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High-Speed Differential Track-Hold Digitizer

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HIGH-SPEED DIFFERENTIAL *
TRACK-HOLD DIGITIZER

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ABSTRACT

Obtaining accurate measurements in noisy environments or measurements with slowly varying background biases can be difficult, and at times impossible, when the background variation has a high dynamic range. Obtaining useful data with resolutions of one part in 10,000 (0.01%) in these types of environments can be simplified through the use of a differential track-and-hold system. This paper describes a differential technique to obtain ground reference correction during real-time high-speed data collection.

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Introduction

The design goal of this track-hold/conversion circuitry was to measure integrated current pulses with an accuracy of 0.01%. Input signals were derived from an optic detection system used in monitoring pulses superimposed on a CW laser beam. The detection system⁽¹⁾ uses a photodiode bridge for first-order noise cancellation. The diode bridge output, resulting from the CW laser, is a DC current of $\sim 0.5\text{mA}$, with low-frequency components corresponding primarily to laser power supply variations. The (fast) signals to be measured are optically coupled to the detection system. The resulting signals occur as $\sim 10\text{ns}$ (FWHM) current pulses repeated at 100ns intervals, superimposed onto the DC current. This total signal is applied to the input of an Ortec 142A amplifier, which integrates the current pulse onto a 1pF capacitor and feeds the resulting voltage to the differential monitoring and recording system to be discussed below.

The RMS value of shot noise is given by⁽²⁾

$$I_{\text{sh}} = \sqrt{2qI_{\text{DC}}\Delta f}$$

where

q = electron charge, $1.59 \times 10^{-19}\text{C}$,

I_{DC} = direct current in A, and

Δf = noise bandwidth in Hz.

The integrated shot noise can be approximated by

$$Q = \sqrt{I_{\text{DC}} T q},$$

where T = time (integration period). This Q represents 2mV when a DC current of 0.5mA is integrated on a 1pF capacitor for 50ns . Thus, the differential track-hold and conversion system has to resolve at least 2mV to be shot noise limited.

The Circuit

The circuitry is housed in a triple-width Nim module provided with $\pm 6V$, $\pm 12V$, and $\pm 24V$ from a standard Nim-powered rack. The construction uses all-ground plane, high-frequency techniques, with major inner connections done with coax and SMA connectors.

The "front end" (see Figure 1) of the differential system consists of two Computer labs THS-0025 Track-and-Hold Modules, with acquisition times of 15ns and linearities of 0.01%. The input range is $\pm 2V$, leading to a resolution limitation of 200 μV . The output of each THS-0025 is connected to a separate input of a Teledyne Philbrick Model 1435 high-frequency, fast-settling operational amplifier. The 1435 has a settling time of 70ns to .01%. The output of the 1435 is fed to a third track-and-hold amplifier, an Analog Device Model SHA-2A. The SHA-2A in turn drives

a Computer Labs analog-to-digital converter, model MAS-1202. This converter generates a 12-bit digital binary word in $2\mu\text{s}$, to avoid errors due to the droop rate of the SHA-2A. The $2\mu\text{s}$ conversion time also sets the repetition rate limitation on the system of 500KHz (more than adequate for the 10Hz data rate.)

The binary output from the MAS-1202 is fed via the rear panel to a PDP-11 for data storage and manipulation. The binary data are also routed internally to a series of SN74185 TTL memories, where the data are converted to BDC for a front panel 4-digit LED display.

The other support circuitry consists of timing modules for signal control and power supplies used to convert Nim power to module power.

Operation

The basic design principle of the circuitry is that of differential noise subtraction. The front end modules (with their inputs in parallel) normally are operated in "track" mode, i.e., the outputs track or follow the inputs. Since (normally) the inputs look at the same input signal voltage and the outputs are subtracted, the resulting output of the 1435 is zero.

With the anticipation of a pulsed signal, one of the THS-0025 modules is commanded to "hold", thereby storing a reference voltage. After the signal propagates through the other module, it too is "frozen", storing the sum of the reference voltage and the signal pulse. The magnitude of the reference voltage will not be exactly the same in both amplifiers, since a finite time has elapsed between the two hold commands. This time delay is variable and can be set to some compromise between noise cancellation and signal rise time: i.e., the delay has to be long enough to allow the input signal to get through the second amplifier; otherwise, it will be clipped.

The 1435 output is the difference of the two input voltages, or simply the pulse signal with respect to ground. This ground-referenced pulse can be of either polarity, depending on which module is triggered first. In practice, this trigger order is critical, since the A/D converter can respond only to positive pulses. The output of the 1435 must be negative, since it is inverted by the SHA-2A before entering the converter, thus satisfying the polarity requirements of the MAS 1202. Internal PC switches determine this triggering order and also the time between the two trigger points, allowing for a higher degree of noise cancellation during shorter pulses.

The SHA-2A sample/hold was needed to compensate for the high droop rates of the THS-0025 (5mV/ μ s); otherwise, a signal integrity would suffer because the converter could not follow the input. The SHA-2A is also used to amplify the differential signal by a factor of 2.4, to allow the least significant bit of the digitizer to represent 1mV. The MAS-1202 has a full-scale input of 10V, giving the LSB (least significant bit) a value of $10/2^{12}$ or 2.4mV. The LSB voltage was set to be conveniently larger than the resolution accuracy limitation of 200 μ V of the front end, and the (worst-case) noise from the front end.

