ULTRA-FAST VOLTAGE COMPARATORS FOR TRANSIENT WAVEFORM ANALYSIS

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ABSTRACT

The time at which an input signal crosses the reference level of a voltage comparator can be used in the analog-to-digital conversion of fast single waveform transients. In such a converter, an array of identical comparators, properly biased, provides stop inputs to a picosecond resolution multistop time digitizer. Each stop represents a point in the voltage-time reconstruction of the measured waveform. A number of state-of-the-art comparators, bipolar and GaAs, have been evaluated for this application to determine the differences in their time propagation as a function of the input signal overdrive and risetime. Normalized data is presented to assist in the correction of a digitizer's measurement errors. A picosecond time resolution measurement system used in the tests is also described.

INTRODUCTION

Electrical transducers are frequently designed to generate voltage waveforms as a response to a measured physical quantity. Voltage comparators are often used as a first step in the chain of analog-to-digital conversion of such waveforms. The leading edge of the comparator's output waveform is generally used as a time reference marking the input threshold crossing. If a sufficient number of identical comparators (each preset to a different threshold) are used to monitor the same input signal, and the appearance of their output signals recorded by time-to-digital converters, the measured waveform can be faithfully reconstructed.

The procedure is illustrated in Fig. 1. A single transient waveform, $V_i(t)$, is preceded by a start pulse, V_{st}. The leading edge of V_{st} initiates the timing in all the time-to-digital converters of the system. V_{thr1} to V_{thr3} are the threshold settings of the three comparators shown and t_1 to t_3 are the times of each threshold crossing as defined by the leading edge of the comparator output pulse. These pulses are used to stop the counting in the time digitizers. Each digitizer thus holds a number (N_1 to N_3) proportional to the times of the threshold crossings referred to the common start.

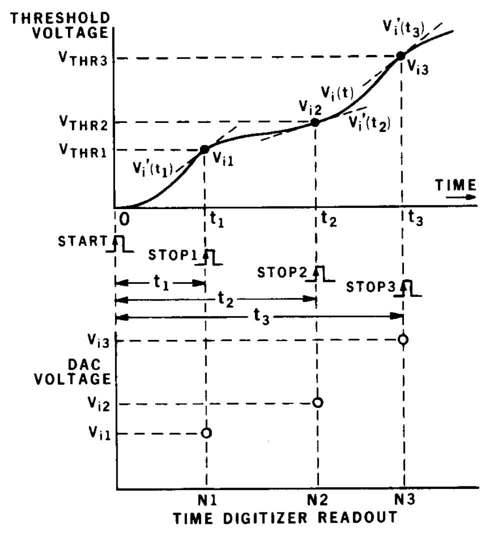

Fig. 1. Procedure for reconstruction of a measured waveform by plotting comparator threshold crossing time.

In practice, the accuracy of the digitization is affected by the response time of the comparators used. If the input waveform changes at too fast a rate, the comparator will exhibit a time walk, resulting in an erroneous measurement. The response of a comparator to a step input voltage is mainly affected by the amount of overdrive, i.e. the portion of the input signal exceeding the threshold level. Comparators with lower gain (for instance some ECL varieties) can be influenced significantly by the rate of signal change immediately above the threshold crossing. To a smaller degree, the portion of the input signal below the threshold may influence the shape of the comparator output and therefore the timing due to a shift of the output reference point.

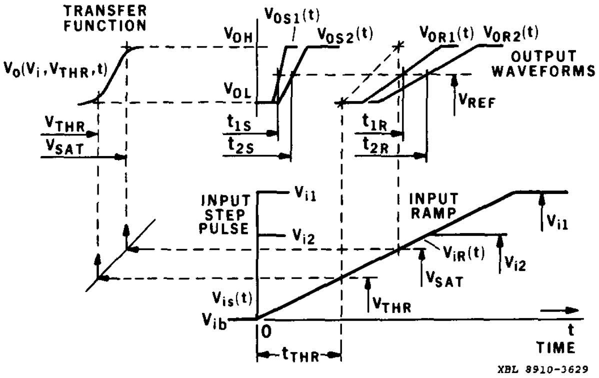

Fig. 2. Illustration of comparator output time walk as a function of input voltage risetime and overdrive.

The response of a model comparator to a step, $V_{is}(t)$ and a ramp, $V_{ir}(t)$ is illustrated in Fig. 2. For each of these waveforms, two amplitudes, V_{i1} and V_{i2} are shown. These amplitudes exceed the comparator threshold, V_{thr} by overdrive voltages $V_{od1} = V_{i1} - V_{thr}$ and $V_{od2} = V_{i2} - V_{thr}$. The corresponding input threshold crossing times are 0 for the step and t_{thr} for the ramp inputs.

