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THE ELECTRONICS BRAIN ON BOARD THE X-RAY TELESCOPE SPECTROMETER EXPERIMENT

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ABSTRACT

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The electronics brain on board the x-ray telescope spectrometer experiment flown on the 1965 high altitude balloon flights is discussed.

A total of seven types of information from the three detectors on board the experiment is fed into the electronics brain but only those which meet all of the prescribed conditions are permitted to be processed and recorded in a 16-track tape recorder. In addition, a real time marker is provided in the tape readout to facilitate the data reduction.

Because of the complexity of the system, this paper emphasizes system operation rather than the individual circuit descriptions.

Author

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1. INTRODUCTION

The primary aims of this experiment are to measure and analyze x-rays having energies between 10 and 100 kev; in particular, to measure quantitatively the number of x-rays detected by three counters. The data from these counters are fed to an on-board tape recorder along with one of the five identification-mode commands as illustrated in Table 1. Briefly, the three counters are:

(1) A transmission-proportional counter filled with 20 mg/cm^2 of krypton gas used to detect x-rays having energies between 10 and 30 kev.

(2) A scintillation counter with 0.9 gm/cm^2 of cesium iodide employed to measure x-rays having energies between 20 and 100 kev.

(3) A plastic scintillator counter used to indicate x-rays characteristic of unacceptable events.

A signal from either the krypton gas counter or the cesium iodide crystal counter corresponding to an x-ray having an energy within the aforementioned limits is considered to be a "good" event. If the system is not busy, the good event will be analyzed by a common time-sharing 64-channel pulse-height analyzer and also stored as a count in the associated rate accumulator. Digital outputs of the analyzer are immediately read out to the tape recorder, while outputs from the rate accumulators are read out every five seconds.

Higher energy events (>100 kev) received by either the cesium iodide or the plastic scintillator counter are monitored once every minute for a 100-millisecond period. These accumulated counts are then read out to the tape recorder at the end of each monitoring period.

If a signal were received simultaneously from both the cesium iodide and the plastic counters, it would represent an unacceptable event. However, it would be analyzed by a four-channel pulse-height analyzer and used only for diagnostic purposes.

Table 1
Modes of Operation

COUNTER DEVICE	MODE 0 ANALYZED PULSE HEIGHT	MODE 1 ANALYZED PULSE HEIGHT	MODE 2 ACCUMULATED COUNTS FOR 5 SEC EVERY 5 SEC	MODE 3 ACCUMULATED COUNTS FOR 0.1 SEC EVERY MINUTE	MODE 4 REAL TIME MARKER EVERY 12 MIN
Krypton Gas Proportional Counter "A"		10 kev $< A <$ 30 kev $\overline{B} >$ 20 kev $\overline{C} >$ 10 kev	10 kev $< A <$ 30 kev $\overline{B} >$ 20 kev $\overline{C} >$ 10 kev		
Cesium Iodide Crystal "B"	20 kev $< B <$ 100 kev $\overline{A} >$ 10 kev		20 kev $< B <$ 100 kev $\overline{A} >$ 10 kev	$B >$ 100 kev	
Plastic Scintillator "C"	$C >$ 10 kev 20 kev $< B <$ 100 kev $\overline{A} >$ 10 kev			$C >$ 100 kev	
Timer					12 Minute Real Time Marker

2. SYSTEM OPERATION

For discussion purposes the electronics brain may be divided into five subsystems as follows:

(1) Channel A: Processes signals received from the krypton gas proportional counter and the generation of a mode-1 command signal.

(2) Channel B: Processes signals received from the cesium iodide crystal counter and the generation of a mode-0 command signal.

(3) Channel C: Processes signals received from the plastic scintillation counter.

(4) Mode Command and Real Time Marker: Generates modes 2, 3, and 4 commands and the real-time marker.

(5) Scaling and Readout: Transfers data from the storage binaries into a 16-track tape recorder.

2.1 Channel A

When an x-ray is encountered by the krypton gas proportional counter, a charge Q proportional to the energy of the detected x-ray is produced. This charge Q is then converted by the charge-sensitive amplifier into a voltage signal, $v \propto \frac{q}{c}$, where c is the circuit capacitance. If the energy is between 10 and 30 kev, it is considered to be a good "A" event and is analyzed and recorded accordingly, providing the system requirements (Table 1) are met and the system is not busy.

Figure 1 shows a block diagram of the Channel A sub-system. An "A" event, once being converted into a voltage signal, is applied to the front end of the pulse-height analyzer which consists of an OR gate followed by a 2-microsecond-delay stage. Thus, this signal is delayed 2 microseconds before it reaches the linear gate so the system has time to determine whether or not this signal should be sent to the analog-to-digital converter section of the analyzer. If it is a good "A" event and a readout is not in progress (as indicated by the absence of a stop gate pulse and a main inhibit pulse), the 10-A threshold detector opens the linear gate for a period of 5 microseconds and allows the delayed signal to pass to the sweep circuit. It is then converted into a saw-tooth waveform with a duration proportional to the input amplitude.

