Information Circular 9425

Multiple-Channel Trigger Circuit for Noise Discrimination in Ultrasonic Acoustic Emission Studies

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea L. Graham, Director

Library of Congress Cataloging in Publication Data:

Hanson, David R.

Multiple-channel trigger circuit for noise discrimination in ultrasonic acoustic emission studies / by David R. Hanson.

p. cm. — (Information circular; 9425)

Includes bibliographical references (p. 10).

Supt. of Docs. no.: I 28.27:9425.

1. Rock bursts—Identification. 2. Acoustic emission testing. 3. Ultrasonic testing—Electronic equipment. 4. Electronic circuits. I. Title. II. Series : Information circular (United States. Bureau of Mines); 9425.

TN295.U4 no. TN317 622 s—dc20 [622'.28] 95-80 CIP

CONTENTS

Page

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

dB	decibel	pF	picofarad
kHz	kilohertz	V	volt
kΩ	kilohm	μF	microfarad
ms	millisecond	μs	microsecond
ns	nanosecond		

MULTIPLE-CHANNEL TRIGGER CIRCUIT FOR NOISE DISCRIMINATION IN ULTRASONIC ACOUSTIC EMISSION STUDIES

By David R. Hanson[1]

ABSTRACT

Transient electrical noise events pose serious problems for data acquisition systems used in monitoring acoustic emissions in laboratory and field environments. The U.S. Bureau of Mines has designed and constructed a trigger discriminator circuit for use in ultrasonic acoustic emission studies. Designed for use with signals in the frequency range of 50 to 400 kHz, the instrument examines incoming signals for frequency content, amplitude, simultaneity, threshold crossings, and number of channels above threshold. If preselected criteria on these properties are met, a plus 5-V pulse is output that may be used to trigger a data acquisition system, allowing rejection of noise events that do not possess useful information. The system was designed for four input channels, but may be expanded to more channels with minimal design changes.

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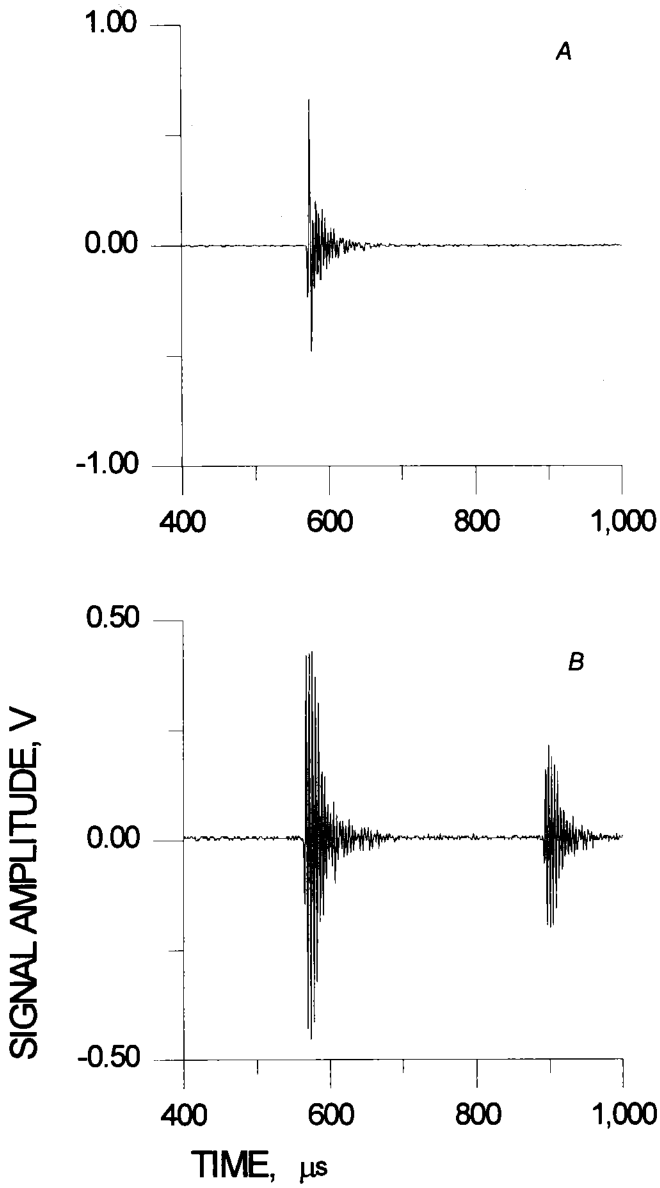
INTRODUCTION

As part of an ongoing effort to reduce hazards associated with failures of underground support structures, the U.S. Bureau of Mines (USBM) is examining ultrasonic acoustic emissions as a possible means of providing warnings of impending roof falls, pillar bursts, and bumps and as a possible method to monitor stress buildups associated with underground mining (Hardy, 1987; Moroz, 1987; Archibald and others, 1988, 1990). The current USBM studies, performed in underground coal mines, involve the collection of acoustic emission waveforms produced during deformation of both support pillars (coal) and roof material (shale, coal, sandstone, etc.) and subsequent analysis of the waveforms.