The output response is dictated by the input-to-output voltage transfer curve of the comparator which extends from V_{thr} to V_{sat} at the input and V_{oL} to V_{oH} at the output. This transfer curve is a function of the comparator gain, input overdrive and signal rate-of-change. Consequently, four different output waveforms are shown in the figure, one for each input overdrive and risetime. The output waveforms are shown simplified as ramps: $V_o - V_{oL} = K(t - t_d - t_{thr})$ where K and t_d are transfer function parameters which are different for each input overdrive and risetime. The output timing is specified as the time, t_{ref} at which the output signal crosses an arbitrary value, V_{ref}, usually the mid point of the response curve as shown in the figure. The measurement error is then given by

$$t_{ref} - t_{thr} = t_d + (V_{ref} - V_{oL})/K$$

The quantities, K and t_d are characteristic of the comparator and cannot generally be influenced externally. However, the second term in the equation can be made smaller if V_{ref} is close to V_{oL}.

Because of the importance of the overdrive, $V_i - V_{thr}$ on the time walk error of the comparator, it is useful to normalize the measured data, presenting the time walk error as a function of the overdrive ratio, r_i where $r_i = (V_i - V_{thr})/V_i$. With this definition, all measured curves fall in the range between 1 (100% overdrive) and 0 (the input signal barely exceeds the threshold) and provide a convenient means of comparing the performance of different devices.

The following commercially available comparators were evaluated:

VC7695, VTC Inc.,(bipolar); AD9685, Analog Devices (bipolar); HCMP96870, Signal Processing Technologies (bipolar); AM685, Advanced Microdevices (bipolar); 10G012B, Gigabit Logic (GaAs); TQ6331, TriQuint Semiconductor (GaAs).

MEASUREMENT SYSTEM AND PROCEDURE

A block diagram of the system used for generating the measured data is shown in Fig. 3 and described in greater detail in Ref. 1. The output of a fast rise time pulse generator was split into two signals of which one was used to start the time digitizer and the other employed to provide a calibrated pulse for the comparator under test. A variable reference voltage was also supplied

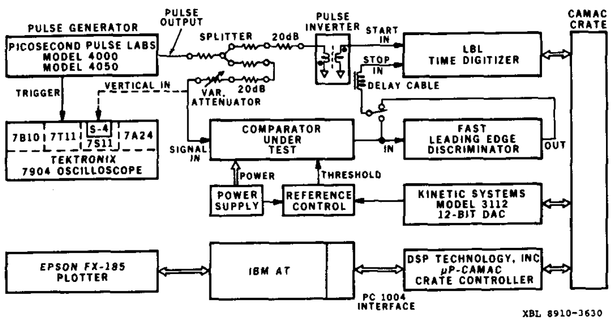

Fig. 3. Block diagram of the measurement system.

to the comparator under computer control. The output of the comparator was used to stop the time digitizer. To obtain high precision in the timing measurements, a large number of measurements were repeated and averaged by the computer.

As shown in Fig. 4 and Ref. 1, averages of 2000 samples yield a measurement precision of better than 5 ps. The following major components were used: A Picosecond Pulse Labs Model 4000 fast rise time pulse generator provided test pulses with a risetime of about 120 ps. (Some measurements were made with a 50 ps risetime model 4050, but it unfortunately became available late in the course of this work.) A Tektronix model 7904 oscilloscope with 7S11/7T11 Sampling plugins was used to evaluate the pulse generator performance.

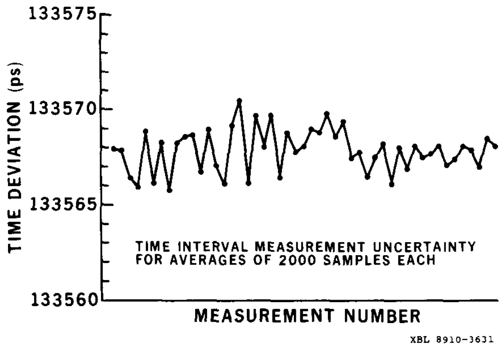

Fig. 4. Statistical timing error of the system in Fig. 3. Fixed time interval of 133.565 ns was measured 40 times with 2000 samples each.

An LBL built 12 channel high resolution time digitizer[1] with a range of 24 bits (1.3 ms) and a LSB resolution of 78.125 ps was used for the timing measurements. The instrument requires either fast NIM or ECL pulses for the start and stop inputs, making it directly compatible with comparators having ECL outputs. The digitizer is CAMAC compatible. A Kinetic Systems model 3112 12 bit DAC, also CAMAC, was employed to scan the threshold level over a 10 V range. Appropriate reference control circuitry was used to adapt its output to the range and level requirements of the comparators tested.