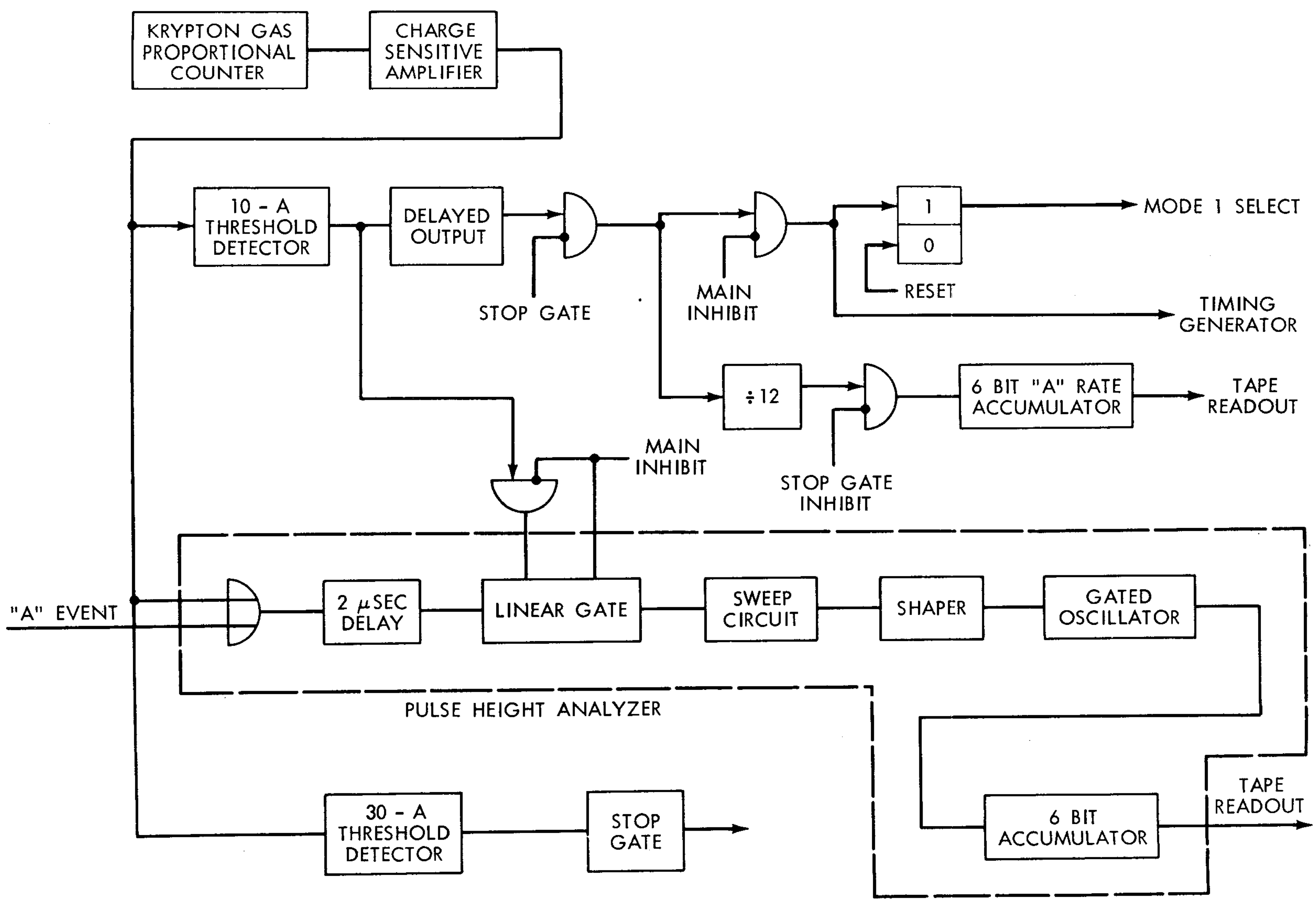

Figure 1. Channel A Sub-system Block Diagram

A delay-line gated oscillator is used over the standard clock oscillator to convert the pulse width to a train of pulses, primarily because it gives noise-free operation during analyzer live time and also because it has a high degree of stability during temperature and supply voltage variations. As in all such circuits, the input driving pulse should have a fast rise and fall time. To meet these requirements, the saw-tooth waveform is sent through a pulse shaping circuit before it is used to drive the gated oscillator. The oscillator will free-run and produce a train of 2-microsecond pulses as long as the input drive is present. These pulses are then stored in 6-bit binaries until a readout command from the timing generator transfers them 11 millisecond later to tracks 1 through 6 of the tape recorder. The reason for the delay in transferring the stored information is to insure that spacing between readouts on the tape is adequate for clear data pick-off.

In order to identify the information on the tape as being from the krypton counter, a marker on track 14 from the readout of the mode-1 select command is used. This is derived from the output of the 10-A threshold detector via a 5-microsecond delay and 2 inhibit gates. The delay is needed to give the system time to determine the acceptability of the event before it reaches the inhibit gates. If this event is acceptable, as indicated by the absence of both the stop-gate pulse and the main inhibit pulse, the delayed output will introduce a bit in the mode-1-select binary.