A major problem in the collection of these data is the recording of electrical noise waveforms, produced by mining equipment and other sources, that have many of the same waveform characteristics as valid acoustic emission events. Typical ultrasonic acoustic emissions are shown in figure 1. They are often impulsive, with widely varying peak-to-peak amplitude, and they typically have a frequency content between 50 and 250 kHz. The signals may or may not be nearly monochromatic. Duration is often less than 200 μs, but is occasionally greater than 4 ms. Noise events (figure 2), unfortunately, often have many of the same characteristics seen in figure 1. Often multiple events (figure 2) are observed. The frequency content of these signals may be lower than the frequency content of valid ultrasonic acoustic emissions, but this is not a universal trait. Often the only way to distinguish noise events from acoustic emissions is from their times of arrival on different sensors of the array. Noise events will arrive on two or more widely separated sensors within a few microseconds of each other. The only reasonable explanation for the origin of these events is an electromagnetic source, since their propagation velocities have been computed to be in excess of several hundred thousand meters per second. These noise events have been traced to pulses electromagnetically coupled to signal cables. The pulses may be produced by switches, relays, and the normal operation of mining equipment. Additionally, noise spikes may be propagated along power lines and leaked to signal cables that are inadequately decoupled from line power. A reliable means of discriminating against these events during data collection is required if ultrasonic acoustic emissions are to be useful in monitoring stress concentrations in underground mines, especially in real time.

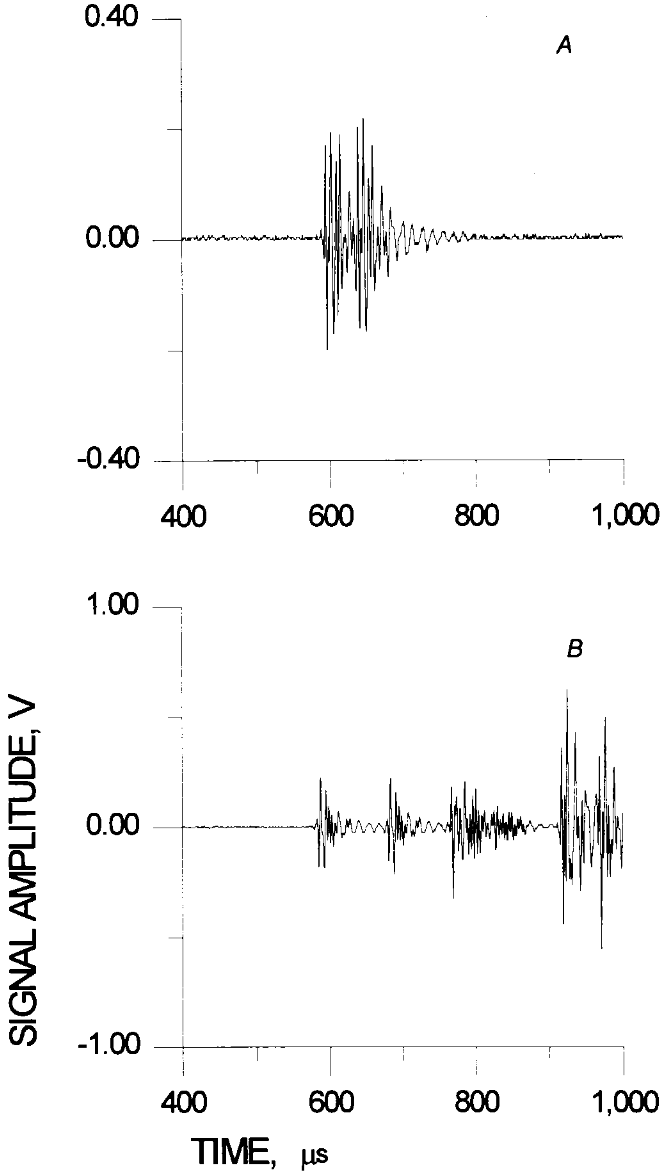
Since acoustic emissions occur at unknown time intervals, the discriminator must operate continuously and be capable of rejecting noise events while providing a signal capable of triggering a data acquisition system when an event is detected that satisfies preselected criteria. The circuit described here is designed to discriminate against noise event signals collected by a four-channel data acquisition system in the frequency range of approximately 50 to 400 kHz. The circuit discriminates on the basis of five parameters: frequency content of the event, threshold voltage amplitude, number of threshold crossings or ringdown count, simultaneity, and number of channels above threshold or "hit" within a given time interval. The instrument thus will not provide an output trigger pulse under the following conditions: (1) the frequency content of the signal is too low, (2) the amplitude of the signal is too low, (3) the number of threshold crossings in the event is too low, (4) three or more channels are hit within too short a time period (a few nanoseconds to microseconds), or (5) an insufficient number of channels are hit within a few tens of microseconds to milliseconds of each other.

