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Authors

Swierkowski, Stefan P.
Lafore, Robert W.

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This article describes the construction and operation of the hardware and software constituting a 4096-channel bistabilized pulse-height analyzer, data-processing, and control system. The system was designed for studying mesic x-ray spectra at the 184-inch cyclotron.[1]

HARDWARE

Figure 1 shows a simplified block diagram of the system. In operation, an x ray of a given energy is stopped in the Ge or Si solid-state detector and converted into a charge pulse which is amplified by a charge-sensitive or voltage-sensitive preamplifier.

The signal now passes through a variable-gain amplifier, a linear amplifier, and a linear gate, and then into an analog-to-digital convertor (ADC). Here it is converted into a 12-bit word and transferred in parallel into the PDP-5 computer for data storage, data display, and feedback control. As the computer data memory periodically fills up, the computer suspends its normal data-taking function while it transfers the data memory contents onto magnetic tape. This forward path, thus far, is essentially a 4096-channel pulse-height analyzer.

The gain, or more correctly, the transfer function, of the system may be changed electrically in two ways. First, the gain may be changed by a variable-gain amplifier which effects a gain change by changing an analog voltage level applied to on a field-effect transistor acting as a variable feedback resistor. Second, the spectrum may be "en masse" shifted up or down by another analog voltage applied to a pedestal adjustment in the linear gate. The linear gate is open only when a desired x ray passes through the beam telescope and also produces a pulse in the timing preamplifier.

These two methods of effecting a transfer function change are used to stabilize the transfer function against drift by employing feedback from the computer as the data are being entered into storage. Previous systems have used a variable-gain amplifier only and have been referred to as "gain-stabilized system."[2,3] This particular system employs both gain and bias stabilization.

This method of stabilization utilizes a naturally occurring peak in an x-ray spectrum, commonly obtained for calibration purposes from a small radioactive source. Since this reference right at the beginning of the system is used, the stabilization with reference to this peak compensates for drift in any amplifier, and includes even the rundown circuitry in the ADC.

A linear transfer curve is convenient for visualizing the stabilization process. Generally, channel zero does not correspond to zero volts input because, first of all, there is always noise present, and to eliminate storage of this noise, a threshold voltage V_t is set (Fig. 2); and secondly, a bias "cut" may have been made to select only the upper portion of spectrum to analyze.

Suppose, for example, that the gain is increased, as shown by the dotted transfer line in Fig. 2; then the computer recognizes the peak shift, within the limits of a window, W, and makes a correction by decreasing the gain a fixed small amount with the variable gain amplifier for each pulse that is analyzed until the peak is back to its desired position. The mechanism for this feedback is shown in Fig. 3. A reversible scaler, normally reset to 512, is continually monitored by a digital-to-analog convertor (D/A) whose output is the actual correction voltage for feedback. Say, for example, the gain has increased; then for every count that falls between P and P+W, including P, the PDP-5 sends a "minus" pulse to the reversible scaler, which then effects a decrease in gain by a small fraction of a channel; conversely, when a count is obtained between P-W and P, excluding P, the gain is increased; thus, the net effect of a peak shift due to gain drift's increasing is a decrease in count on the reversible scaler, although this net effect is achieved in a random three-steps-forward–one-step-back type of process.

The zero adjustment or pedestal feedback is accomplished in a manner similar to that of the gain. The gain is an angular control about an origin; the bias is a parallel motion and the combination is, in effect, a polar coordinate system which defines the straight-line transfer function. Note that a change in bias affects both the bias reference peak and the gain reference peak by the same amount; a shift in gain, however, affects the bias peak less then the gain. It is difficult to imagine the simultaneous effect of these two dependent corrections upon each other, and a computer program was written to simulate the behavior of this system using the straight-line transfer function as a model; the model predicted two types of behavior later verified in operation. First, it predicted a piecewise linear correction rate to a step response, and secondly, an unstable system if the lower-energy reference peak (the bias peak) effected much more feedback (channel shift per count) than the gain peak.

In actual practice, the x rays come from two sources. First, there are x rays from a target which captures the π mesons; these x-ray spectra are of prime interest to the experimenter. Second, there are x rays from two calibration sources; these sources actually emit a pair of x rays in opposite directions. One passes into the main detector for stabilization; the second passes into an adjacent lower-quality Si detector which produces a timing pulse. This timing pulse is used to mark or tag the second source of x rays from the target x rays. Thus, actually, two complete and independent 4096-channel spectra are produced at the same time: one for calibration, which has a minor percentage of the total counts, and one for primary data. The main input into the computer consists of the 12-bit data word, and this may be accompanied by the two stabilization flags, all of which are read essentially in parallel by the computer every time an event occurs; thus, there are two types of data words. The primary data are distinguished from the stabilization data by the presence of a flag for the stabilization data. The only other inputs are an electrical turnon-turnoff for gating the storage, and the two 10-bit scaler correction monitors, which may be used at the discretion of the operator. The interface hardware is essentially in three sections. First, there is an interface between the ADC and the PDP-5. Second and third are the bias and gain interface for feedback, and these are very similar to each other.

