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THE ASTRE - AN ELECTRONIC REAL-TIME STATISTICAL ANALYZER

[Unclassified Title]

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Communication Branch
Radio Division

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NAVAL RESEARCH LABORATORY
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ABSTRACT

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The Laboratory has developed the Astre, an interim model of an electronic real-time statistical signal analyzer. The primary purposes in building the analyzer were to develop adequate means for making statistical measurements in real time corresponding to certain specified probability distributions, to automatize the routine and repetitive parts of the statistical analysis of time series, and to expedite decisions relating to a time series by measurements made on a portion of it. The real-time approach precludes the necessity for recording equipment that is usually required for autocorrelation and crosscorrelation point-by-point techniques.

The concern here is mainly with a binary stream of information and the measures corresponding to autocorrelation, crosscorrelation, distribution of runs and patterns, and the Bernoulli distribution. The system is designed for synchronous operation at communication information rates from any constant-rate real-time signal source, or from a variable-rate source with rate information available, such as in the associated continuously driven paper tape input. Provision is made for selection of total sample size for all programs, and of class interval for the appropriate program. In addition to cross checks built into each program, certain checks are available by switching to test the shift register delay line, detectors, integrators, and related circuits for marginal operation.

PROBLEM STATUS

This is an interim report on the problem; work is continuing.

AUTHORIZATION

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Manuscript submitted June 26, 1957

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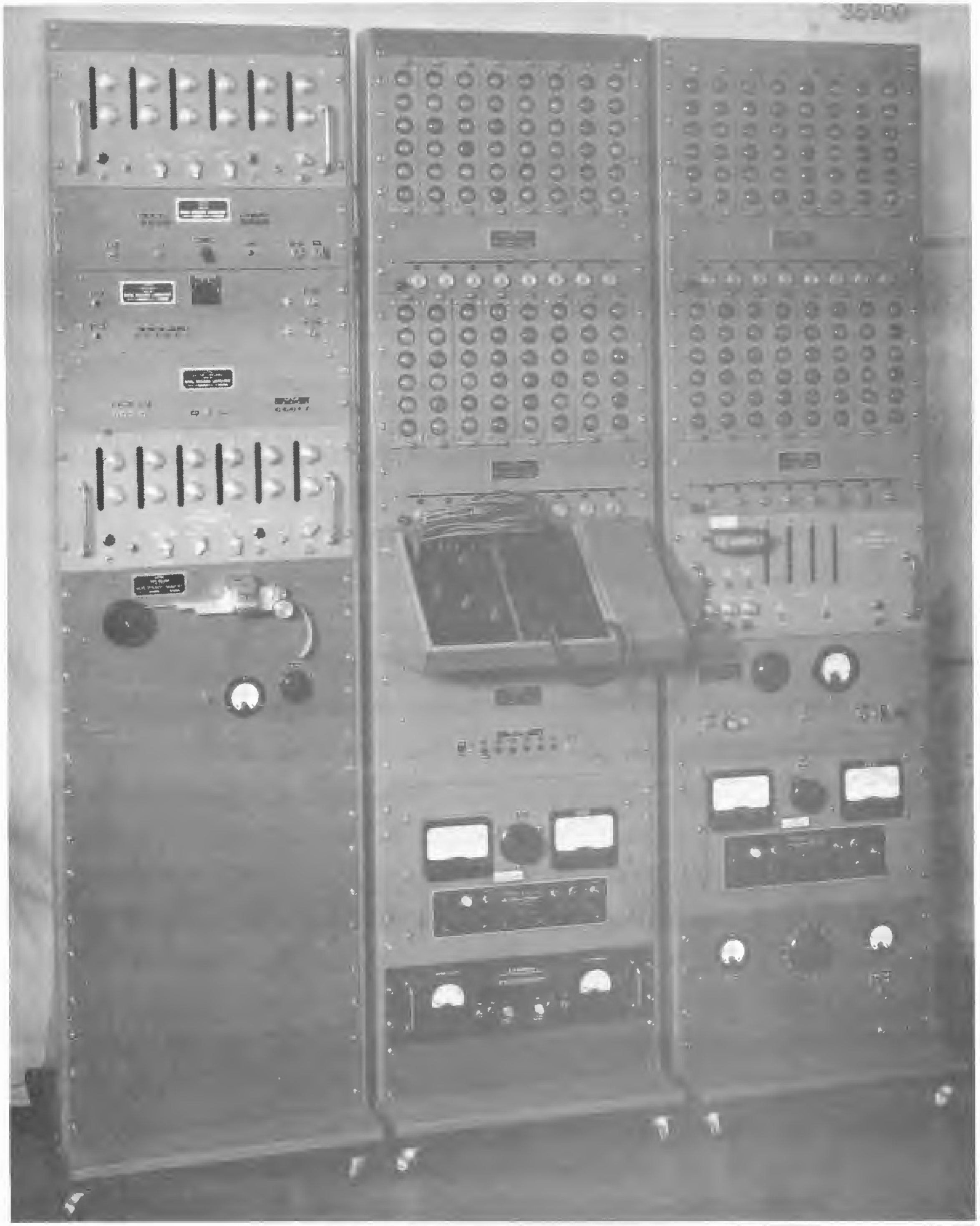

The Astre

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THE ASTRE - AN ELECTRONIC REAL-TIME STATISTICAL ANALYZER

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INTRODUCTION

In noise analysis a problem often arises as to the most effective means of differentiating between noise and a signal deeply embedded in it. In search for a more efficient method, a set of several analysis techniques was instrumented as programs for a statistical analyzer. It was decided that a discrete approach in time and amplitude would serve as a basis for the analysis. A binary stream of information arriving at a fixed rate or at least at a rate synchronous with some known function of time was assumed.

The analysis methods correspond to measurements resulting in outputs from the device which consist of statistical distributions, these outputs to be compared with their corresponding probability distributions. The methods will be derived and the Astre equipment, the means of instrumenting the procedures, will be described. The code name Astre is derived from the initials of Electronic Real-Time Statistical Analyzer taken in reverse order.