Figure 1
Typical Ultrasonic Acoustic Emission Waveforms



Ultrasonic acoustic emissions were collected with an accelerometer mounted in contact with a coal pillar. Events collected were often single (A), but occasionally multiple (B) events within the data collection window were observed.

Figure 2
Typical Noise Waveforms



Noise events collected in an underground coal mine are often due to some type of electromagnetic interference. Duration and frequency content are often identical to valid ultrasonic acoustic emissions (figure 1). As with valid acoustic emissions, both single (A) and multiple (B) events were recorded.

CIRCUIT DESCRIPTION

The circuit discused here is based largely on one described by Sondergeld (1980) and Cress.[2]

Window Comparator

Figure 3 shows the window comparator used to provide amplitude discrimination. Typically, acoustic emission signals detected with accelerometers are amplified by 40 to 80 dB. After this amplification, the signals are input to the window comparator at point CHAN.1 in figure 3. Initially, the input signal is filtered by the high-pass resistor-capacitor (RC) network formed by capacitor C1 and resistor R1. The minus 3-dB frequency of this network is found from $f_{3dB} = 1/(2\pi C1R1)$. With the component values given, the minus 3-dB frequency is at approximately 6.64 kHz. This is lower than the 50-kHz lower band-pass limit, but further discrimination increases the lower band-pass limit to the desired frequency.

In figure 3 the comparator is made up of U1A-B (quad comparator), U2, and U3 (operational amplifiers). The 5.6-V Zener diodes allow the upper and lower thresholds to be set anywhere between plus 5.5 V and minus 5.5 V through adjustment potentiometers R9 and R13, respectively. The output of the comparator is used to turn a PNP transistor (Q1) on and off. The output of the entire comparator circuit is taken at SIG1 to be used in the next stage of the discriminator. This output voltage changes state between plus 13.4 V, when the signal voltage is within the threshold window, and about 0.08 V, when the input exceeds either the positive or negative thresholds. This change of state occurs each time the signal voltage passes from inside to outside the window and so may occur up to twice each cycle of the input signal. The light-emitting diode (LED), D1, is added as a diagnostic tool. As designed here, the LED is off when the signal level is within the desired window. When the signal passes outside the window, the LED is turned on by the PNP transistor, Q1, and lights. This lighting is usually not detectable by eye for normal acoustic emission or noise signals because of their short duration, but it is useful for determining the background noise level present. If the window thresholds are set too low, in either a positive or negative sense, the LED becomes lit and stays lit, and the threshold can be adjusted to avoid false triggers. The capacitors C8 and C9 in figure 3 are needed to prevent oscillation in the comparator (U1, LM339). In addition, 1-μF tantalum capacitors (not shown) should be added between the power lines (± 15 V) and ground for added stability. The manufacturer's specifications for the LM339 shows power connections to positive supply voltage and ground, but the ground connection should instead be made to minus 15 V to allow bipolar operation. The number of window comparator circuits used here was four, one for each data channel.