The correct feedback setting depends upon the resolution of the detector and the energy window as expressed by keV/channel; the channel change per count of feedback should be much less than the (resolution)×(channels/keV). According to this criterion, measurements indicate that the effect of feedback upon the system resolution is negligible.

In Fig. 1 the block diagram labeled "detector"[4] refers to the cryogenic chamber which contains the detector, liquid nitrogen cooling system, vacuum system, and three FET stages; this is shown in Fig. 4.

Timing resolution of the various detectors presented somewhat of a problem initially, since a narrow gate was desired to exclude the large quantities of background noise from the beam. Timing resolution on the order of 20 nsec has been achieved, although this depends upon the signal-to-noise ratio and the type of detector used. This figure is being improved.

SOFTWARE

As noted above, the software serves three basic functions:

(a) storage of data on tape;
(b) scope display,
(c) system control and its options.

TAPE STORAGE

Since the PDP-5 memory is only 4096 12-bit OCTAL CODED words, it was not practical to pulse-height sort all the data as they arrived; instead, the data are stored sequentially in a buffer memory of 1536 words. Disadvantages of this approach are the increased quantity of tape necessary and a slightly increased analysis time for the tape. Advantages are that the increased redundancy makes it impossible for a noise error on the tape to invalidate the data, and that "marker words" or "tags" can be used to distinguish between different types of data.

SCOPE DISPLAY

The scope display is separate from the data buffer and it is pulse-height sorted; however, for full-scale display, the spectrum is condensed by integrating piecewise in 8 channel blocks, thereby reducing the memory requirement by 1/8 but still leaving a more than adequate display resolution. Single-channel visual resolution is possible by 1/8- or 1/64-scale display (see Fig. 5).

KEYBOARD-CONTROLLED OPTIONS

In addition to the functions noted above, the program also contains a number of options controlled from the teletype keyboard, which provide different modes of operation to facilitate initial setup of equipment, checking, and so on.

The storage in tape memory can be suspended during setup or while tape is changed, and a special end-of-tape marker can be written when data storage on a particular tape is complete. Four words of the tape memory buffer are reserved for a title to identify the data tape after analysis. These are filled in with a keyboard option.

The scope display, besides having the different scale options already mentioned, can be reduced vertically by half, either manually, or automatically when it grows to the top of the screen. Options can also select whether the display includes stabilizing data or not, and whether the display occurs while data acquisition is taking place, or without concurrent data acquisition to provide a faster display time for better visibility.

The peak centers for gain and bias stabilization are typed in via the keyboard, and the operator may also turn either stabilizer on or off, or cause stabilization to occur without triggers.

The computer also rewinds data tapes automatically and alerts the operator if any transfer function shifts are not compensated.

Other keyboard characters cause the status of all options to be printed out, lock the keyboard to prevent accidental activation of undesired options, and unlock it.

DEAD-TIME CONSIDERATIONS

A problem of some concern in the design of the program has been the minimization of "dead time," or the time the computer is unable to record an incoming event because it is still busy handling the previous one. Clearly the dead time should be less than the average rate at which data arrive, if the percentage of data lost is to be kept low.

A formula has been derived[5] relating dead time, data rate, and the percentage of events recorded (efficiency). Figure 6 shows the plot of the formula and the results. The system was about 90% efficient.

In summary, the system has proven effective and easy to use, and the flexibility of the PDP-5 and hardware has greatly facilitated making modifications since the experiment was begun.