ASTRE THEORY

A continuous time function $F(t)$ may be assumed to be given as in Fig. 1. Perhaps the simplest example of a discrete function derived from $F(t)$ is the binary function obtained by sampling at discrete time intervals t_i, $i = 0, 1, 2, \ldots$, the quantizing being binary, that is, $f(t_i) = 1$ for $F(t_i) \geq A$, $f(t_i) = 0$ for $F(t_i) < A$. Letting $t_i = i = 0, 1, 2, \ldots$, the form of $f(t_i)$ will be as in Fig. 2. The quantizing at this point amounts to a decision process; for example, if $f(t_i) = 1$, the decision is that a signal was present at t_i, and if $f(t_i) = 0$, the decision is that the signal was absent at t_i.

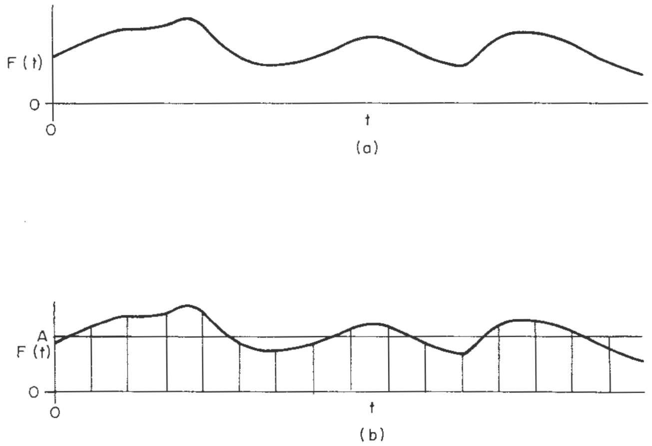

Fig. 1

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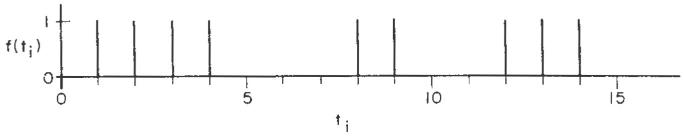

Fig. 2

Except for material to be covered in the section on program 6, only the binary case will be treated, although the procedures to be described can be immediately extended to n quantizing levels with a corresponding increase in the complexity of the electronic equipment.

In the assumed binary case, one is immediately confronted with the distribution of a binary random variable, and some necessary but not sufficient conditions for randomness are examined. Any deviation from randomness which may be measured with an assumed confidence limit may be a signal. The problem is to examine some measures of randomness, set up the control limits for each type of measure, make statistical measurements on $f(t)$, and decide on the basis of those measurements and limits, whether or not a signal is present. These decisions themselves may be thought of as binary decisions made on the basis of the observed statistics. The following six programs were chosen as a means of processing the input information into usable statistical form for comparison with the known appropriate probability distribution.

DESCRIPTION OF PROGRAMS

Program 1 - Autocorrelation, Shift Register Gated

The first program is concerned with finite unnormalized autocorrelation of the binary stream $f(t)$, the actual operation produced being

$$g_0(\tau) = \sum_{t=0}^{T} f(t)\, f(t-\tau)$$

where τ is the discrete delay, $\tau = 0, 1, 2, \ldots$

The layout of the program (Fig. 3) is such that any 32 delays of a 150-bit magnetic-core delay line (shift register) may be chosen by means of a plugboard. These 32 delay points arrive at 32 corresponding coincidence detectors, through the detectors to the 32 integrators, which are 6-place decimal scalers. The other terminal of all the coincidence detectors is common and connected to $f(t)$ as it arrives at the start of the delay line. The clock pulse f_0 is assumed synchronous with the information pulse $f(t)$ and they do not necessarily arrive at a regular rate. The DPS is a Berkeley dual-preset scaler for generating the sample period T.

Figure 4 shows an example of data from program 1 showing strong correlation for $\tau = 1, 2, 3$.

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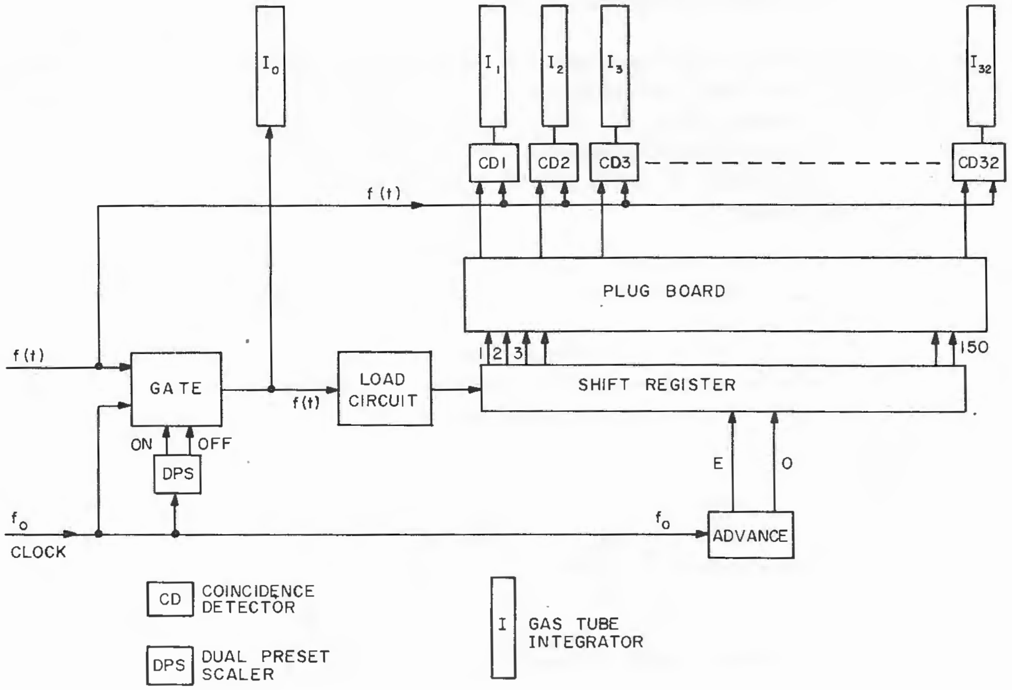