Ringdown Counter

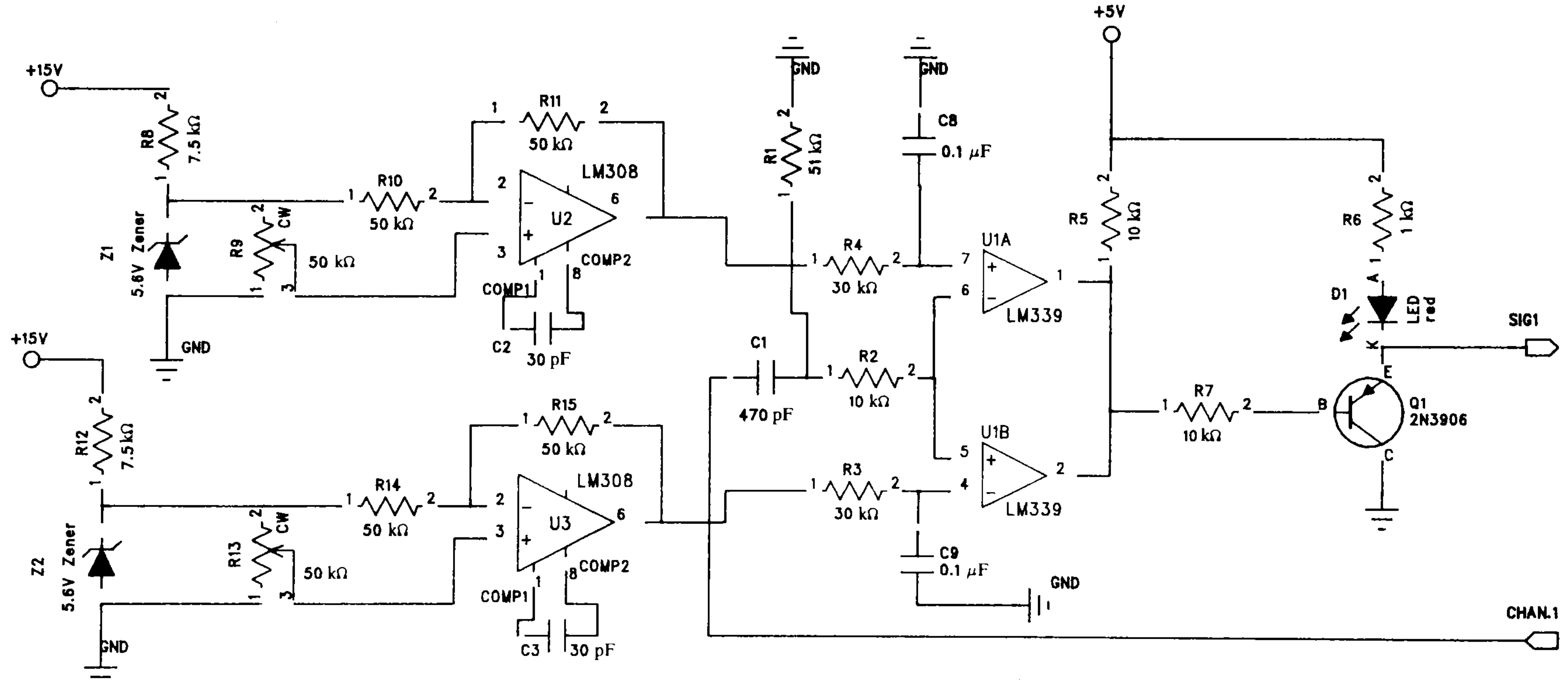
The output pulses from the comparator are used in two ways. First, the pulses are used to trigger a retriggerable monostable multivibrator (U4A, 74HC123, figure 4). The pulse width from this multivibrator is set by the resistors R16 and R17 and the capacitor C4 and is given approximately by $t_w = (\ln 2)C4(R16 + R_{var})$, where R_{var} is the resistance set by the potentiometer R17. With the values given in figure 4, the pulse width may be varied between about 7 and 76.4 μs. The pulse length is set to one-half the period of the signal with the longest period (or lowest frequency) expected. If the input signal does not contain frequencies high enough (or periods short enough) to retrigger U4A during the original pulse, the four-bit binary counter (U8, 74HC161) is cleared. With the values used here, the low-frequency limit may be set between about 6.55 and 71.45 kHz. The output pulses from the window comparator (from point SIG1) are also directed through a series of invertors (U6A-D) before being sent into the clock input of the binary counter, U8. The invertors provide a delay sufficient for the multivibrator, U4A, to change state before counting begins.

