume that the experiment is capable of running at the maximum trigger rate of the boxcar. In this case, the 4121B's 80 kHz trigger rate will allow data to be taken **four times faster** than when using the SR 250, which is limited to a 20 kHz maximum trigger rate.

Inter-Sample Correlation

Both the 4121B and SR250 provide a Last Sample Output signal. This is an analog voltage that represents the integral of the input signal during the gatewidth for the sample initiated by the previous trigger pulse. Clearly it is desirable that the voltage at this output should relate only to the sample corresponding with the last trigger pulse, but in practice this may not be the case. In the SR250, for example, this output is not fully reset between triggers, and up to 5% of the sample corresponding to trigger t_{n-1} can remain and thereby affect the sample corresponding to trigger t_n. The equivalent figure for the model 4121B is less than 0.5%.

One way of trying to obtain the same performance from the SR250 as that from the 4121B is to ignore every other sample at the last sample output. Hence, for example, the sample taken at t_{n-2} is used, but that at t_{n-1} is ignored. The next sample, at t_n is also used, since this now has a maximum error due to the last sample which was used, at t_{n-2} of 5% × 5%, or 0.25%. However, this technique clearly results in the maximum data collection rate for the SR250 being half of that for the 4121B, when using the Last Sample Output. When the maximum trigger rate is also taken into account, this gives a maximum data acquisition rate for the 4121B which is eight times that provided by the SR250.

Trigger to Sample Time

Boxcar averagers always take time to respond to a trigger, which is known as the *intrinsic delay*. This delay is the time from the receipt of a trigger to the point at which the sampling gate opens. Designers struggle with keeping this time as short as possible, since the signal of interest often starts at the same time as, or only shortly after, the trigger.

In the model 4121B the minimum intrinsic delay is 20 ns, while that in the SR250 is 25 ns. Although this difference of 5 ns is small, it can still make a difference between measuring the signal and not finding it at all. In really difficult situations, the 4121B's internal delay board can be bypassed to reduce its intrinsic delay even further, down to 15 ns

Long Gatewidths

The model 4121B has gatewidths that are continuously variable from 1.5 ns to 150 µs, while the SR250's longest gatewidth, without dismantling it and changing a capacitor, is 15 µs

Analog Averaging Mode

Both the 4121B and SR250 include an analog output averager, with both offering an exponential averaging mode that is good for following changing signals. This is because it "forgets" older data in an exponentially weighted fashion. The weighting factor for a given output sample is $e^{1/-t}$, where time t is the time between this sample and the most recently acquired one. Because of its forgetful nature, the exponential averaging is not the optimum choice when measuring the smallest signals.

The 4121B offers a second mode of analog averaging that is not provided in the SR250. This is linear averaging, in which each output sample contributes equally to the output, ensuring that none of the precious signal is "thrown away". The result is the best signal-to-noise improvement in the shortest amount of time.

Baseline Subtraction

In some experiments using laser sources it is useful to be able to sample both the signal of interest and the baseline signal, subtracting one from the other to eliminate baseline drift. The baseline subtraction mode of the boxcar averager can help in such cases. In this mode, both the experiment and boxcar are triggered at twice the required rate, but the boxcar generates an output signal that indicates whether the given trigger will be treated as a signal or a baseline value. This signal can then be used to driver a shutter or light chopper, such as the ***SIGNAL RECOVERY*** models 197 or 651-1, which effectively block alternate laser pulses from exciting the experiment.

Both the 4121B and SR250 include this Baseline Subtraction mode. But the model 4121B also includes another baseline mode, which can be used at high trigger rates when the chopper or shutter used in the normal mode cannot respond fast enough. In this second mode the boxcar accepts a TTL "steering" input that indicates whether a sample is to be treated as a signal or a baseline value. Hence, for example, in an experiment running at 20 kHz trigger rate, an external chopper, running at say 1 kHz could be used to drive this input. The effect would be that groups of 20 samples would be treated alternately as signal and baseline values. The SR250 does not provide this extra flexibility.

Summary

Table 2 below summarizes the above discussion, from which it will be seen that the ***SIGNAL RECOVERY*** model 4121B Boxcar Averager offers a number of significant advantages over the SRS SR250

Specification	***SIGNAL RECOVERY*** model 4121B	SRS SR250
Input Time Response	1.7 ns	4.0 ns
Max. Input Bandwidth	400 MHz	100 MHz
Amplitude Response	Flat over all gatewidths down to 2 ns	Flat to gatewidths to 100 ns Drop by 30% at gatewidths down to 10 ns Drop by 50% at gatewidths down to 2 ns
Max. Sensitivity	All gatewidths: 20 mV	> 100 ns gatewidth: 50 mV 10 n gatewidths: 71.2 mV 2 ns gatewidth: 100 mV
Input Impedance	1 MΩ or 50 Ω	1 MΩ only
Max. Trigger Rate	80 kHz	20 kHz
Inter-Sample Correlation	less than 0.5%	less than 5%
Min. Trigger to Sample Time (Intrinsic Delay)	With Delay Board in circuit: 20 ns Delay Board bypassed: 15 ns	25 ns
Standard Gatewidth Range	1.5 ns to 150 μs	1.5 ns to 15 μs

Table 2, Comparison of Key Specifications - Model 4121B vs. SRS SR250

Further Information

This Technical Note compares the specifications of two commercial boxcar averagers. Additional information may be found in other ***SIGNAL RECOVERY*** publications, all of which may be downloaded from our website at **www.signalrecovery.com**

In addition, staff at any of our offices or those of our distributors and representatives will be happy to answer any questions you may have. For contact details, please visit our website at **www.signalrecovery.com**

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