Fig. 3 - Program 1, autocorrelation, shift register gated

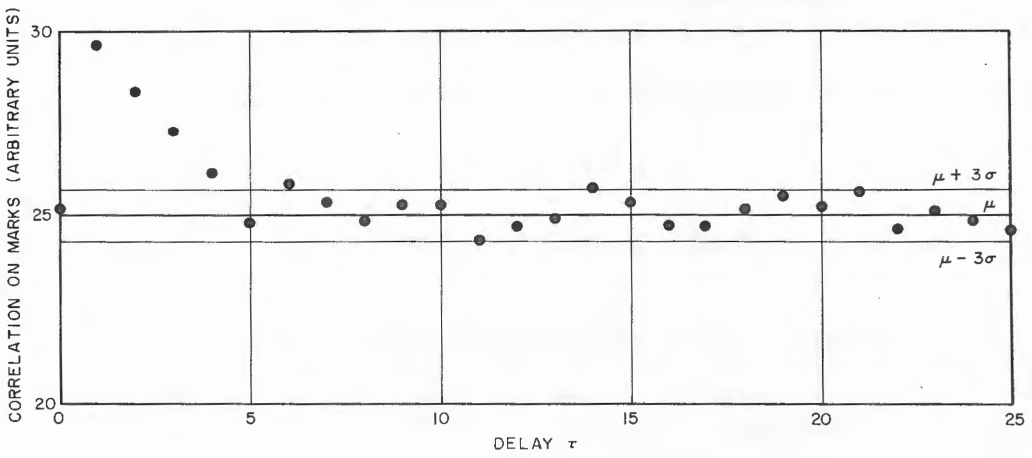

Fig. 4 - Typical output for program 1

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Program 2 - Autocorrelation, Detectors Gated

Program 2 is identical with program 1 except that the information signal going into the delay line is not gated with the sampling interval. The detectors are gated from the main gate control as shown in Fig. 5. The interpretation is almost the same as in program 1, except that correlation immediately takes place with information stored previous to the gate on time. Programs 1 and 2 can be used in studies of short-term correlation communications techniques.

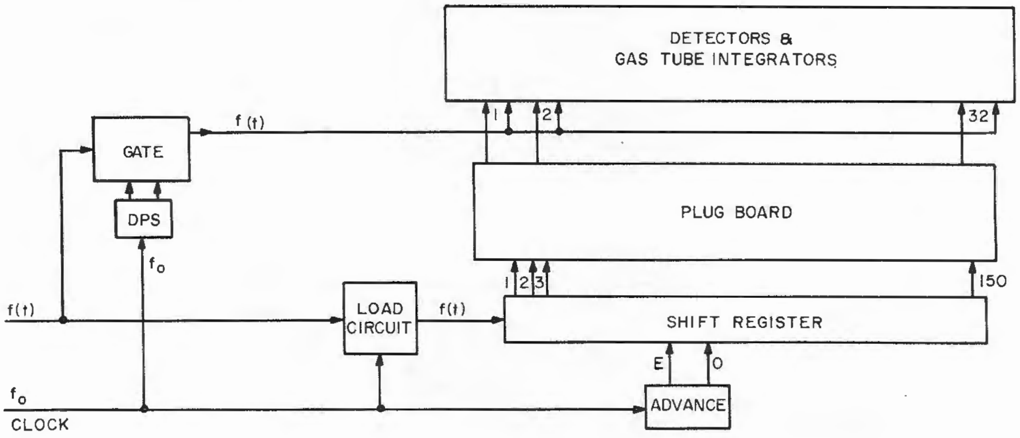

Fig. 5 - Program 2, autocorrelation, detectors gated

Program 3 - Crosscorrelation

Program 3 is similar to programs 1 and 2 except that the function in the delay line is an arbitrary function, say $h(t)$, correlating with $f(t)$ which is gated to the detectors.

The detectors form the product $f(t)h(t-\tau)$ and the accumulators integrate

$$g_1(\tau) = \sum_{t=0}^{T} f(t)h(t-\tau),$$

each detector scaler combination summing for a different value of τ where $\tau = 0, 1, 2, \ldots, 31$.

As shown in Fig. 6, $f(t)$ correlates with $h(t)$ which is here shown as a preset scaler sending a pulse down the delay line every k pulses of $f_o(t)$. The delay line is arranged so that small loops with an arbitrary load may be set up for correlation with $f(t)$, the loads of these subloops again being potentially arbitrary. This program can be used for experiments in comb filter techniques.

Program 4 - TUE, Time per Unit Event

Program 4, the TUE or Tuesday program (Fig. 7), reads and classifies the time per unit event,* the event being the length of an isolated pulse group. These groups may be

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*Beck, H.M., "Time-Dependent Probabilities," NRL Report 3915 (~~Confidential~~), Dec. 1951

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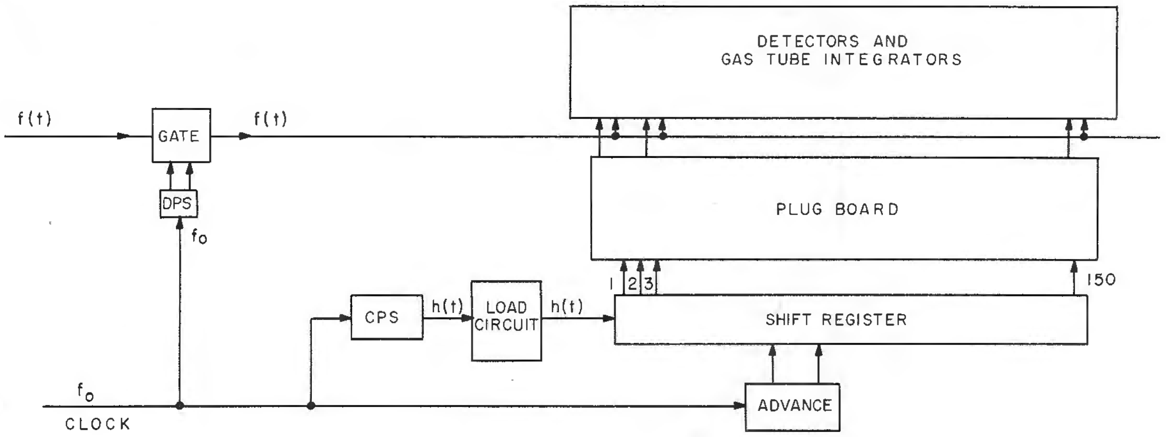