ACKNOWLEDGMENT

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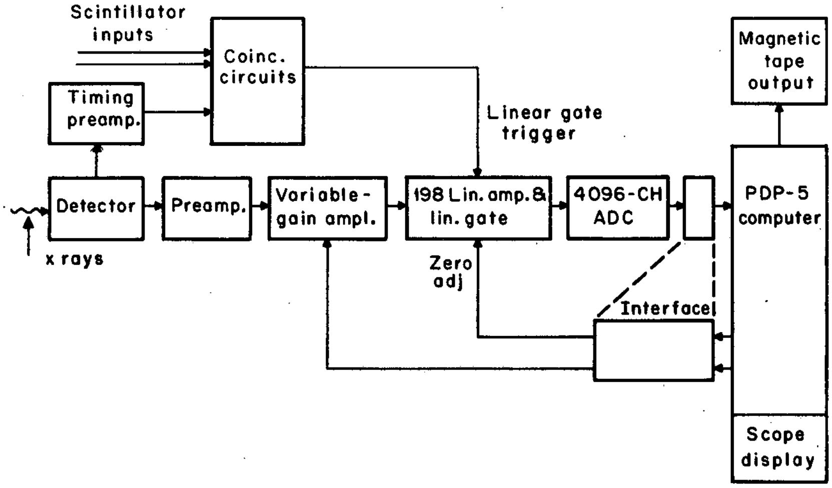

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Fig. 1. System block diagram.

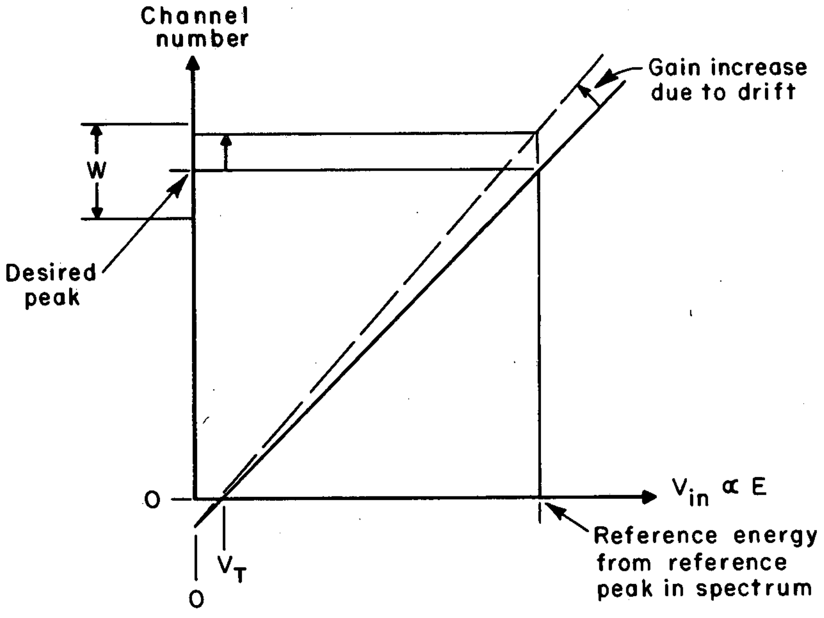

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Fig. 2. Gain shift on transfer curve.

