TRAC 32: A 32-CHANNEL CAMAC CURRENT CONVERTER WITH WIDE DYNAMIC RANGE

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INTRODUCTION

A multi-range beam diagnostic system was required for the new Ion Source at TRIUMF. It was needed to provide displays for operators, and generate safety trips to protect the Ion Source beam line.

To simplify the system design, a 32-channel current input multiplexing scanning Camac ADC with wide dynamic range called TRAC-32 has been designed. The multiplexing feature has the obvious advantage of cost saving. The auto-ranging feature eliminates the requirement to design a control interface and problems associated with over or under-ranging. Therefore, accurate current readings from the different devices are always available and are used for software safety trip generation as well as for display purposes.

The design of multiplexed auto-ranging analog modules is non-trivial. The high gain end involves small signals which are difficult to multiplex since conventional multiplexer chips are designed for voltage signals and have per channel leakage currents which when summed together are comparable to current signals. Multi-channel auto-ranging by software is slow because of signal settling time between range changes and range selection algorithms. Hardware auto-ranging amplifiers or digitisers were not available until the MN5420 hybrid from Micro Network which is primarily designed for use with software for spectrum analysis of AC signals. The TRAC-32 design is based on the MN5420 chip. It has been tested under laboratory test conditions and is used in the TRIUMF new Ion Source diagnostic system.

The General Function of the TRAC-32

The general block diagram of the TRAC-32 is shown in figure 1. Table 1 provides general information on the TRAC-32. There are 32 channels with similar input stages. They are multiplexed to an operational amplifier buffer with auto gain control. The buffer output is then digitised by the MN5420. The 12 bit mantissa and 4 bit gain output of the MN5420 together with the extra buffer gain bit is stored in 32 successive locations of three 8 x 2K randomly accessible memories (RAM).

The sampling time of a channel is twice the response time of the buffer. The buffer gain control is enabled only at the first half of the sampling time so that if it is switched there is enough time for the buffer to settle properly. The gain bit is delayed to coincide with the pipeline conversion technique of the MN5420. A delayed counter is used to synchronise the addressing of the RAM for data storage.

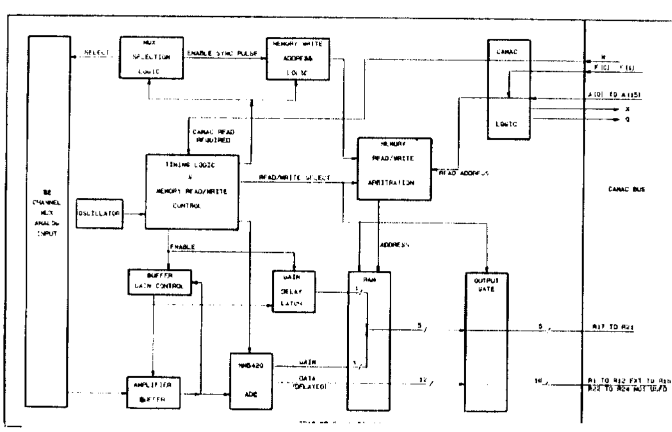

Figure 1. The general block diagram of the Trac-32

The MN5420 Hybrid Floating Point ADC

The MN5420 Hybrid ADC converts a signal with auto-ranging in less than 4 microseconds. The worst noise performance of the hybrid is at the highest gain range of 19.5 mV full scale where the input noise is around 60 uVrms, or 0.3% of the full scale. The signal to noise ratio is 42.9 db where the noise is less than 1% of the signal. It utilises a pipeline conversion technique. Output data becomes valid during the subsequent conversion cycle.

Whereas the pipelined technique costs extra control hardware the fast auto-ranging feature of the MN5420 simplified the design of the TRAC-32. With an additional gain feature at the buffering stage to cover 5 decades, we provide an auto-gain conversion in 160 microseconds. This short sampling time is also a determining factor for the success of the flying capacitor multiplexing technique.