An IBM PC/AT computer fitted with a DSP Technology model 6001 crate controller served to control the CAMAC modules, process and store the data, and plot the results. A C-language program called VDIG, described previously[1], was used to control the experiment.

Each tested comparator required a different printed circuit test card with circuitry providing proper power and bias levels, filtering and decoupling. Very wide band components of this kind need carefully laid out printed circuits in order to avoid a disappointing performance. The GaAs devices are particularly difficult to evaluate. For each of these devices, a factory built test jig was purchased which allowed for a relatively easy change of the component under test and provided an adequate heat sink protect it from damage.

The output waveforms of some comparators required reshaping by a leading edge discriminator in order to make sure that the timing was always related to the known reference level. In this case, measurements were taken with and without the discriminator in order to evaluate the effect of its use.

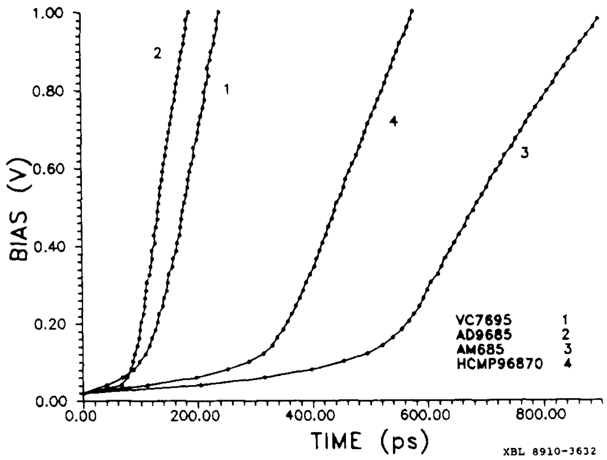

Fig. 5. Response of four bipolar fast comparators to 1.4V, 120 ps rise time pulses. The curves are shifted horizontally to compensate for propagation delay differences.

TEST RESULTS

The four tested bipolar comparators exhibit significantly different time walk characteristics as shown in Fig. 5 where an identical 120 ps risetime pulse of amplitude 1.4 V was applied and measured as a function of the threshold bias. Fig. 6 shows the behavior of the VC7695 device for a sequence of pulse amplitudes: (a) 1.31V, (b) 0.98V, (c) 0.69V, (d) 0.48V and (e) 0.245V. The repeated measurement for (a) illustrates the precision of the data, i.e. no time drift occurred for the duration of the measurement.

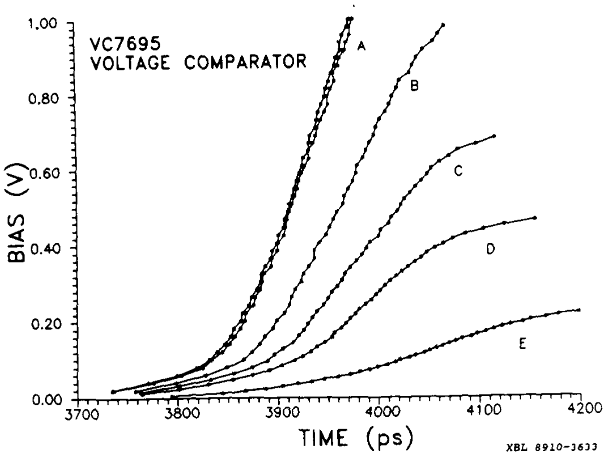

Fig. 6. VC7695 comparator response to 120 ps rise time pulses of amplitudes (a) 1.31V, (b) 0.98V, (c) 0.69V, (d) 0.48V and (e) 0.245V.

In order to compare the results obtained for the different devices, the data shown in Fig. 6 was normalized and plotted as a function of the overdrive ratio as described above. The normalized data is shown in Fig. 7. As can be seen, the time walk increases for very small input pulses and is best controlled over the central 20-80% of the overdrive range. Normalized test data for AD9685, AM685 and HCMP96870 are shown in Figs. 8, 9 and 10.

The normalized data shows the total time walk of the comparator and includes contributions from the finite risetime of the input pulse. To separate these contributions, a sampling oscilloscope photograph of the input waveform was digitized and subtracted from the data. The result is shown in Fig. 11 for the VC7695. Corrected curves such as these can be used to estimate the precision with which a given transient signal can be measured and offer a means whereby a first order correction to the digitized data can be obtained.