Fig. 6 - Program 3, crosscorrelation

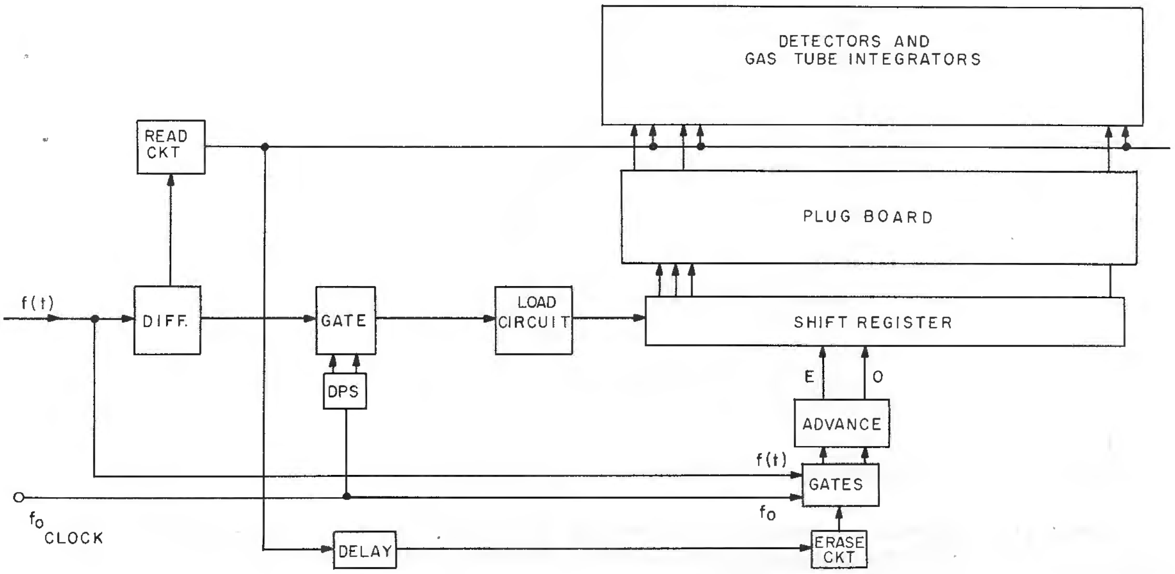

Fig. 7 - Program 4, TUE (time per unit event)

isolated singlets, doublets, etc., up to some maximum value for the sample. The probability that a group will have length r is

$$p_r = q^2 p^r$$

where p is the probability of a pulse in the binary stream, and $q = 1 - p$. If p_r is plotted on semilogarithmic paper against r, the resulting curve for a random distribution is a straight line, the slope being a function of p. Aberrations from randomness in a sample can show up as deviations from or dispersion about the straight line. The result of a representative experiment is shown in Fig. 8.

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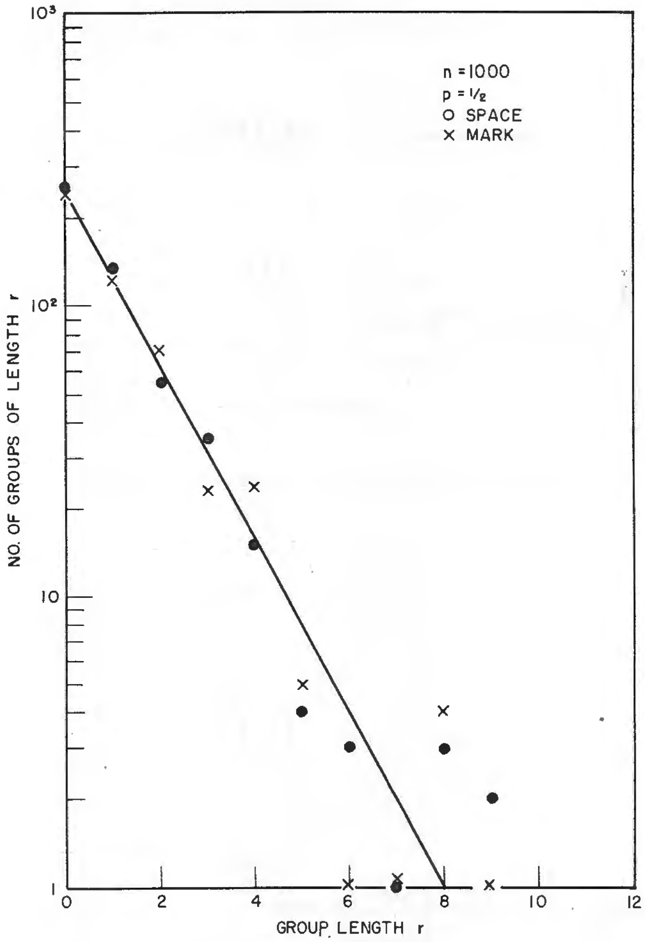

Fig. 8 - Typical output for program 4

Program 5 - EUT, Events per Unit Time

Program 5 provides a means of measuring the number of events (pulses) per unit time, and classifies the measurements according to the sample size in the appropriate class intervals. Design provisions have been made for increasing the size of the class interval from one to K where K is arbitary, and this is shown in Fig. 9. This program gives essentially a measure of the energy distribution of nonoverlapping samples of the binary stream. For example, one may wish to measure the distribution of marks in 100 samples of size 10. The main gate in Fig. 9 is set on the DPS to remain open 100 x 10 = 1000 clock pulses and the CPS is set at 10. When the main gate closes, there will be 100 readings of the subsample of size 10 in the registers.

These individual subsamples

$$x_j = \sum_{i=T_j}^{T_{j+1}-1} f(t_i), \qquad j = 0, 1, 2, \ldots$$

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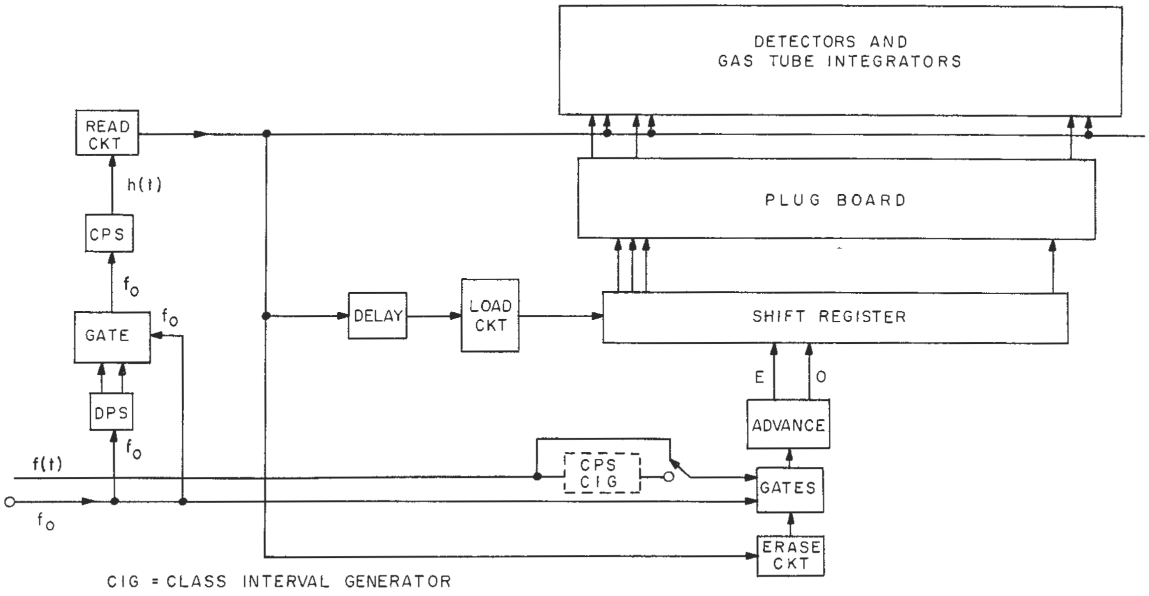