The 6-bit "A" rate accumulator receives an event in the same manner as the mode-1 select command; however, the signal is extracted before it reaches the main inhibit gate. Thus, good events are allowed to store as counts even while the system is busy processing some other event, thereby permitting the total accumulating time to approach 100% of the real time. The pre-scalers placed in front of the accumulator are used to assure that the accumulator will not overflow for the maximum predicted rate of events. The inhibit gate between the pre-scalers and the rate accumulator prevents any events from being counted during the mode-2 readout sequence which occurs once every 5 seconds. At that time the bits in the "A" rate accumulator are read out to tape recorder tracks 7, 8, 10, 11, 12 and 13, and the mode-2 is read out to track 15.

If the energy of an x-ray is greater than 30 kev, the 30-A threshold detector will also trigger and cause the stop gate to generate a 10-microsecond pulse which is used to block the signal from getting through the linear gate of the pulse height analyzer. This sets the upper limit for which an "A" signal can be analyzed in the pulse height analyzer.

2.2 Channel B

An x-ray detected by the cesium iodide crystal is considered to be a good

"B" event if the energy is greater than 20 kev but less than 100 kev. Therefore it is analyzed and counted if the system requirements (Table 1) are met and no readout is in progress.

By comparing the block diagram of Channel B (Figure 2) with the block diagram of Channel A (Figure 1), it can be seen that with the exception of the first two stages, both channels use the same pulse height analyzer.

Unlike Channel A, where the first stage receives its input from only one counter, the first stage of Channel B is subjected to signals from either or both the CsI crystal and the plastic scintillator counter because of the mechanical construction of these counters. Hence, the exact waveform of the incoming signal must be unaltered until the system can determine its origin and acceptability. The process by which this is done will be described in the Channel C portion of this paper. For the present, it is sufficient to state that a CsI signal will be processed but a plastic signal will be rejected by the Channel B subsystem.

Assume that an input signal is from the CsI crystal: it is amplified and shaped before being applied to the lower and upper threshold detectors and front end of the pulse height analyzer. The lower detector (20-B) is set at 20 kev while the upper detector (100-B) is set at 100 kev. The good "B" signal $100 > v > 20$ kev, once it has passed through the linear gate, is processed and converted into digital form by the delay-line-gated oscillator. These pulses are then stored in 6-bit binaries until a readout command from the timing generator transfers them 11 milliseconds later to tracks 1 through 6 of the tape recorder. In this readout sequence the mode-0 command is used in conjunction with the timing-generator pulse, and the manner in which the mode-0 command is obtained is similar to that of the mode-1 command pulse for an "A" event.

As was the case for the good "A" event, this good "B" event is allowed to store in the 6-bit "B" overload accumulator and read out to tracks 1 through 6 of the tape recorder once every 5 seconds in the same readout sequence as the "A" rate accumulator.

An x-ray with an energy higher than 100 kev will fire the upper level detector 100-B, which causes the stop gate to ignore this signal in the pulse height analyzer. However, the system will accept this event if it occurs during a 100 millisecond period immediately preceding the mode-3 command pulse. The event will be stored in the 6-bit "B" overload accumulator and then read out to tracks 1 through 6 of the tape recorder during the mode-3 readout sequence. A marker on tracks 14 and 15 is used to identify the mode-3 readout.