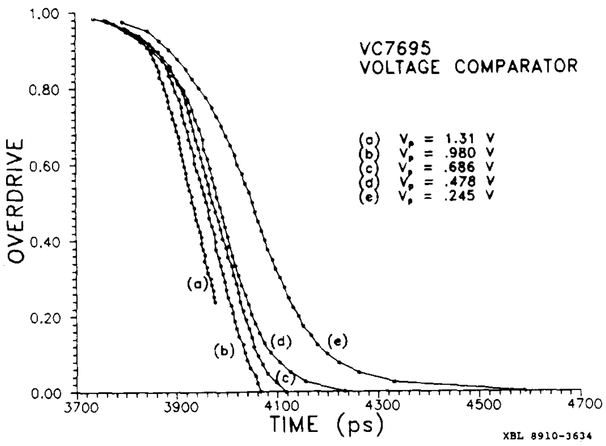

Fig. 7. Normalized data from Fig. 6 showing comparator time walk as function of overdrive ratio $r_i=(V_i-V_{thr})/V_i$.

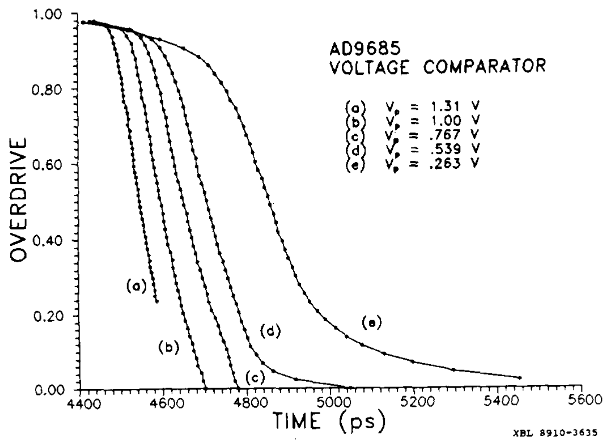

Fig. 8. Normalized time walk of AD9685 comparator.

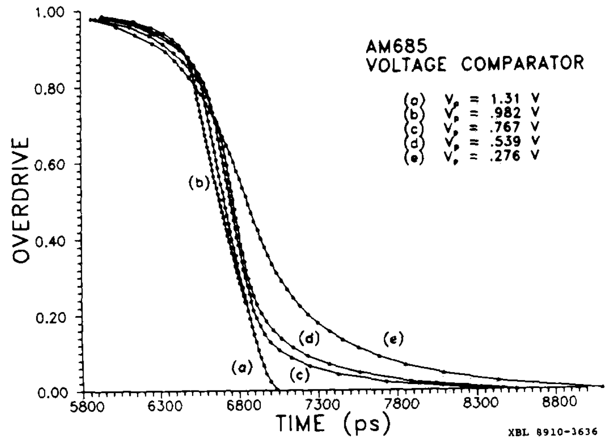

Fig. 9. Normalized time walk of AM685 comparator.

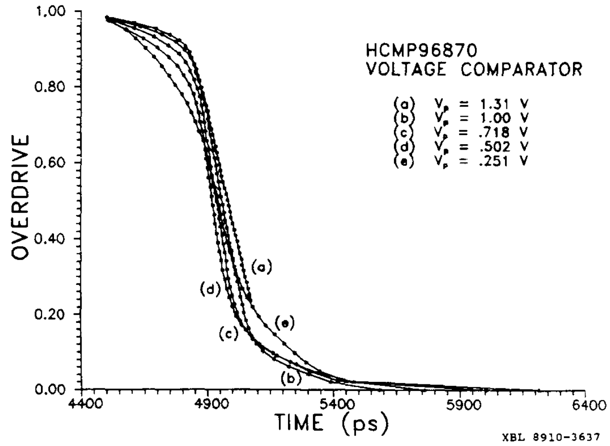

Fig. 10. Normalized time walk of HCMP96870 comparator.

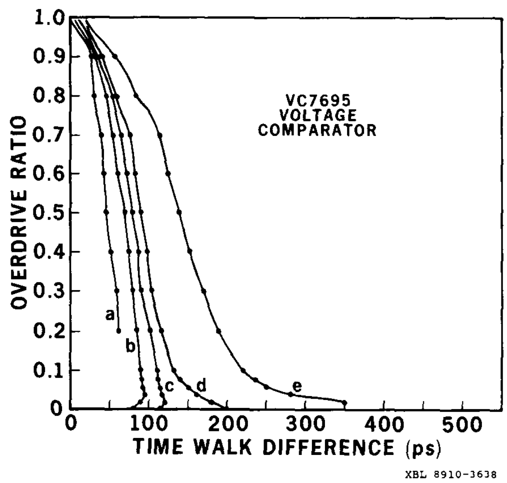

Fig. 11. Compensation of normalized time walk of VC7695 (Fig. 7) by subtracting the input pulse leading edge time.