Fig. 9 - Program 5, EUT (events per unit time)

are associated with the Bernoulli distribution

$$P_r = \binom{m}{r} p^r q^{m-r}.$$

A given sample may be plotted on standard plots of the binomial probability density curve and compared directly with it for immediate interpretation of consistent aberrations, or the data may be retained for standard tests of randomness. The result of a measurement on a nonrandom function is shown in Fig. 10. This program is also suitable for studies in discrete short term integration communications methods.

Program 6 - Pattern Count

Program 6 has several uses. In the analysis of a binary stream either five adjacent or five noncontiguous pulses of the stream are selected on the delay line through the plugboard as shown in Fig. 11. These five pulses determine a five-place binary number from 0 to 31, and these numbers are translated by a diode network to 32 outputs which are separately integrated in 32 class intervals.

In a similar manner with five-level punched tape input, the read-in being parallel into the matrix translator, the distribution would be rectangular with a random function on the tape.

The five-place binary number may also be thought of as numbers derived from a sampling process on a continuous stream, and the distribution measured would then be a distribution of amplitudes. This program may also be suitable for use as a component in studies of dynamic coding techniques.

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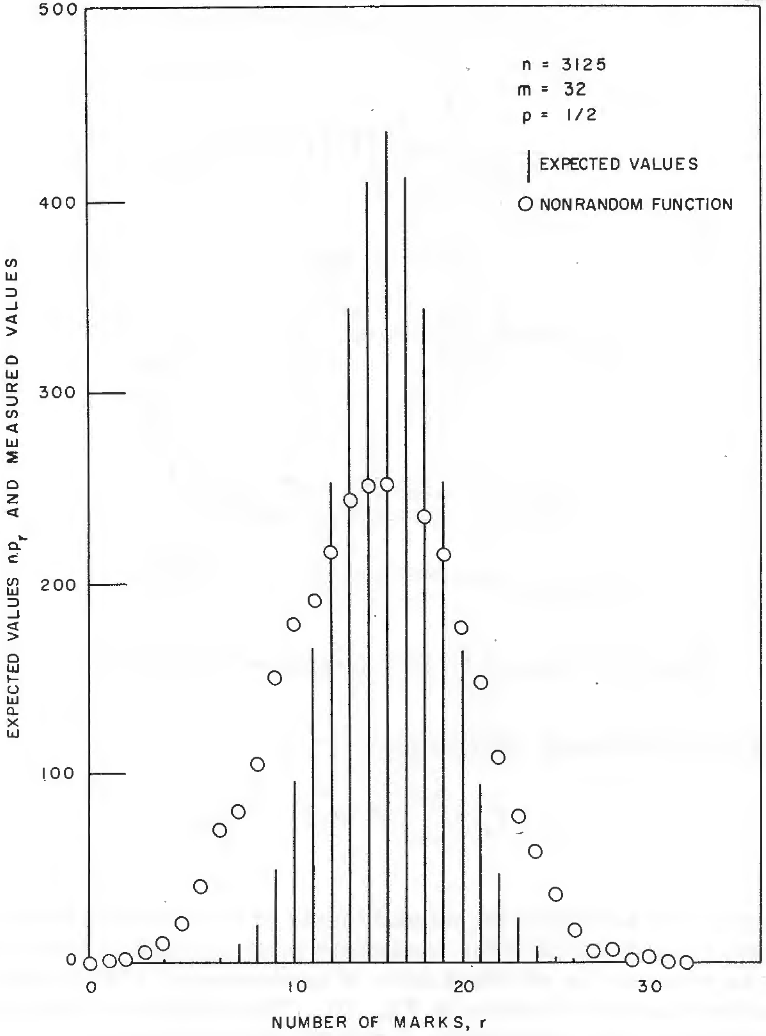

Fig. 10 - Typical output for program 5

ASTRE INSTRUMENTATION

The interim model of the Astre is designed for 32-channel operation. The analyzer was built for noise studies in the lower kilocycle ranges. The processed information is visually available on 32 six-place gas-tube decade counters. Any one of six programs can be selected by a simple switching arrangement. Several checks are available to test the correct operation of the equipment and programs. The equipment consists essentially of eight principle parts:

1. Magnetic-core shift register
2. Wired-in switchable programs
3. Thirty-two integrators

[redacted]

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4. Thirty-two coincidence detectors
5. Diode matrix network and circuits
6. Timing, shaping, gating, and drive circuits
7. Interval timing equipment
8. IBM patchboard.

A simplified block diagram is shown in Fig. 12. The input information F(t) can be in the form of either pulses or square waves. $F_o(t)$ is the clock information which can be in the form of either pulses or a sine wave.