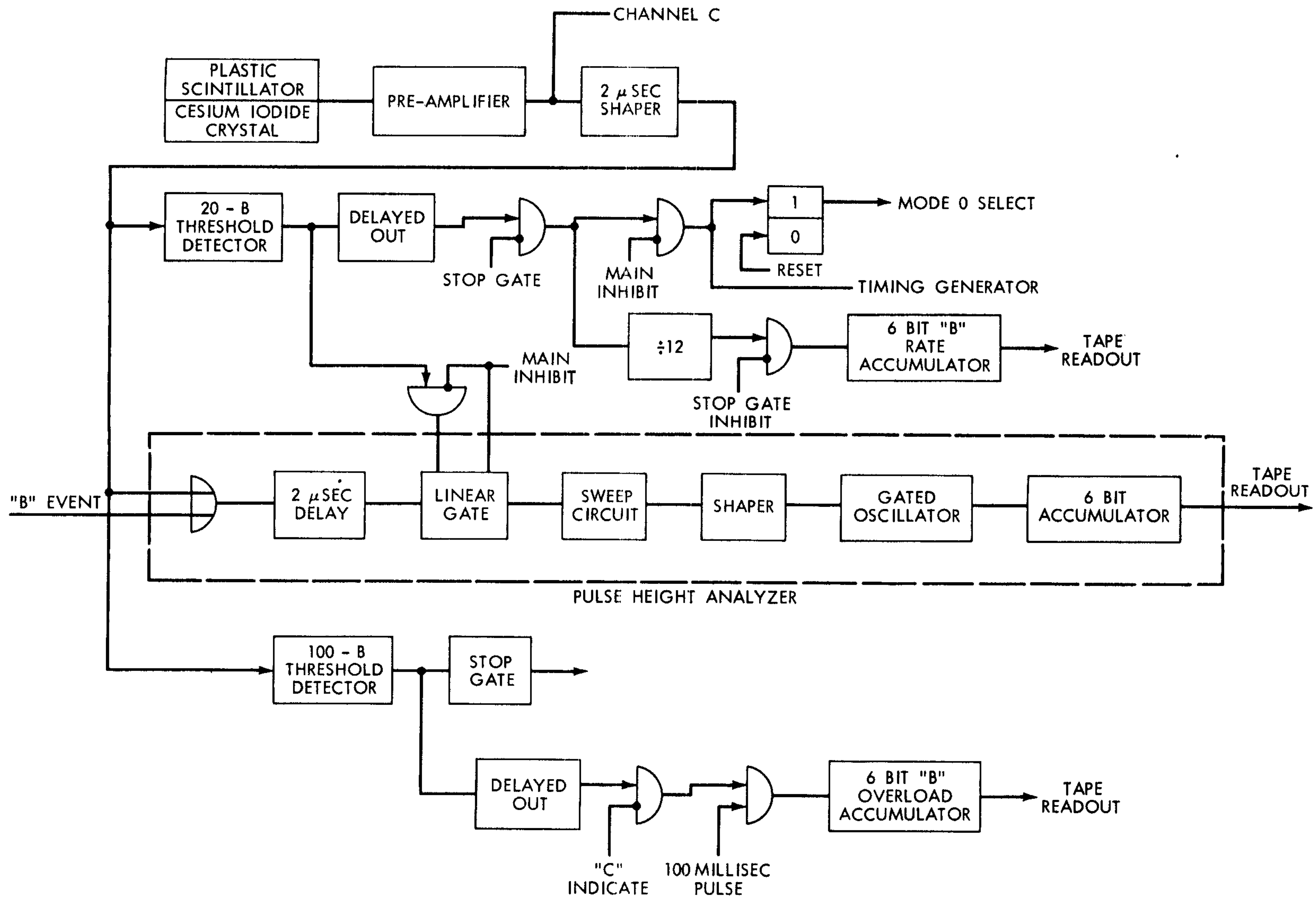

Figure 2. Channel B Sub-system Block Diagram

2.3 Channel C

As was just stated, it is necessary to determine the origin before allowing processing of an output which has been received from either the cesium iodide or plastic counter and fed to a common preamplifier. To accomplish this end, a phoswitch discriminator is used to identify all unacceptable plastic scintillator events from the acceptable cesium iodide crystal events. This phoswitch is essentially a 40-nanosecond shaper followed by a threshold detector, a peak detector and a coincidence gate. Figure 3 shows a block diagram of this phoswitch, the 4-channel pulse-height analyzer, and other miscellaneous logics which make up the Channel C sub-system.

When a signal from the preamplifier is applied simultaneously to both the peak detecting circuit and the 40-nanosecond shaping circuit, the outputs from these circuits will trigger the coincidence gate, but only if this signal is from the plastic counter resulting from an x-ray with energy greater than 10 kev. Now, if the signal originated from the CsI counter (which has a nominal rise time of 1.8 microseconds) instead of from the plastic counter, it would cause the outputs between the shaper and the peak detecting circuits to be 1.8 microseconds apart; thus, the coincidence gate would not be triggered and Channel B would be allowed to accept this signal to be analyzed. On the other hand, a signal from the plastic counter having a nominal rise time of only 30 nanoseconds will cause the above two outputs to be in coincidence, resulting in an output from the coincidence gate. This, in turn, activates the stop gate to take the following actions: (a) to prevent the initial readout of the 4 channels to the tape recorder; (b) to inhibit the signal from the preamplifier from getting through the linear gate of the Channel B pulse height analyzer; and (c) to block the "B" overload accumulator via the "C" indicator one-shot.

Because of the photon fluctuations emitted by the cesium iodide crystal when such relative low energy events are being received, the rise time of these signals produced by this counter will vary. If the rise time of the good event is less than 0.5 microsecond, it will be treated by the system as it were a plastic counter signal and therefore rejected by both the Channel B and Channel C sub-systems. A good event having a rise time between 0.5 and 1.8 microseconds will be analyzed by both sub-systems, while a good event having a rise time greater than 1.8 microseconds will be analyzed by the Channel B sub-system only. Thus, by comparing the results between these two channels, one can predict the nature of an x-ray event.

The 4 channel-threshold detectors in this sub-system are set at 10, 20, 40, and 100 kev by the 10 C, 20 C, 40 C, and 100 C stages respectively as shown in Figure 3.

