A Four-channel Digital Kicksorter

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> *"One of the most remarkable instruments used in conjunction with an ionization chamber and linear amplifier for alpha-particle counting is the pulse analyzer, sometimes familiarly known as a kicksorter. It consists of a number of electronic circuits permitting only the passage of pulses exceeding a certain minimum, ..., and then sorting them and counting them according to size. In this way the alpha particles originating from several radioelements in a mixture can be counted independently and simultaneously."*
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> S. Glasstone, Sourcebook on Atomic Energy, 1950

Introduction

Measuring the spectrum of particle emissions from radioactive substances has always been one of the main pursuits of nuclear science. Quantitative measurement began in the 1890s with the simplest of instruments (electroscope, electrometer [galvanometer]) and now has progressed to a process which usually is fully automated and often is based on personal computers.

Kicksorter instrument design began in the 1930s as a mostly mechanical apparatus and evolved with increasing sophistication into the 1940s through the use of vacuum tubes. The Montreal Laboratories (ML) of the National Research Council (1942 -1952) used spectrum analysis and the instrument at that time was known as a *kicksorter.* It enabled the production of unique radioactive spectra and, hence, identification of radioactive sources. Their instruments typically had 20 to 32 channels, built up typically from four-channel units. The kicksorter processed pulses from a detector, most often the amplified output from an ion chamber, into discrete amplitude buckets for counting. Several papers from the ML era, including [1] and [3], show very clever use of electronic circuits, bordering on digital techniques, exemplified by the then well-established flip-flop circuit for data storage and scaling. Tubes, although having the particular advantage of speed, exhibited the disadvantages of high power consumption, poor stability, large size and weight, and cooling issues.

Subsequently, the kicksorter function was implemented with solid-state devices and the increasing use of fast analogue-to-digital conversion and digital signal processing software. Today such instruments are categorized as pulse-height analyzers (PHAs) or, more simply, channel analyzers.

Objective

Having become impressed by the accomplishments of the ML in electronics, it was decided as a comparative exercise, to build a four-channel kicksorter, using readily available integrated circuits to achieve the same functionality as their early instruments. It reflects the basic structures of the original design, a purely hardware solution, as there was no software involved then.

The kicksorter was built in accordance with the block diagram in Appendix 1, schematic in Appendix 2 (Sheet 1), parts list in Appendix 3 (Sheet 2), and waveform timing diagram in Appendix 4 (Sheet 3).

Theory of Operation

A general description of the kicksorter is provided below and a block diagram is given in Appendix 1. Sections 1 to 5 give a detailed description referenced to the schematic in Appendix 2.

To represent the output from an ionization chamber, a rectangular signal source was devised to form the input for processing. The output from an ionization chamber more resembles a bell waveshape but a rectangular wave shape was deemed to be sufficiently representative for this project. The waveform timing diagram (Appendix 4) also shows a staircase example of circuit performance. This signal is applied via a resistor network to four comparator/flip-flop pairs, which together represent what can be best described as a basic analogue-to-digital converter.

An interesting kicksorter feature in the tube version was that the output from each flip-flop was used to cancel the previously set flip-flop until a signal peak was reached. This is implemented in this design so that when the signal falls below the comparator with the lowest reference voltage, the output from it goes to a timing network that provides clock and reset timing pulses. These timing pulses generate a signal to clock the data output from the four flip-flops through delay flip-flops, for counting by a pair of single-digit counters and then to provide a reset for all flip-flops. In this implementation there is only one two-digit counting circuit which may be connected via a multiplexer to any of the four channels for counting observations.

1. Signal source

An approximately 15Hz, 60% duty, rectangular wave test (TST) signal source is derived from a precision timer (U4) operated in the astable mode. The test signal varies between 0 V and 5 V and forms an input to prove kicksorter basic functionality. In normal operation the test signal would be switched out and a real signal applied.