Simultaneity Detection

The positive output pulse, or Q, of each of the initial monostable multivibrators (one for each channel) provides the signals used to test for simultaneity. During the collection of ultrasonic data, it is possible that any two channels may be triggered at nearly simultaneous times if the source is equidistant from the two sensors. However, for three or more sensors to be triggered simultaneously, an unlikely set of conditions must be met. The probability that the events causing such a triggering are electrical

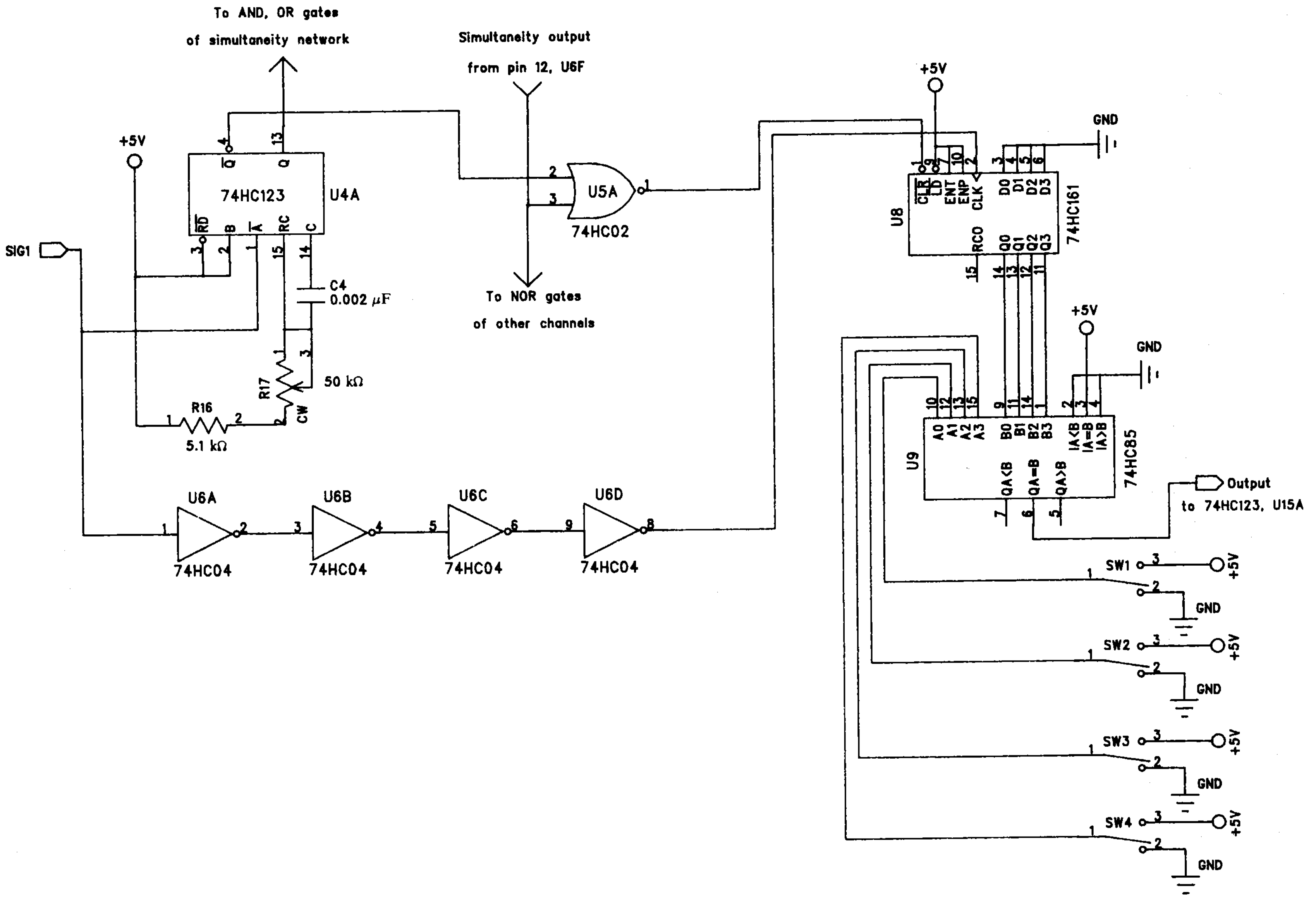
[2]Personal communication from G. O. Cress, geophysicist, Denver Research Center, USBM, 1993.

Figure 3
Window Comparator Schematic



An excursion of the detected signal outside the upper or lower threshold set by R9 and R13, respectively, turns on Q1, illuminates D1, and results in a change of state from +13.4 V to +0.08 V at SIG1. There is one window comparator used per input channel.