Input Multiplexing and Buffering with Additional Auto-Gain Switching

The input multiplexing and buffering circuitry is as shown in figure 2. The design considerations are explained in the following sections.

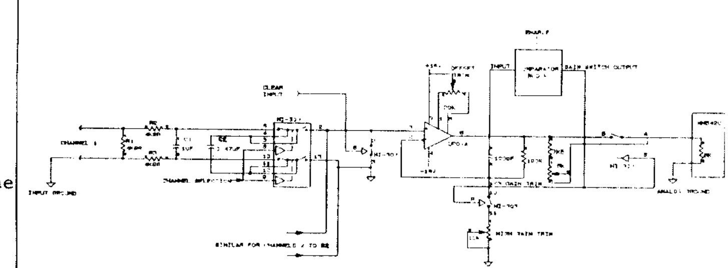

Figure 2. The input and buffering circuitry of the Trac-32

Input Stage Design Consideration

Current to Voltage Signal Conversion

A resistor is used across each input as a current to voltage converter, the value of which should be as high as possible to give the best signal to noise ratio (SNR). However, the converted signal is limited by the supply voltage of the analog switches which were chosen to be 15 volts to guarantee the best performance. The resistor is therefore limited to 5 K for the maximum input current of 3 mA.

The Flying Capacitor Design

A capacitor is used at each input to transport the converted signal to the buffer. They are selected by two 16 channel decoders. When a channel is not being sampled, the capacitor is connected to the input side and charged up to the converted input signal. During sampling time, it is swung to the OP-07 buffer. The input ground is isolated from the buffer ground and the buffer bias current is isolated from the input currents.

The additional resistors and capacitors, for example R2, R3 and C1 of the first channel, are used to improve the first order input filter. They also provide over voltage protection to the analog switches.

Advantages of the Flying Capacitor Design

High Common Mode Rejection

When collecting signals, the flying capacitor multiplexing design provides high isolation between both leads of the input capacitor and the module analog ground. A common mode 140 DB DC rejection and 90 DB 60 Hz rejection is achieved. Common mode is a time variant signal distortion problem caused by the potential difference between the input ground and the module ground. They are particularly important when small signals are involved.

Low Leakage Analog Switch Causes Negligible Leakage Error

The generally low leakage current of the HI 303 analog switches are in the order of 30 pA. When a channel is not being sampled, the leakage current discharges through R1 and R2 to the input ground, creating an error of less than a microvolt across C1 and C2. During sampling time, the accumulated leakage from all 32 channels of about 2 nA and the OP-07 bias current of 2 nA will cause C1 to discharge, creating a sampling error. This sampling error is limited to less than 2 uV by a short sampling time of 160 uSec.

Shunt Capacitance Effect Sampling Error is Tolerable

During sampling time, the stray capacitance from all the analog switches and the input capacitance of the OP-07 created a shunt capacitance on the input capacitor. As a result the input signal is diminished by 0.1%.

The Relationship of Scan Interval and the Input Filter Time Constant

When the input capacitor is swung back to the non-sampling position, the sampling error caused by both the leakage currents and the shunt capacitance effect is corrected as it settles towards the input signal with the time constant of the input filter. If sufficient time is not allowed before it is sampled again, this error accumulates and diverges. The relationship is expressed in equation 1, where V_{er} is the accumulated sample error. V_{ser} is the sample error caused by a sampling process and the terms inside the summation sign are fractional error contributions from previous samples. t_1 is the time between samples and t_2 is the time constant of the input filter. The scan rate of each channel was selected to be 100 msec, which is about 7 x t_2. However, the scan rate could be improved to 30 msec where V_{er} is 1.2 x V_{ser} and is negligible.

$$V_{er} = V_{ser} \left(1+\sum_{n=1}^{\infty} e^{-n(t_1/t_2)}\right)$$

Design Consideration for the BUFFERING Amplifier Circuitry

Selection of the OP-07 Operational Amplifier

The OP-07 was selected because it has a small bias current of 2 nA. It is very stable over temperature and time. The resulting temperature drift error per degree Centigrade is in the order of microvolts. The low noise figure of the OP-07 also helps to keep the input noise to the MN5420 down to less than 100 uVolts.