2. Analogue-to-digital conversion

The test signal is fed to a resistor network (R1-5), with four comparator/J-K flip-flop (U1, U2, U3) pairs forming a basic analogue-to-digital converter. The resistor network is designed to cause the comparators to change state at discrete, nominal 1 V (1, 2, etc.) intervals. These J-Ks are positive edge types and so will only be triggered by positive going signals. As the signal rises at the inputs of the comparators it will generate an input for the corresponding J-K, setting a 1 on the J-K Q output. Note that the Q-N output of each J-K is connected to the CLR input of the previous J-K. Thus when the signal continues to rise, succeeding J-Ks will also be set to 1 and thus will clear the previous J-K. As a result only one J-K, i.e., the peak, will remain in the 1 state and is presented at the inputs of a D-type flip (U5). The process is terminated by a signal end detector pulse. Note: Signals below 1V will be rejected, thus providing a measure of noise immunity.

3. Signal End Detector

The signal end detector (SED) pulse is developed by comparator (U1A1) and is a 5-V pulse of variable duration, depending on the pulse width, and is a reflection of the input signal pulse as it rises and falls. It is generated as soon as the input signal rises above 1 V and subsequently decays below 1 V, thus signifying the end of the input signal. The SED pulse is sent to the timing section.

4. Timing Section

Using the SED pulse, the timing section provides timing signals that first clocks the data from U5 to a channel multiplexer, U7, and thence to the counter/displays, and then resets all flip-flops. The timing section consists of a differentiating RC network (C2, R6, R7) with associated 555 timer (U6) operated in the monostable mode, followed by another similar arrangement (C6, R11, R12, U8). Signal conditioning and buffering is handled by inverters (U9). Both 555 timers provide pulse delays of 100 us.

The first timer provides a100 us CLK pulse to U5 via U9, to transfer data via U7 to the counter/display, the end of which initiates the second timer which then provides a RESET pulse via U9 to reset all flip-flops, i.e., (U3b, U5) and (U2, U3a).

5. Counter/Display

Two counter/display assemblies (EA01-02) are connected in series and can process data counts up to 99 for presentation on 7-segment LED displays. These assemblies are quite sophisticated, with comprehensive circuitry and three control signals: P - preset, R - reset, U - upcount. There is a maximum counting frequency of 15 kHz which is handled by the CLK signal which persists for 100 us, reflecting a safe response rate of 10 kHz.

Conclusion

A kicksorter emulation of early tube designs was built from readily available integrated circuits and was shown to operate successfully. Some thought is being given to providing an alternate source input from a commercial smoke detector or a Geiger-Mueller tube (GMT), to generate pulses of radioactive character.

An in-depth appreciation of the state of the art of tube technology applied to early nuclear research can be gleaned from [2], a book by none other than W.B. Lewis, who some regard as Canada's greatest nuclear engineer, and who was recognized as a very good electrical engineer earlier in his career.

References

[1] Freundlich, H.F., E.P. Hincks, and W.J. Ozeroff. "A Pulse Analyzer for Nuclear Research", The Review of Scientific Instruments. Vol. 18, No. 2, p. 90-100. February 1947.

[2] Lewis, W.B. Electrical Counting: with special reference to counting alpha and beta particles. The Macmillan Company, New York, N.Y. 1943.

[3] Wescott, C.H. "The 1945 Kicksorter – preliminary information". National Research Council, Montreal Laboratory, Montreal. 22 June 1945.

Construction Notes

a. Kicksorters are calibrated using radioactive sources with a known energy signature and this was not undertaken here.

b. The main part of the kicksorter was built on a dual-column Protoboard.

c. The comparators noted in the text are actually operational amplifiers used as comparators.

d. The timing circuit used two 555 Precision Timers but a single 556 Precision timer could have been used for simplification.

e. An LM324 Operational Amplifier was used. It has a requirement that Vcc must be at least 1.5 V more positive than the input common mode voltage and this was achieved with a voltage-dropping resistor, R1. It has the effect of modifying the nominal input setpoints from 1, 2, 3 and 4 V to 0.81, 1.61, 2.42 and 3.23 V, respectively.

Note on Authors

After productive careers in the Canadian military/aerospace industry, Jim Arsenault and Terry Hicks retired to pursue their many interests. Their expertize ranges from devices to systems and includes extensive management experience. The authors were doing High Technology before the term was popularized.

Appendices

Appendix 1. Kicksorter Block Diagram
Appendix 2. Kicksorter Schematic (Sheet 1)
Appendix 2. Parts List (Sheet 2)
Appendix 3. Timing Diagram (Sheet 3)