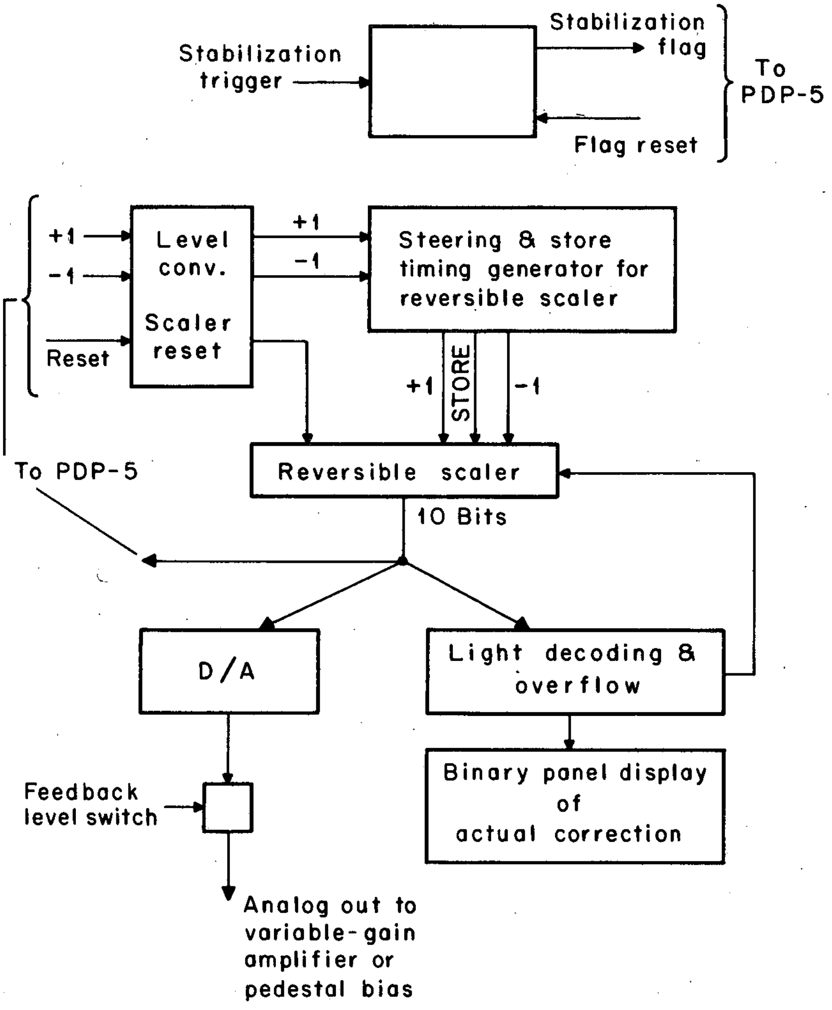

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Fig. 3. Feedback scheme.

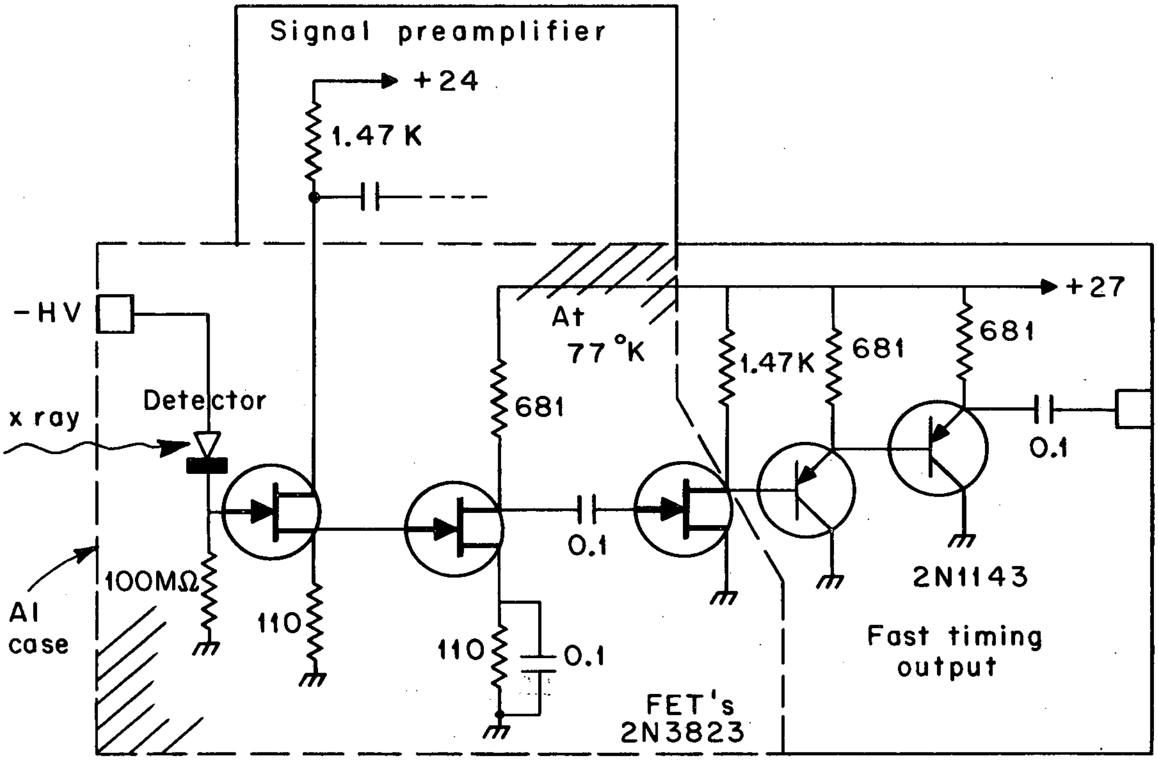

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Fig. 4. Detector details.