The Decision Not To Have Compensation Resistors

The typical offset current and bias current of the OP-07 are of similar magnitude, 1.2 nA and 2 nA respectively. Therefore compensation resistors wil not improve the offset voltage significantly. Addition of compensation resistors would increase the input noise significantly due to the noise current flowing through the compensation resistors.

Buffer Auto Gain Control, Offset Trim and the Selection of Gain Values

A pair of comparators with hysterisis are used to control the gain switching of the OP-07 for signals of both polarities. The hysterisis cycle is shown in figure 3.

For signals smaller than 45 uA, the buffer gain is trimmed at 20 so that a 0.975 mVolt signal equivalent to 195 nA input is amplified to 19.5 mV which coincides with the full scale of the highest gain range of the MN5420. All nine gain ranges of the MN5420 are utilised with the maximum 5 volt full scale representing a 50 uA signal.

For a signal bigger than 45 uA, the buffer gain is trimmed to one third so that the maximum input of 15 volts of a 3 mA signal will coincide with the maximum 5 volt full scale of the MN5420. Only six of the lowest gain range of the MN5420 are utilised, with the 156.25 mV full scale range representing 93.75 uA input.

The input of the OP-07 is grounded between samples to guarantee low output at idle time for low power operation. The buffer, therefore, always starts from the high gain stage.

An offset trim is provided and the OP-07 offset should be trimmed at high gain. The offset change, when it is switched to low gain, is of the order of microvolts and is small compared to the 200 mV signal required to trigger the switch.

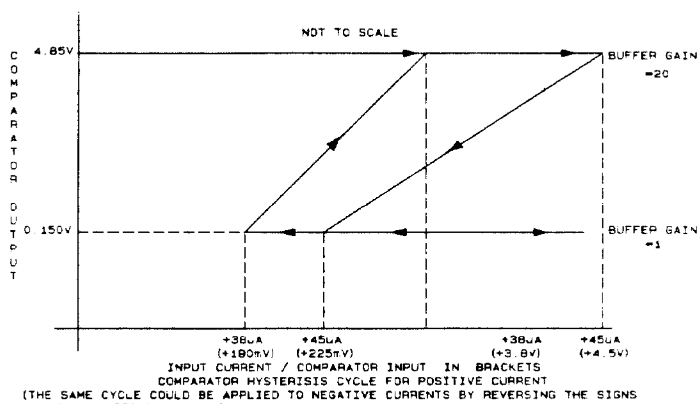

Figure 3. The comparator hysterisis cycle

Laboratory Test of the TRAC-32

A TRAC-32 was mounted on a CAMAC bus extender in a low noise environment and all 32 channels were read and displayed on a terminal. The offset was trimmed so that all channels were within +/- 10 nA. A channel with typical noise and/or offset of +/-2nA was used for the test. A variable current source of one milliampere was used as the input.

The error band was within the specifications as stated in Table 1. The noise level was less than +/- 4nA for signals below a microampere. Above one microampere it stayed within 0.5% of the signal, which is the best noise performance of the MN5420.

Table 1 TRAC-32 General Information

Maximum full scale range +/- 3 mA
or +/- 15 volts

Input impedance
5 K in parallel with 1.0 uF when selected
5 K in parallel with 1.47 uF when unselected

Input filter
3 DB point at 10.6 HZ for voltage noise
6.67 HZ for current noise

Common mode rejection
140 dB DC
90 dB at 60 HZ

Channel crosstalk
Less than 120 dB AC

Channel to channel zero offset
+/- [0.2% + 10 nA]

Accuracy
Of full scale:
At highest gain (5120) range is better than +/- 3%
At lowest gain range (1/3) is better than +/- 1%

Accuracy temperature drift per degree C
At the highest gain range 0.1% of full scale