Figure 4
Frequency Discrimination and Ringdown Counter Schematic



A signal must contain a high enough frequency to retrigger U4A and count the number of threshold crossings set by switches SW1-4 before U4A times out or the four-bit counter, U8, will be cleared. U5A supplies simultaneity discrimination. Each input channel has the circuit shown in this figure.

noise is much higher. Therefore, if three or more channels exceed their amplitude threshold within a preset time interval, they are considered to be noise, and no trigger pulse will be sent to the data acquisition system. The first step in this discrimination is provided by the network of AND and OR gates made up of U10A-D and U11A-C (figure 5). The pulse output from the monostable multivibrator (U4A, for example), when it is triggered by the window comparator, is input to the logic network as shown in figure 5 at CHAN.1. The output of this network (pin 8 of U11C) is high only if three or more of the four inputs are high at the same time. Simultaneously, the pulses are fed to a network of OR gates (U12A-C) that trigger another monostable multivibrator (U14A, 74LS221). The output pulse length of this multivibrator is adjusted so that if signals arrive within this time window, they are considered to be simultaneous. For example, if three or more channels trigger within a pulse width equal to 2 μs (as set by U14A in figure 5), they are considered simultaneous noise events and are not collected. The pulse width is selected by R18, R19, and C5 and can be varied between 42 ns and 2 μs. The outputs of U14A and U11C are directed to an AND gate that passes a pulse only if three or more channels are hit within the time window selected. Thus, if three or more of the initial monostable multivibrators (such as U4A, figure 4) are triggered (signal level is out of the preset amplitude window) within a time period set by the output pulse width of U14A, the output of U13A is high for the length of time set by U14A.

This pulse and that from U12B (pin 6) are input to a flip-flop (U6E-F, U7A-C, U13B-C, R20, D2, and C6). If the condition for simultaneity is met (three or more channels out of threshold within a time set by U14A), the output of the flip-flop is high until it is reset when the output of U12B becomes low. That is, the flip-flop output will be high for the duration of the entire noise event. After the amplitude of the noise event drops below the trigger threshold, the flip-flop is reset and it waits for the next potential acoustic emission. This signal (pin 12, U6F), along with the original pulse from the first multivibrator (U4A) goes into a NOR gate whose output is directed to the clear of the counter (U8) as shown in figure 4. The NOR output is low, so the counter is latched off until the first pulse times out. It is then rearmed and is ready to count for the next event. If the flip-flop logic were not employed, noise events that were outside the amplitude window for longer than the pulse width set by U14A could still be counted. In the design here, the counter is latched off until the first pulse out of the frequency discriminator (U4A) times out. If three or more of the channels are not hit within the pulse width set by U14A, the counter (U8) is armed by the output of the NOR gate, U5A, and counts.