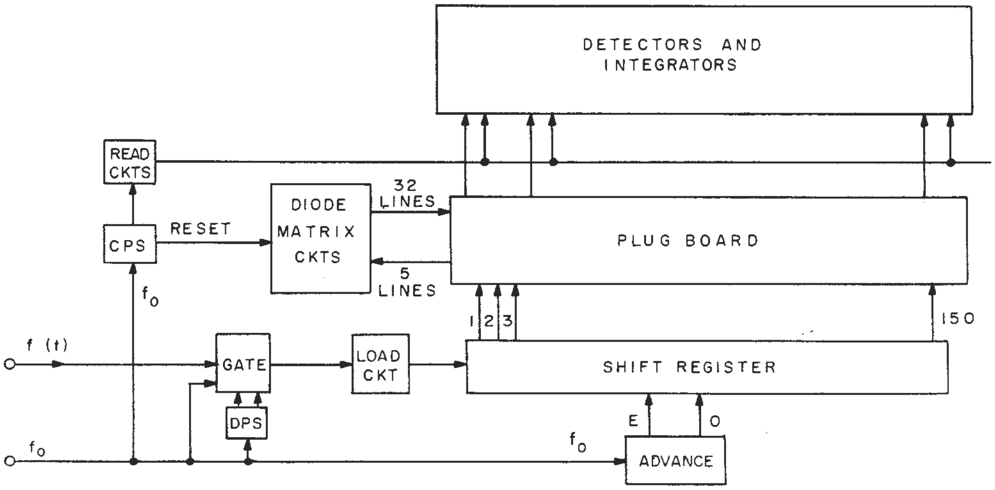

Fig. 11 - Program 6, pattern count

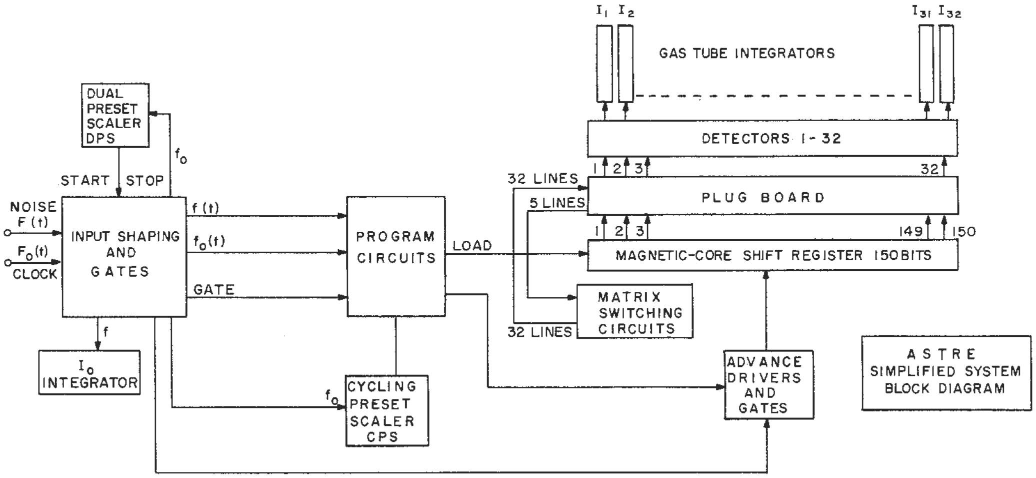

Fig. 12 - Simplified diagram of Astre equipment

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Magnetic-Core Shift Register

Basic to the Astre equipment is a magnetic two-core-per-bit shift register of length 150 bits. The core is made of a magnetic material that has a nearly rectangular hysteresis loop, which gives it the property of having two stable states, "0" and "1". Each core has three windings: an input winding, an output winding, and an advance winding (Fig. 13). When a core receives an advance, a magnetizing current flows in such a direction as to cause those cores in the "1" state to change to "0". Those cores already in the "0" state remain in the "0" state. When a core is switched from the "1" to "0" state by the advance, it generates a voltage into its output winding which is coupled to the input winding of the following core and causes that core to switch to the "1" state. In this manner information is shifted down the line.

The output and input windings of each bit of the shift register are connected to the plugboard. The 32 detectors can be plugged into any 32 bits in the shift register. This method of connection also makes it possible to form from the shift register any number of independent ring loops of any desired length.

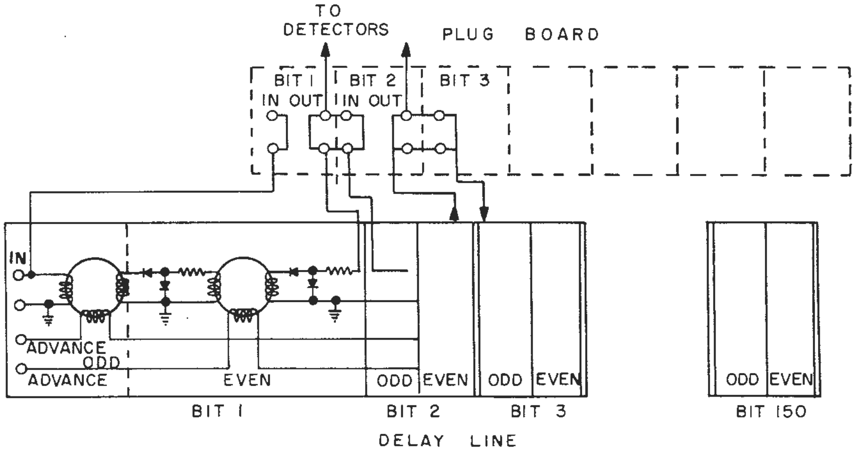

Fig. 13 - Detail of wiring of shift register bit and plugboard

Switchable Programs

The wired-in programs of the Astre equipment are changed chiefly by switch 1 as shown in Fig. 14. For program 1, the autocorrelation program, information in the form of a square wave is applied to grid 3 of V_3. Sample pulses f_0 are applied to grid 1 of V_3. A start-stop step gate under the control of the DPS interval timer is also applied to this grid 1. The output from cathode follower V_5 loads the shift register. The load, then, that is fed into the shift register and shifted down the line corresponds to the $f(t)$ input. The amount of delay at a given output of the register corresponds to the bit position in the register. This delayed output information is correlated against the information $f(t)$ in the coincidence detectors.

Program 2 is the same as program 1, except that the DPS step gate is not used to gate V_3; instead $f(t)$ is gated as shown in Fig. 5.