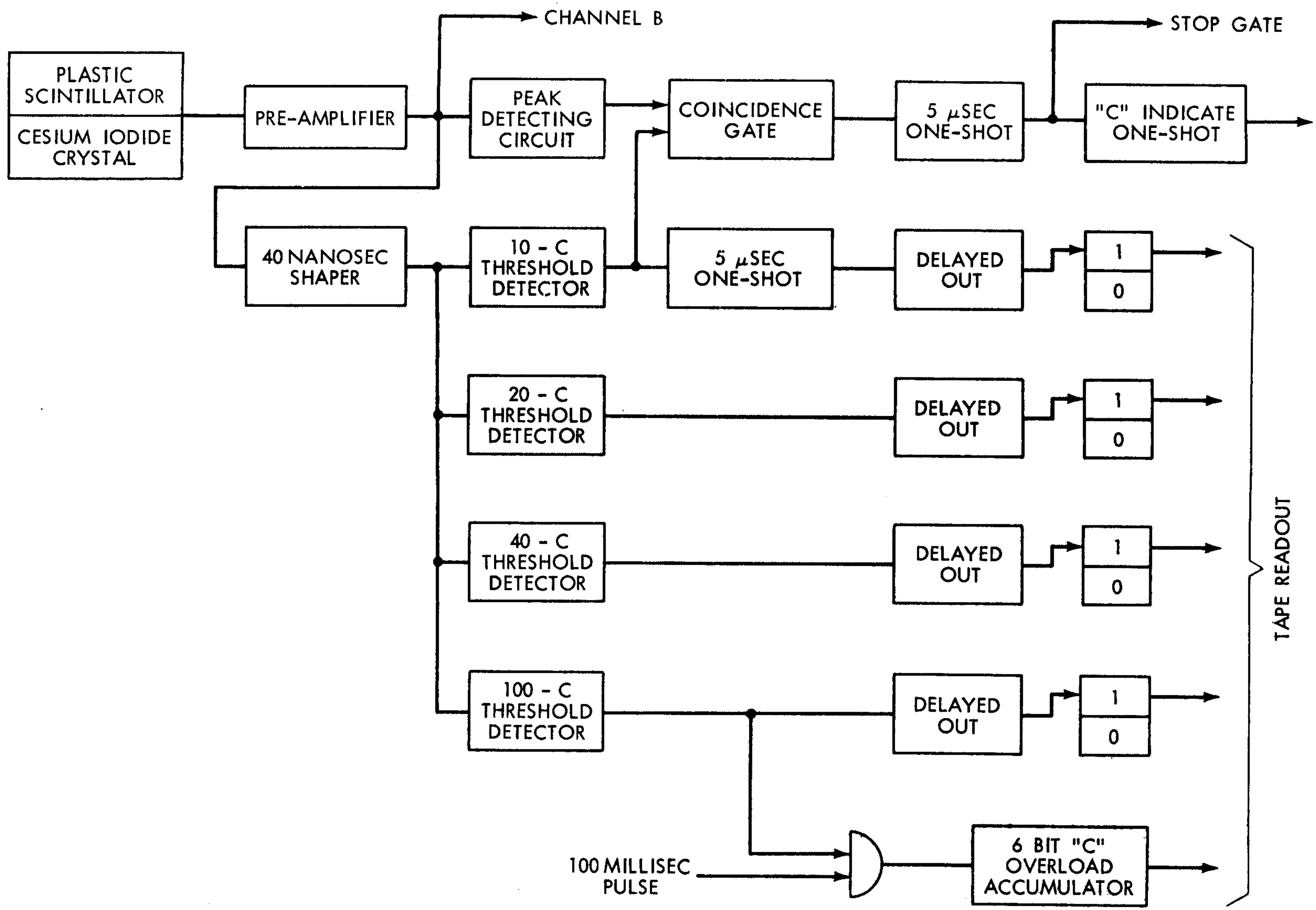

Figure 3. Channel C Sub-system Block Diagram

Plastic events having energies greater than 100 kev are sampled and counted once a minute for a period of 100 milliseconds, as was the case in the high energy cesium events. The mode-3 command signal and the timing generator then allow these overload counts to be read out to tracks 7, 8, 10, 11, 12, and 13 of the tape recorder.

2.3.1 Stop Gate—As was previously mentioned, if any event does not meet the system requirements as defined in Table 1, a 10 microsecond pulse from the stop gate will block the offending event from being analyzed and/or counted. Figure 4 shows that the stop gate will generate this blocking pulse under any of the following conditions:

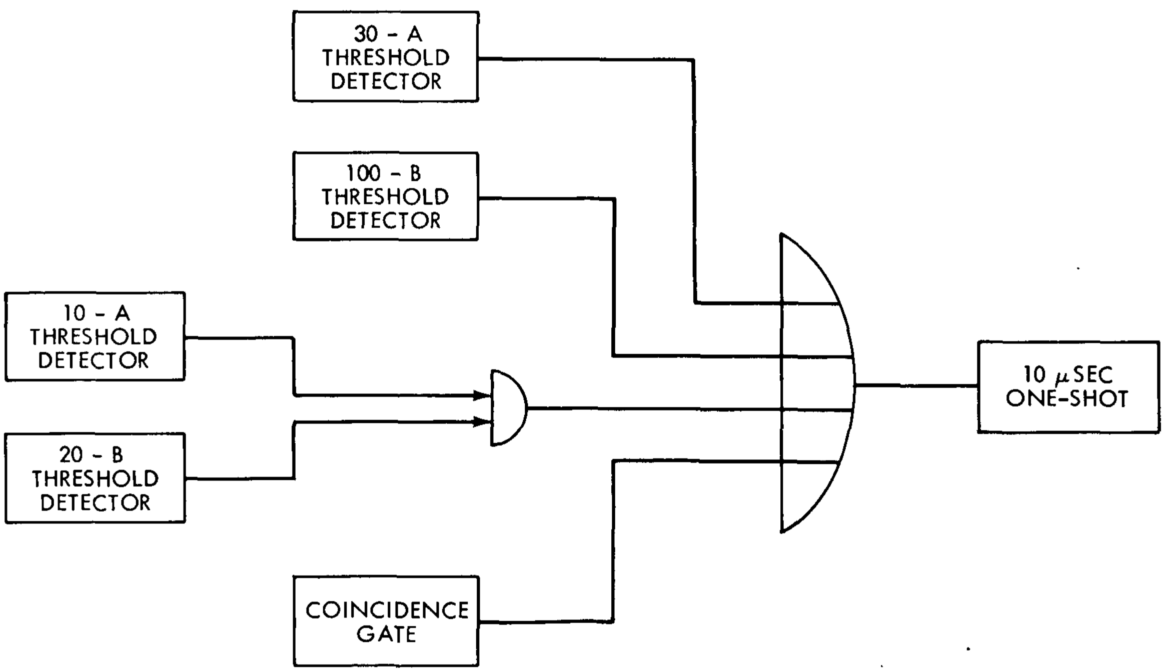

Figure 4. Stop Gate Logic Diagram

(1) If the 30-A threshold detector is triggered, indicating an "A" event corresponding to an energy greater than 30 kev has been received by the krypton gas counter.

(2) If the 100-B threshold detector is triggered, indicating a "B" event corresponding to an energy greater than 100 kev has been received by the cesium iodide counter.

(3) If the good "A" event and good "B" event occur within 5 microseconds of each other.

(4) If the coincidence gate is triggered, indicating that a "C" event corresponding to an energy greater than 10 kev has been received by the plastic counter.

To summarize, the only time the stop gate will not fire upon receiving an event is when a good "A" or a good "B" event is present by itself, i.e., if the time between these two good events is greater than 5 microseconds.

Since the optimum operating speed of the magnetic tape system used is approximately 76 events per second, a good event occurring between 5 microseconds and 13 milliseconds from the previous good event will also be rejected by the system. This process will be discussed in more detail under the "scaling and readout timing" section of this paper.

2.4 Mode Command and Real Time Marker

The 5 modes of operation with the type of information received, the system requirements that must be met, and the timing involved for each mode is summarized in Table 1.

In general, mode-0 or mode-1 will appear whenever there is a good "A" or a good "B" event. However, the readout system can operate in only one mode at a time; for example, if a good "A" event occurs while the system is in any other mode of operation, it will not be analyzed. The timing of modes 2, 3, and 4 is controlled by an on-board 5-second-clock oscillator.

A block diagram of the Mode Command and Real Time Marker sub-system is shown in Figure 5.

The mode-2 command signal is used to permit readout of the number of good events received from the krypton gas proportional counter and the cesium iodide counter during the previous 5-second period. This command is initiated by the 5-second oscillator and normally starts immediately; however, if a good event was received within the previous 13 milliseconds, the mode-2 command sequence will not start until the readout cycle of the good event is completed. This is accomplished by allowing the 5-second pulse to trigger a standby 20-millisecond one-shot multivibrator. The output of this one-shot is then applied to an inhibit gate where it is blocked by the presence of the timing-generator inhibit pulse, lasting up to 13 milliseconds from the time the system starts its readout sequence. Since the standby one-shot pulse is 20 milliseconds wide, it is still able to go through the inhibit gate and fire the mode-2 command one-shot after the inhibit pulse has ended. The pulse that starts the 20-millisecond mode-2 command one-shot is also fed to the timing generator to commence the