The system can be used in a single-ended mode by grounding one of the inputs of the front end, or in a biased single-ended mode by applying a DC offset to either input, providing that the polarity to the A/D converter is positive. The result is a gated fast digitizer with a 0 to ± 2 V input range.

Limitations

The major limitations of the existing design consist of system noise, temperature drift, and pedestal error.

The system (or rms) noise to the A/D converter is comprised of the sum of the squares of contributions from the individual modules -- roughly 310V -- which sets a minimum weight of the least significant bit.

The temperature drift in the individual modules, although specified quite low (typically less than 30ppm/C°), creates a total system variation of 1 to 2mV during warm-up. This warm-up time can be as much as 30 minutes.

The pedestal or trigger feed-through error can be very troublesome. Several millivolts of trigger pedestal can be injected through the different sample/hold pulses from their respective trigger pins. Once the DC calibration has been accomplished (gain and zeroing) for each of the modules, the pedestal error can be subtracted by using the offset of either the last track-and-hold amplifier or the A/D converter. The visibility of the pedestal does lead to one advantage during initial setup. By examining the various test points during setup, it is possible to determine exactly when each module is triggered, to allow for fine tuning of the system timing.

Summary

The differential system provides real-time noise cancellation with a dynamic range of 4V ($\pm 2V$) and a resolution of 500 μ V detectable by one-half the LSB. It also provides front panel test points for ease of the initial timing setup and calibration verification. The operator can also observe a digital display on the front panel during real-time data acquisition. The overall data rate is limited to 500kHz with the proper TTL level triggering.

The system is currently being used on two different research projects:

1. To acquire spontaneous Raman temperature and density measurements in an operational internal combustion engine with equivalence ratios greater than one. (Previously limited to lean mixtures, i.e. equivalence ratios < 0.8 .)

2. Single pulsed data limited to shot noise during stimulated Raman and inverse Raman diagnostic development.

TABLE I

Performance Characteristics

Resolution	12 bits
Accuracy	.1% of FS $\pm$ LSB
Nonlinearity	$\pm$ LSB
Conversion Time	2 μ s
Repetition Rate	500KHz Max (less differential separation time)
Common Mode Rejection	.01%

Analog Input Characteristics

Input Range	$\pm 2V$ (0 to $\pm 4V$ with DC offset)
Input Impedance	1 Megohm
LSB Weight	1 mV
Over Voltage	$\pm 4V$

Encode Command

Logic Levels	TTL
Logic '1' Input Current	50 μ A (Incode)
Logic '0' In Current	-2 μ A or 0
Differential Separation	
Max	100 NS
Min	0 NS

Outputs

Parallel Data	12 lines of Binary plus 'data ready' line (held until next encode command)
Format	
Logic Levels	Standard TTL up to 10 loads per line (inverted logic)
Digital Display	
Full Scale	4096 (mV)
Min Display Resolution	0001 (mV)

Acknowledgment

The author wishes to thank L. A. Rahn for technical suggestions during this project..

REFERENCES

1. L. A. Rahn and P. L. Mattern, "Coherent Raman Spectroscopy for Combustion Applications," SPIE, Vol. 158, 1978.
2. C. D. Motchenbacher, F. C. Fitchen, "Low-Noise Electronic Design," J. Wiley, Canada, 1973.

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1. APPENDIX STATIONS:
 ANSI P22.3 GRAPHIC SYMBOLS FOR ELECTRICAL &
 ELECTRONIC DIAGRAMS
 ANSI P31.1-1 DISCRETE ELECTRICAL AND ELECTRONIC
 SYMBOLS
 ANSI P31.1-2 GRAPHIC SYMBOLS FOR LOGIC DIAGRAMS
 ANSI P31.1-3 PHYSICAL AND ELECTRICAL SYMBOLS
 AND TERMINALS
 ILLUSTRATES HOW TO USE THE SYMBOLS IN THE APPENDIX
 TO THE STANDARD

CK-A14658

APPLICABLE STANDARDS:
ANSI X3.2 GRAPHIC SYMBOLS FOR ELECTRICAL AND
ELECTRONIC DIAGRAMS.
ANSI X3.19 GRAPHIC SYMBOLS, ELECTRICAL AND ELECTRONIC.
ANSI X3.19 GRAPHIC SYMBOLS, ELECTRICAL AND ELECTRONIC.
ANSI X3.19 GRAPHIC SYMBOLS, ELECTRICAL AND ELECTRONIC.
ANSI X3.19 GRAPHIC SYMBOLS, ELECTRICAL AND ELECTRONIC.