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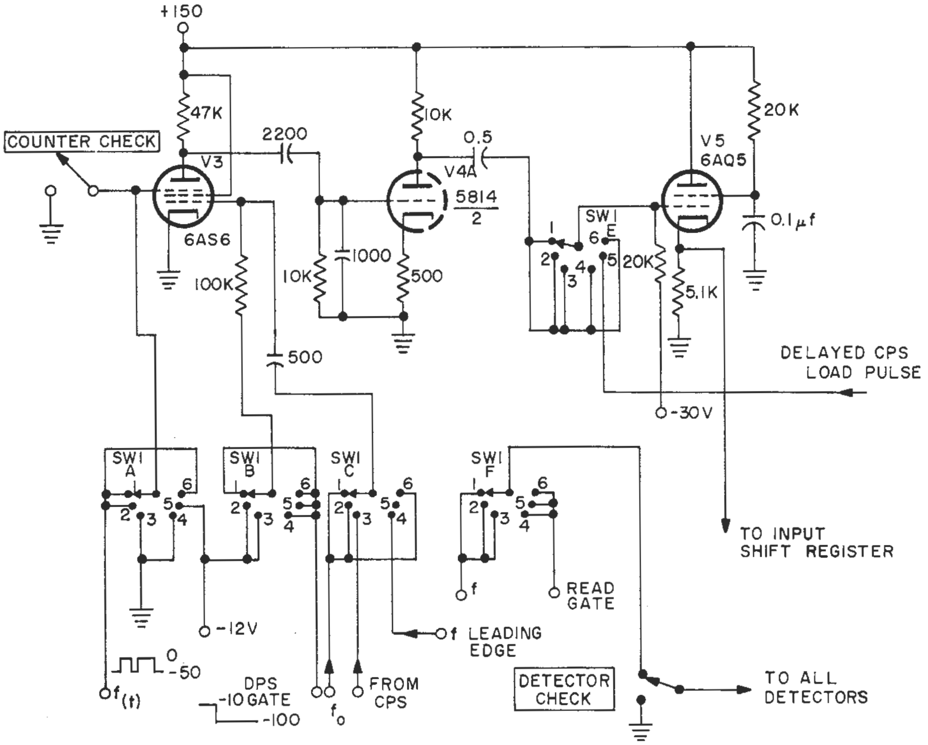

Fig. 14 - Detail of program control circuits

For crosscorrelation, program 3, the output pulse of the CPS interval timer is substituted for f_o. Grid 3 of V_3 is grounded. This results in a load fed into the shift register with every CPS output pulse.

Programs 4 and 5 are best seen with the aid of a block diagram (Fig. 15) along with Fig. 14.

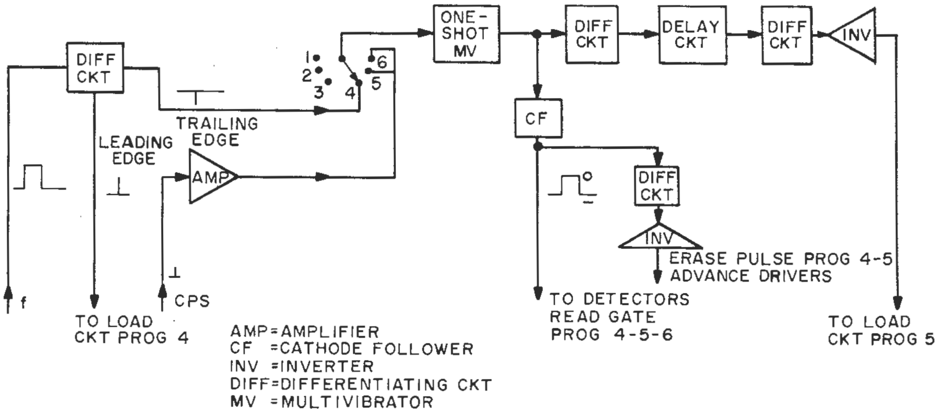

Fig. 15 - Detail of control circuits for programs 4 and 5

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In program 4, the leading and trailing edges of the mark intervals of f(t) are differentiated. The leading edge of the mark loads the shift register through V_3, V_{4a}, and V_5 in the regular manner. At the same time, the mark interval is used to gate on the advance drivers, through gates 1 and 4 in the advance drivers unit, as shown in Fig. 21. On the trailing edge of the mark interval the shift register advance ceases, a read pulse is generated and is applied in parallel to all the detectors. A read is obtained, however, only from that shift register bit which corresponds to the length of the mark interval. This count is fed directly into the corresponding gas-tube integrator. After a slight delay an erase pulse is generated which clears the shift register in preparation for measuring and recording the duration of the next mark interval.

In program 5, the shift register is loaded with a single delayed pulse derived from the CPS interval timer. The advance drivers are gated on with the f(t) marks, which advance the single load down the register. On the next CPS pulse, a read pulse is gated into the detectors. The gas-tube integrator receives a count only if it is connected to that bit which corresponds to the total f(t) mark count received during that CPS interval. After a small delay an erase pulse is generated which clears the shift register, and a new load pulse is then fed into the first bit of the register. The equipment is now ready to count automatically the number of marks of f(t) during the next CPS interval.

In program 6, the shift register is loaded in the normal manner as for programs 1 and 2. The detectors, however, are fed from the 32-level diode matrix rather than from 32 bits of the shift register. The gas-tube integrators are told when to read by a read pulse to the detectors derived from the CPS interval timer. (Refer to the description of the diode matrix under "Multiposition Switching Circuits.")

Two simple checks are built into the program circuits. One check, the counter check, grounds grid 3 of V_3. This results in a constant f_0 loaded into the shift register. Since the advance is not gated for this test, all counters should read the same number of counts in a given time interval determined by the DPS interval timer. The second test, the detector check, grounds one input of all the detectors. The integrator counters, therefore, will record the number of f(t) mark intervals in a given DPS time interval. Since the advance is not gated, all the counters should read the same. Other checks are also available in the equipment by proper setup and by interpretation of ouput readings.

Integrators

In this model of the Astre, the integrators are plug-in decade gas-tube counters. This selection was based on size, power consumption, and simplicity, and not on speed, since the average operating noise signals to be analyzed were of relatively low frequencies. The British Dekatron GS-10B was selected as a good compromise. The GS-10B is a single-ended cold-cathode bi-directional gas-tube counter. The count is determined by noting the position of the glow on one of the radially spaced cathodes in reference to a bezel engraved 0 to 9.