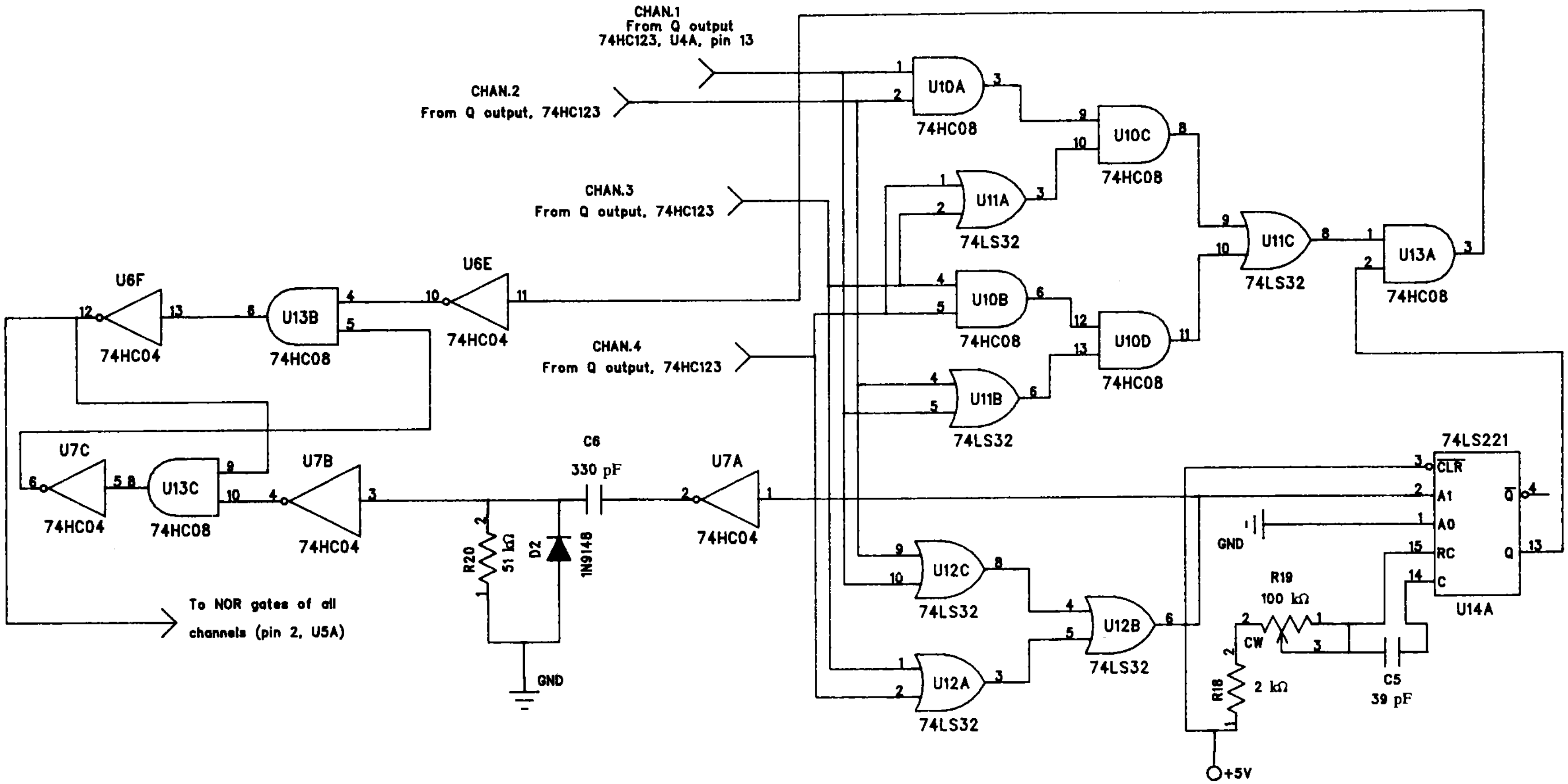
Trigger Pulse Output

If the signal is determined to be valid and not noise or too low a frequency, the number of excursions outside the amplitude window are counted by the counter, U8 in figure 4. This allows the output of the counter to be compared with the settings of switches SW1-4 by the four-bit comparator (U9, 74HC85), and when the two are equal the output of the comparator changes state. The output of the window comparator (figure 3) must change state at least once during the time window set by the pulse width of U4A. This allows signal discrimination based on a ringdown count (Sondergeld, 1980). There is one counter and one four-bit comparator for each input channel. The change of state of the comparator U9 triggers another monostable multivibrator (U15A, 74HC123, figure 6). This happens for each of the input channels independently. The length of this pulse is not critical as long as it is enough to trigger the data acquisition system. The system in use here has this pulse width set to about 1 ms, adequate if the data collection window is 4 ms long and the dead time of the computer system is 200 to 300 ms. The term "dead time" refers to the time required for the computer to record the waveforms, archive them to hard disk, and rearm itself in preparation for the next event.

This final pulse goes into three OR gates (U16A-C, 74LS32, figure 6) so that if any of the four channels satisfies the trigger requirements, a pulse is sent to the data acquisition system. By changing the logic in this stage, a trigger pulse can be prevented unless a given number of channels are hit in the same time window. The double-pole, double-throw (DPDT) switches shown in figure 6 allow each channel to be turned off by shorting it to ground if the channel is not in use. This prevents spurious triggers that may arise from open inputs in the discriminator and still allows a trigger pulse to be output if any of the other channels detect a valid acoustic emission.