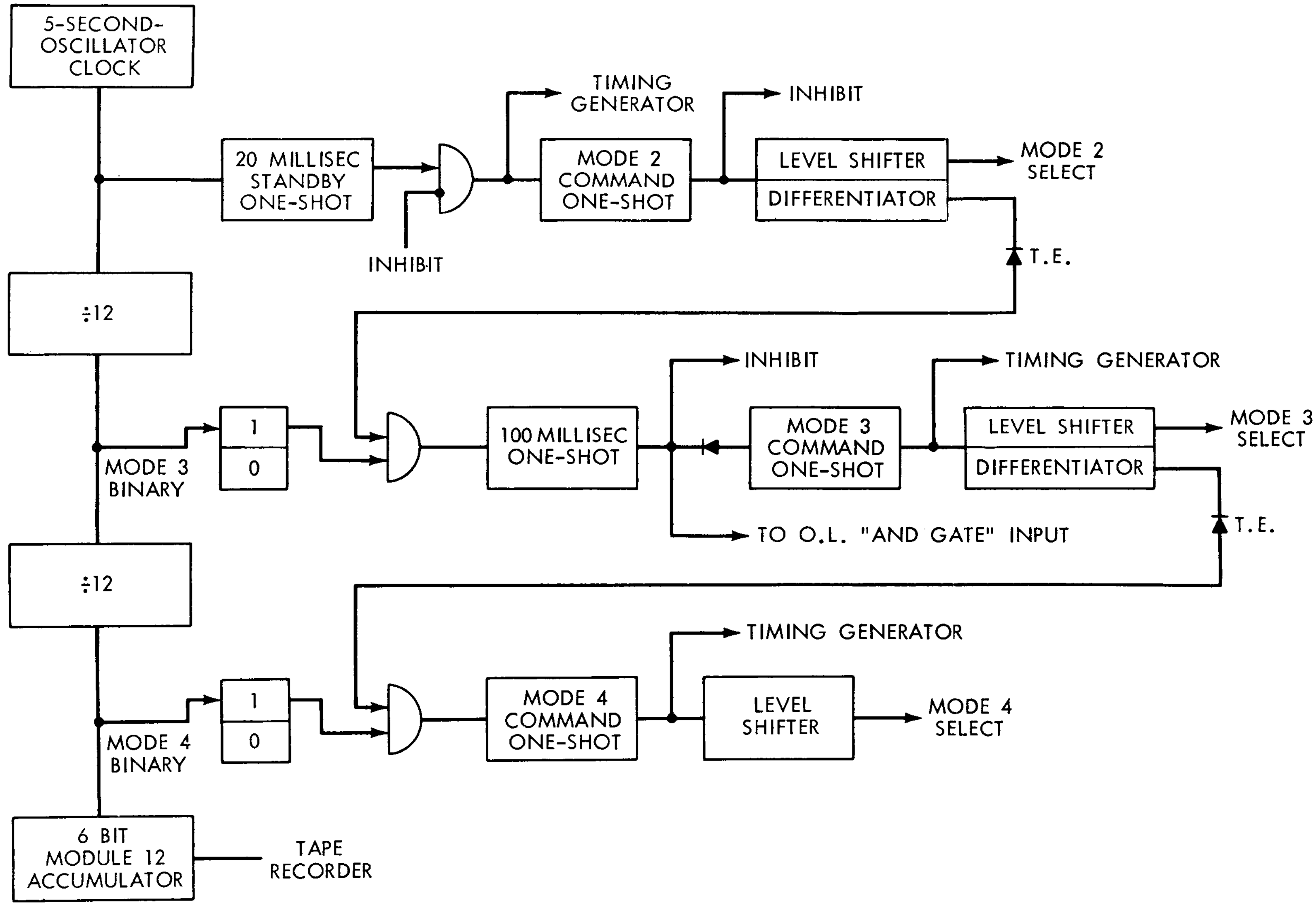

Figure 5. Mode Command and Real Time Marker Sub-system Block Diagram

mode-2 readout cycle. The trailing edge of the mode-2 command one-shot is used to: (1) reset the 6-bit-rate accumulators where stored data are being read out at this time, and (2) as an indication that the mode-2 operation is complete. The full 20-millisecond positive pulse is used to shut down the system during this readout period and also inverted and used as the mode-2-select indication for the readout system.

The mode-3 command signal is used to permit readout of the number of high energy (> 100 kev) events received from both the cesium iodide and the plastic scintillation counters during a 100 millisecond period immediately preceding the mode-3 readout cycle. Referring to Figure 5, pulses from the 5-second oscillator are fed through a frequency divider network where the input is scaled down to one pulse per minute. The one-minute pulse then changes the mode-3 binary into the one state. Its output plus the trailing edge of the mode-2 command one-shot (which is used as a completion indicator) cause the AND gate to produce a signal which initiates the 100-millisecond one-shot. As was mentioned earlier, this pulse sets the system so that only high energy (> 100 kev) events are permitted to accumulate. The trailing edge of this 100-millisecond pulse starts the mode-3 command one-shot and also resets the mode-3 binary. The mode-3 command one-shot is 20 milliseconds wide and performs a parallel function similar to the mode-2 command one-shot.

The mode-4 command signal is used to read out the Real Time Marker once every 12 minutes. The starting sequence of the mode-4 command one-shot is similar to the one used for mode-3. The one-minute pulses are fed through another frequency divider network, thus producing a pulse every 12 minutes which changes the state of the mode-4 binary. The AND gate, upon receiving the combination of this binary output and the trailing edge of the mode-3 command one-shot, causes the mode-4 command one-shot to trigger, thereby starting the mode-4 readout cycle.

The Real Time Marker is derived by allowing the 12-minute pulses to be accumulated in a 6-bit module-12 counter. Each bit is reset automatically to the zero state when the system power is applied. In this manner the starting point and the total elapsed time can be recorded against real time.

3. SCALING AND READOUT TIMING

Figure 6 shows a block diagram of the Scaling and Readout Timing subsystem plus a graphic representation of the timing involved.

The timing action is accomplished by a magnetic-core multivibrator which produces one complete cycle of an unbalanced bi-polar square wave for each