Gain	Gain Code	Full Scale	Auto Gain Switch Level	Accuracy of Reading
1/3	10100	3.00 mA		1.0% @ full sc.
			1.20 mA	2.5%
2/3	10111	1.50 mA		
			600.00 uA	2.5%
4/3	10110	750.00 uA		
			300.00 uA	2.5%
8/3	10101	375.00 uA		
			150.00 uA	2.5%
16/3	10100	187.50 uA		
			75.50 uA	2.5%
32/3	10011	93.75 uA		
			40.00 uA	5.0%
20	01000	50.00 uA		
			20.00 uA	5.0%
40	00111	25.00 uA		
			10.00 uA	5.0%
80	00110	12.50 uA		
			5.00 uA	5.0%
160	00101	6.25 uA		
			2.50 uA	5.0%
320	00100	3125.00 ua		
			1.25 uA	5.0%
640	00011	1562.50 nA		
			625.00 nA	5.0%
1280	00010	781.25 nA		
			312.50 nA	5.0%
2560	00001	390.62 nA		
			156.25 nA	5.0%
5120	00000	195.31 nA		+/-6 nA

Note: 1. For signals that are smaller than 156.25 uA the accuracy is +/- 6 nA.
2. Channel offset error should be added to the error signals smaller than 400 nA.

CAMAC Functions
F(0) A(i) i = 0 - 15 Response Q = 1, X = 1
Read channels 1 to 16
F(1) A(i) i = 0 - 15
Read channels 17 to 32 Response Q = 1, X = 1
C,Z reset module

On-Line Performance of the TRAC-32

Two TRAC-32s were installed in the Third Ion Source diagnostic system. The on-line performance is shown in Table 2. The modules perform very well for signals above one microampere where the noise is about 2% of the reading. For signals smaller than one microampere the error is greater than 14% and the noise is greater than 10%. This shows that although we have succeeded in multiplexing small signals, we have not eliminated the problems associated with environmental noise which is a significant ratio of the small input signals. For a 1 mV converted signal of 200 nA, 100 uV of environmental noise gives a 10% noise figure. It would not be cost effective to shield against such noise levels. To resolve measurements down to nanoamperes on line, the present design will be useful only with the help of software digital filtering.

RANGE OF INPUT SIGNAL	ENVIRONMENTAL NOISE	TRAC-32 ERROR	OVERALL SYSTEM ERROR	OVERALL SYSTEM NOISE
LESS THAN 200nA	$> \pm 9\%$	$< \pm 5\%$	$> \pm 14\%$	$> \pm 10\%$
200nA-1uA	$\pm$ (2-9) %	$< \pm 5\%$	$\pm$ (7-14) %	$\pm$ (3-10) %
(1uA-2uA)	$\pm$ (1-2) %	$< \pm 5\%$	$\pm$ (6-7) %	$\pm$ (1.5-2.5) %
(2uA-40uA)	<1%	$< \pm 5\%$	$< \pm 8\%$	$\leq \pm 1\%$
(40uA-3mA)	~ 0%	$\pm$ (1-2.5) %	$\pm$ (1-2.5) %	0.5%

THE PERFORMANCE OF THE TRIUMF I3 DIAGNOSTICS SYSTEM.

TABLE 2

CONCLUSION

In laboratory tests, the TRAC-32, met its design specification, however the on-line performance has revealed the weakness of the module at the high gain end. With the help of software digitial filtering the module provides an efficient solution to the problem of digitising multi-channel wide-range analog signals.

The implementation of TRAC-32 in the TRIUMF Third Ion Source diagnostic system not only saved the cost of multi-analog channel and range control hardware, but allowed safety interlocks to be provided by software which further simplifies the system design.

The TRAC-32 range span could be changed by changing various design parameters. The front end input current to voltage conversion resistors and the buffer gain and its control could be altered to give better overall noise performance in exchange for a smaller range.

With the speed of the MN5420 the module has the potential to be redesigned for fast signal acquisition systems, such as wire scanners.