INSTALLATION: WIRE WINDING DIRECTLY TO THE WINDING ON
TERMINAL BLOCKS

DESIGNATION	DATE	REVISION
A	3-1-75	REVISION 1
B	3-1-75	REVISION 2
C	3-1-75	REVISION 3

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SHEET 1		TITLE	
DRAWING		SCHEMATIC, TRACK HOLD SYSTEM	
PART CLASSIFICATION		CK-A14658	
UNCLASSIFIED		SHEET 1 OF 1	

REVISED		REVISIONS		APPROVED	
DATE	ISS. C	DESCRIPTION	DATE	APPROVED	
	A	REVIS. 8224 VAAH 24 8342	1-8-75		
	B	REVIS. 8224 VAAH 24 8342	3-8-75		
	C	REVIS. 8224 VAAH 24 8342	1-8-75		

PART OF
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SHEET 1 PAGE 1 PART NUMBER PART NAME PART DESCRIPTION	TITLE SCHEMATIC, TRACK HOLD CIRCUIT
UNCLASSIFIED SHEET 1 OF 1 DATE BY CHECKED APPROVED	QWG NUMBER CK-A13525 SHEET 1 OF 1 MIA CODES

1. APPLICABLE STANDARDS:
 ANSI Y32.2 - GRAPHIC SYMBOLS FOR ELECTRICAL AND
 ELECTRONIC DIAGRAMS
 ANSI Y32.3 - SYMBOLS, ELECTRICAL AND ELECTRONIC
 AND Y32.4 - GRAPHIC SYMBOLS, LOGIC DIAGRAMS
 AND Y32.5 - SYMBOLS, ELECTRICAL AND ELECTRONIC
 AND ELECTRONIC

2. ALL RESISTANCES ARE IN OHMS UNLESS OTHERWISE SPECIFIED.
 3. ALL CAPACITANCES ARE IN MICROFARADS UNLESS OTHERWISE SPECIFIED.

REVISIONS		DATE	APPROVED
A	REVISION 1 / 1000000000	10-78	
B	REVISION 2 / 1000000000	10-78	
C	REVISION 3 / 1000000000	10-78	

TITLE	
SCHEMATIC, A/D CONVERTER	
CK-A13527	

REF: 74185-1, 74185-2, 74185-3, 74185-4, 74185-5, 74185-6, 74185-7, 74185-8, 74185-9, 74185-10, 74185-11, 74185-12, 74185-13, 74185-14, 74185-15, 74185-16, 74185-17, 74185-18, 74185-19, 74185-20, 74185-21, 74185-22, 74185-23, 74185-24, 74185-25, 74185-26, 74185-27, 74185-28, 74185-29, 74185-30, 74185-31, 74185-32, 74185-33, 74185-34, 74185-35, 74185-36, 74185-37, 74185-38, 74185-39, 74185-40, 74185-41, 74185-42, 74185-43, 74185-44, 74185-45, 74185-46, 74185-47, 74185-48, 74185-49, 74185-50, 74185-51, 74185-52, 74185-53, 74185-54, 74185-55, 74185-56, 74185-57, 74185-58, 74185-59, 74185-60, 74185-61, 74185-62, 74185-63, 74185-64, 74185-65, 74185-66, 74185-67, 74185-68, 74185-69, 74185-70, 74185-71, 74185-72, 74185-73, 74185-74, 74185-75, 74185-76, 74185-77, 74185-78, 74185-79, 74185-80, 74185-81, 74185-82, 74185-83, 74185-84, 74185-85, 74185-86, 74185-87, 74185-88, 74185-89, 74185-90, 74185-91, 74185-92, 74185-93, 74185-94, 74185-95, 74185-96, 74185-97, 74185-98, 74185-99, 74185-100

DESIGN PART 01

1. APPLICABLE STANDARDS:
  - ANSI Y32.2 GRAPHIC SYMBOLS FOR ELECTRICAL AND ELECTRONIC DIAGRAM.
  - ANSI Y14.15 DIAGRAMS, ELECTRICAL AND ELECTRONIC.
  - ANSI Y32.14 GRAPHIC SYMBOLS, LOGIC DIAGRAM.
  - ANSI Y32.16 REFERENCE DESIGNATIONS, ELECTRICAL AND ELECTRONIC.
2. ALL CAPACITANCES ARE IN MICROFAPADS UNLESS OTHERWISE SPECIFIED.

DWG NUMBER CK-A13526

1. APPLICABLE STANDARDS:

APPLICABLE STANDARDS:
ANSI Y32.2 GRAPHIC SYMBOLS FOR ELECTRICAL AND
ELECTRONIC DIAGRAMS.

ANSI Y14.15 DIAGRAMS, ELECTRICAL AND ELECTRONIC.

ANSI X3.14 GRAPHIC SYMBOLS, LOGIC DIAGRAMS.

ANSI Y32.16 REFERENCE DESIGNATIONS, ELECTRICAL AND ELECTRONIC.

2. ALL CAPACITANCES ARE IN MICROFARADS UNLESS OTHERWISE SPECIFIED.

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SHEET 1										TITLE SCHEMATIC, BINARY-TO-BCD CONVERTERS									
ISSUE A																			
SHEET INDEX																			
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DDP CLASSIFICATION LEVEL										DDP NUMBER									
UNCLASSIFIED										CK-A13526									
SIZE FCSC NO. D 14214										SHEET 1 OF 1									
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