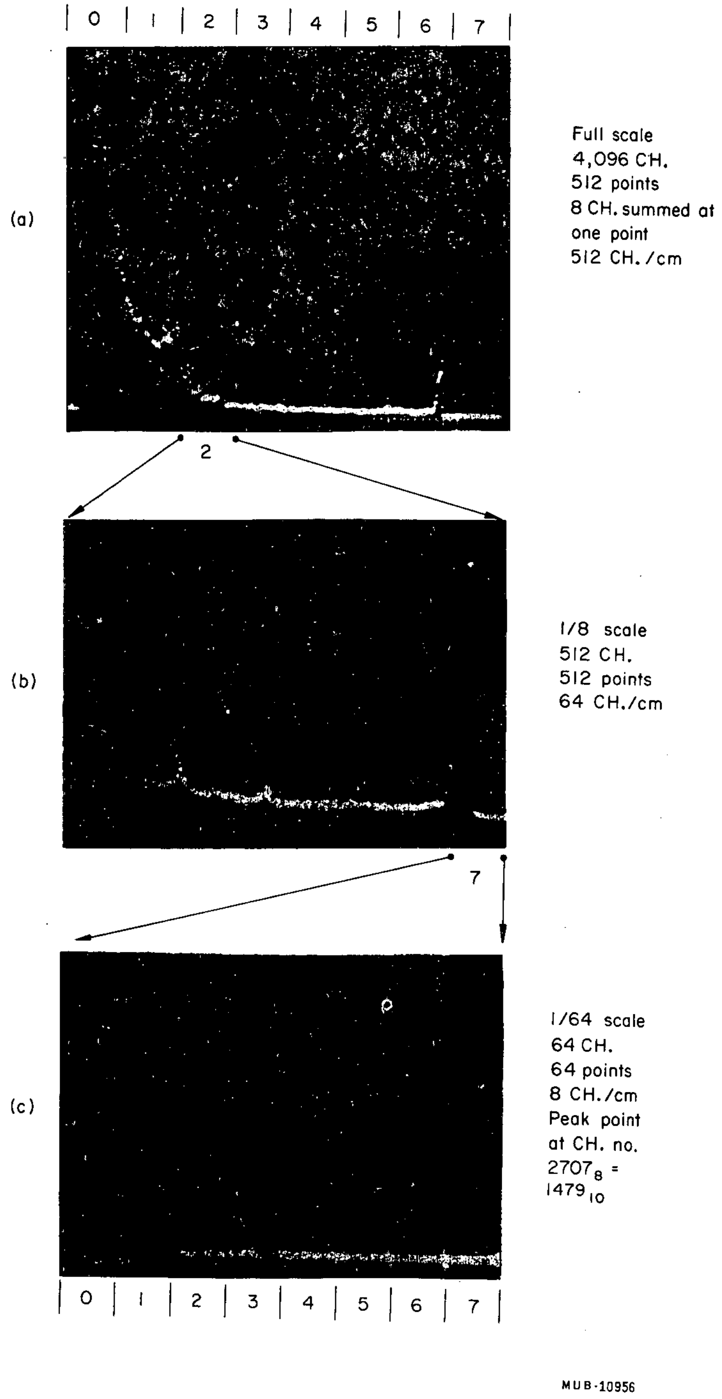

Fig. 5. Cesium-spectrum computer display.

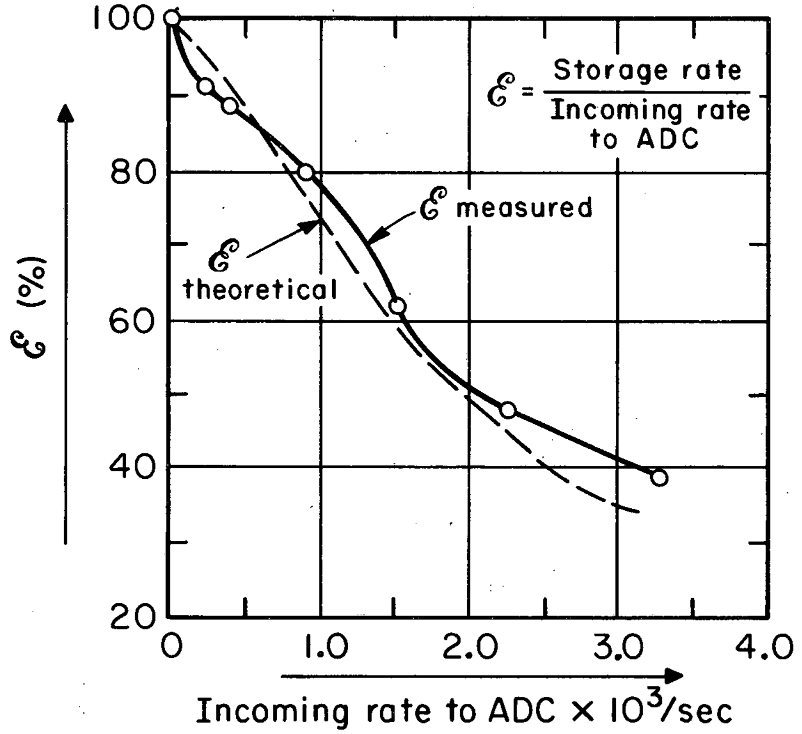

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Fig. 6. Efficiency curve.