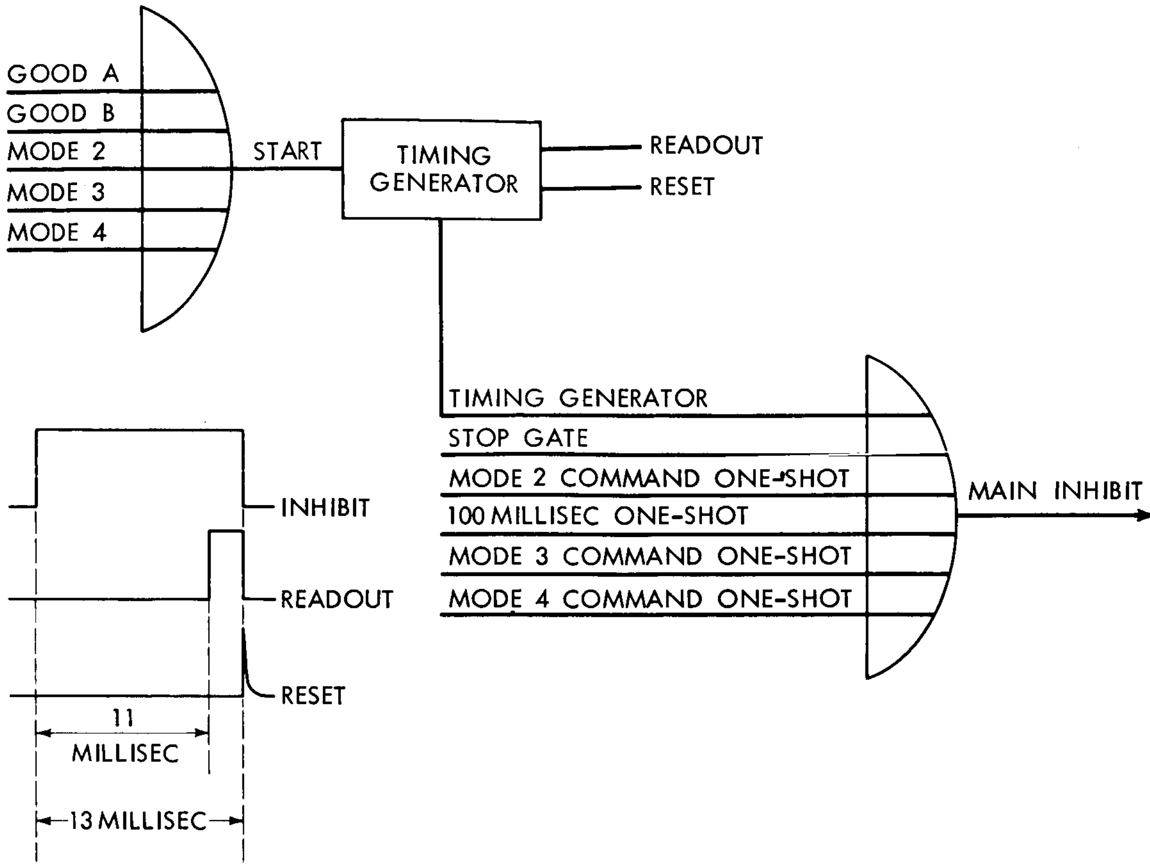

Figure 6. Scaling and Readout Timing Sub-system Logic Diagram

input pulse. The positive portion of this square wave, lasting for 11 milliseconds, is the scaling time period in which the time input signal is processed by the system. For example, during mode-0 or mode-1, this time period is used for the processing of a good event in the analog-to-digital conversion circuits and the digital information is fed to the 6-bit scalers. The negative portion of the 2-millisecond bi-polar square wave activates the parallel readout of stored bits in the scalers, an index bit, and a mode selection bit into the 16 magnetic-tape-recorder heads. Table 2 illustrates the track allocations and various types of data available for each readout cycle. A reset pulse is generated at the end of the 2-millisecond readout pulse for the purpose of setting each of the 6-bit scalers back to its zero state.

The timing generator also produces an inhibit pulse of 13 milliseconds duration which blocks the system from receiving any new events into the pulse height analyzer during the readout cycle. This limits the maximum possible operating speed to 76.1 events per second. Because the system is also blocked from accepting events during the readout cycle of modes 2, 3, and 4, the average operating speed is further reduced to 74 events per second.

Table 2

Tape Recorder Track Allocations

TRACK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	$20 < B < 100$ kev						"C"	"C"		"C"	"C"					
Mode 0	2^0	2^1	2^2	2^3	2^4	2^5	>10kev	>20kev	ID	>40kev	>100kev					
	$10 < A < 30$ kev															
Mode 1	2^0	2^1	2^2	2^3	2^4	2^5			ID					1		
	B Bit Rate						C Bit Rate									
Mode 2	2^0	2^1	2^2	2^3	2^4	2^5	2^0	2^1	ID	2^2	2^3	2^4	2^5		2	
	B Overload						C Overload									
Mode 3	2^0	2^1	2^2	2^3	2^4	2^5	2^0	2^1	ID	2^2	2^3	2^4	2^5	1	2	
	Time (x 12)															
Mode 4	2^0	2^1	2^2	2^3	2^4	2^5			ID							4

4. CONCLUSION

This system is quite flexible in its handling and processing of data and can be easily adapted to other types of detection apparatus. The overall trigger levels of the threshold detectors can be changed by increasing or decreasing the gain of the appropriate amplifier. However, in order to change the ratio between two detectors, it is necessary to adjust the sensitivity of the individual detector circuits. This can also be done with relative ease.

The power consumption of this electronics system is approximately 2 watts. This is somewhat high for satellite experiments but is relatively low for balloon and sounding rocket experiments, particularly when the amount of information received is taken into consideration.

The x-ray telescope spectrometer experiment described in this paper was flown in December 1965 from Holloman Air Force Base, New Mexico. Preliminary data analysis indicates that the system performed very satisfactorily in attaining its designed objectives.