Tests of the GaAs comparators have so far been limited to the GigaBit Logic 10G012B and 10G013 Dual Complementary Driver/Comparator and to the TriQuint Semiconductor TQ6330 and TQ6331 Pin Driver/Line Receiver.

A High Speed Prototyping Kit (90GKIT-40) was used for testing the 10G012B and 10G013 and a model ETF-MIC44/24 Test Fixture was employed to evaluate the TQ6330 and TQ6331. These kits were designed for testing the devices for high speed digital applications and had to be adapted for the comparator tests. Since access to the internal circuitry of the devices is limited, an interpretation of the results is difficult in some cases.

Several devices of each kind were tested, and within each group performed uniformly. Typical normalized data for the 10G012B is shown in Fig. 12 and for the TQ6330 in Fig. 13. The performance of the former is comparable to the best of the bipolar devices (VC7695, Fig. 7), while the latter was found to be quite inferior, contrary to expectations.

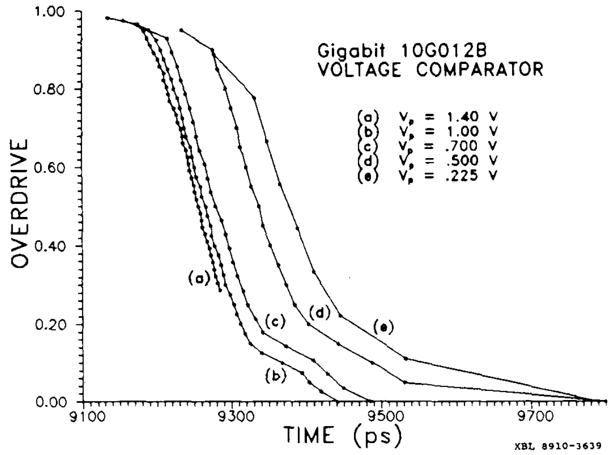

Fig. 12. Normalized time walk for 10G012B GaAs comparator.

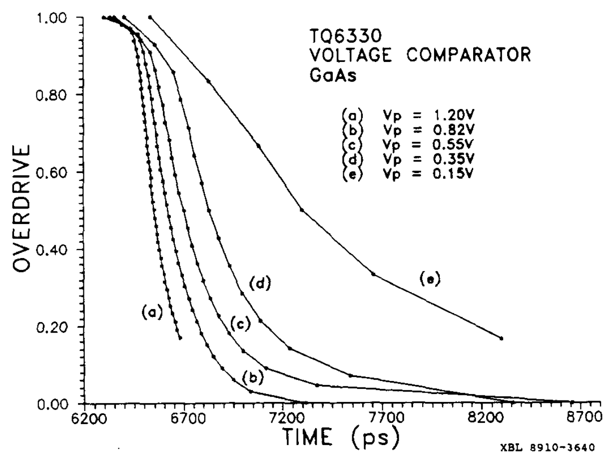

Fig. 13. Normalized time walk for TQ6330 GaAs comparator.

CONCLUSION

A selection of six state-of-the-art fast voltage comparators was tested under almost identical conditions. The measured data was normalized for easy comparison of the devices' performance. Each device exhibits a distinctive individual timewalk characteristic of its input voltage pulse amplitude and the amount of input overdrive. Of the bipolar devices, the VC7695 performance is the best. The GaAs 10G012B device is equally good or somewhat superior. However, high power dissipation and more complex power and bias supply requirements make this device less attractive.

The objective of this work is to describe reliable instrumentation for a consistent automatic measurement of time walk in the picosecond time region and establish a way to normalize the data in order to provide an easy comparison of various devices. More work is required to evaluate other available fast comparators in order to select those with the best time walk characteristics.

ACKNOWLEDGMENTS

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REFERENCES

[1] W.F. Kolbe, B.T. Turko and R.C. Smith, Evaluation of Fast Voltage Discriminators in the Picosecond Time Range, IEEE Transactions on Nuclear Science, 36, No. 1, pp. 412-415, February 1989.

[2] Data Manuals: 1. Analog Devices Inc., Norwood, MA; 2. Signal Processing Technologies, Honeywell Inc., Colorado Springs, CO; 3. VTC Incorporated, Minneapolis, MN; 4. Advanced Microdevices, Sunnyvale, CA; 5. Triquint Semiconductor, Inc., Beaverton, OR; 6. GigaBit Logic, Inc., Newbury Park, CA.