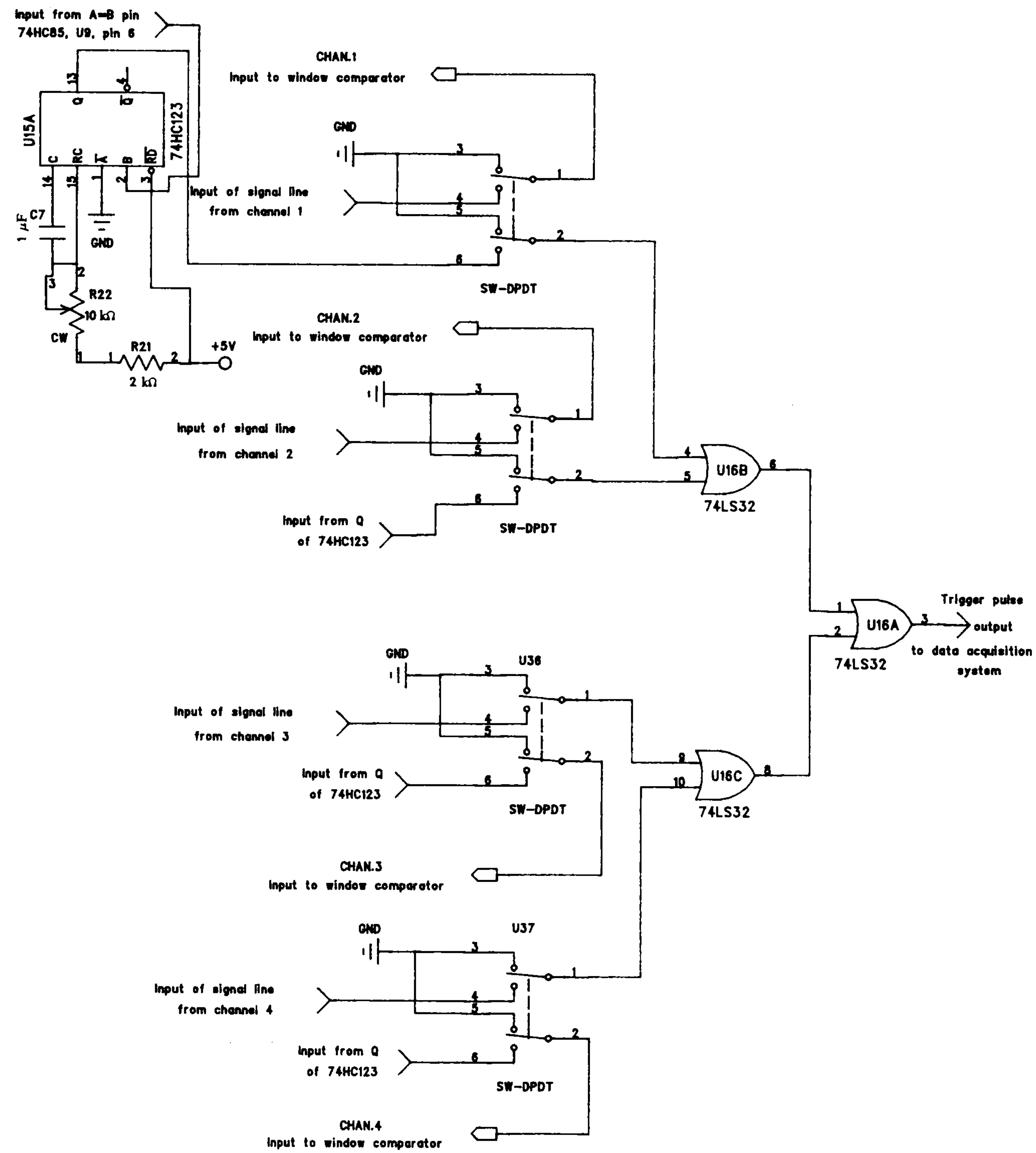
The circuit as designed is set up for four channels and signal frequencies in the range of 50 to 400 kHz. The design could easily be modified for more than four channels by adding additional amplitude comparators, counters, etc. The logic for simultaneity discrimination would have to be changed to allow for the number of simultaneous hits desired. The circuit could also function for higher frequency signals with the choice of faster comparators and transistors.

Figure 5
Schematic of Simultaneity Detection Circuit



If three or more channels exceed their threshold within the time set by U14A's pulse width, a high pulse is sent to the NOR gate shown in figure 4, latching the four-bit counter, U8, off.

Figure 6
Schematic of Trigger Pulse Output Circuit



If all criteria for a valid ultrasonic acoustic emission signal are met, a pulse long enough to trigger a data acquisition is output by the circuit shown. As designed, if any of the four channels detects a valid event, a trigger pulse is output. Each input channel has its own monostable multivibrator, U15A, to supply a trigger pulse. U16 allows this pulse to be output if any of the channels are hit by an acoustic emission. The DPDT switches allow unused channels to be turned off.

SUMMARY

A trigger discriminator circuit has been designed for use in the collection of multichannel, ultrasonic acoustic emission data. The circuit will output a pulse that can be used to trigger a data acquisition system only if preselected criteria are satisfied. The criteria include frequency content, threshold voltage amplitude, number of threshold crossings or ringdown count, simultaneity, and number of channels hit. The system was designed for use with a four-channel data acquisition system collecting signals with a frequency content between 50 and 400 kHz, but it may be easily expanded to more channels with minimal redesign. Use of the design for higher frequency signals, such as those expected in laboratory studies of acoustic emissions, should be possible if faster response time components are used and timing of the various pulses is verified.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Glynn O. Cress, geophysicist, Denver Research Center, USBM, for his patience and assistance in the design and construction of this instrument. Also acknowledged is Daniel L. Gerlick, engineering technician, also of the Denver Research Center, for his assistance in the instrument construction.

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