The counter tube has ten reading cathodes plus two guide or transfer cathodes between each of the reading cathodes. It works on the principle that the starting voltage of a gas discharge is lowered if ions and electrons are already present in the anode-cathode region. The glow can be made to move from one cathode to an adjacent one by means of a negative voltage pulse on a new cathode. For example, if the glow is on cathode 1, and guide 1 is hit with a negative pulse, the glow will transfer to guide 1 adjacent to cathode 1. Then if

[redacted]

guide 2 receives a negative pulse as the pulse decays on guide 1, the glow will transfer to guide 2. At the conclusion of this negative pulse, the guides return to a positive voltage, with the result that a reading cathode, in this case cathode 2, is now more negative than the guides, hence the glow immediately transfers to it. By reversing the sequence of the negative guide pulses, the direction of the glow transfer can be reversed. The zero cathode is brought out separately so that when the glow reaches it, a voltage is obtained which is used to drive the following counter tube through a hard tube driver stage (Fig. 16). A six-stage counter, with a count capacity of 10^6 is used for each of the 32 channels. A compact plug-in unit for each channel was designed and built in the Laboratory for the Astre equipment (Fig. 17).

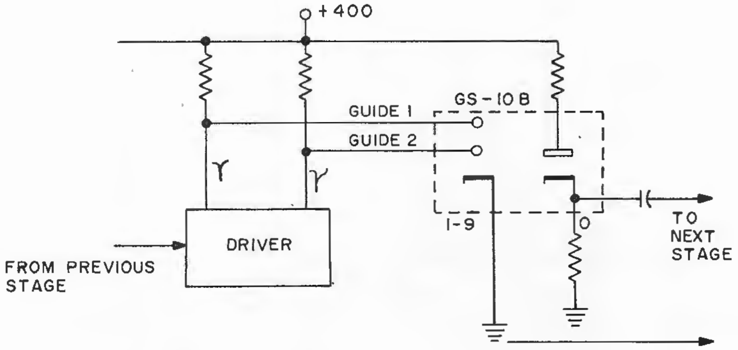

Fig. 16 - Typical Dekatron stage

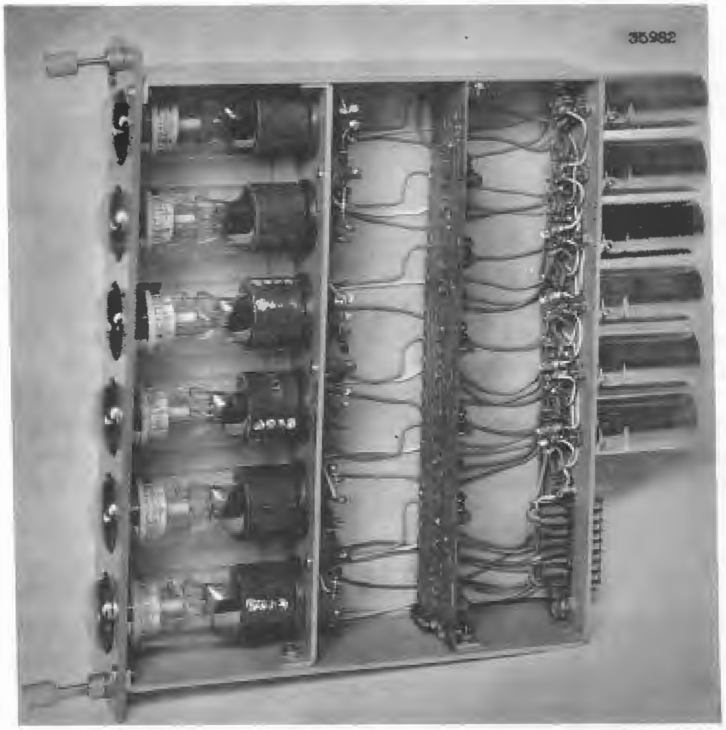

Fig. 17 - Dekatron indicating integrators

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Coincidence Detectors

The circuit for a coincidence detector channel is given in Fig. 18. The information from the shift register $f(t - \tau)$ is fed via the plugboard into the grid of V_{1A}, where it is integrated by R_1C_1 to reduce the effect of any spurious transient pulses from the shift register. Impedances in this stage are low to reduce noise pickup and to prevent crosstalk between detectors. In V_2, $f(t)$ is compared for coincidence on grid 3 with $f(t - \tau)$ on grid 1. A coincidence results in an output pulse which is inverted and shaped in V_{1B} and fed directly to the first driver stage of the gas-tube integrator counter. A typical output from the detectors is a positive rectangular pulse of 30 volts amplitude and 80 microseconds duration.

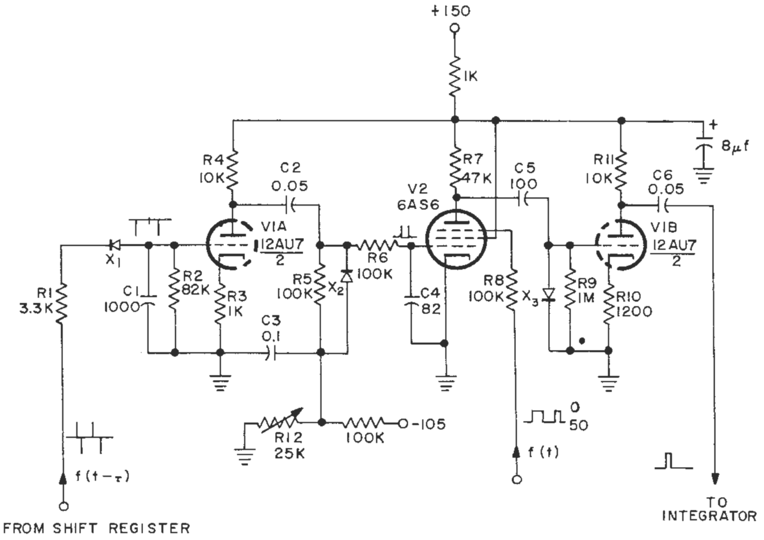

Fig. 18 - Coincidence detector for one channel

Multiposition Switching Circuits

A block diagram of the 32-level matrix and switching circuits is shown in Fig. 19. Five inputs from the shift register are brought into the unit by way of the plugboard. These inputs are shaped and control five flip-flops which in turn set up the diode matrix through ten buffer stages. The matrix is essentially a network of diode "and" gates so arranged that each combination of states of the flip-flops yields a ground voltage on one and only one of the 32 output lines.* All the other lines are biased far negative. A read pulse is obtained from the line when the line is returned to the negative bus state by resetting the flip-flops through the reset circuit.

Input Shaping and Timing

The timing unit (Fig. 20) provides the master time or clock signals for the entire system. The input clock information can be in the form of either a sine or a square

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*Brown, D.R., and Rochester, N., "Rectifier Networks for Multiposition Switching," Proc. I.R.E. 37:139 (1949)

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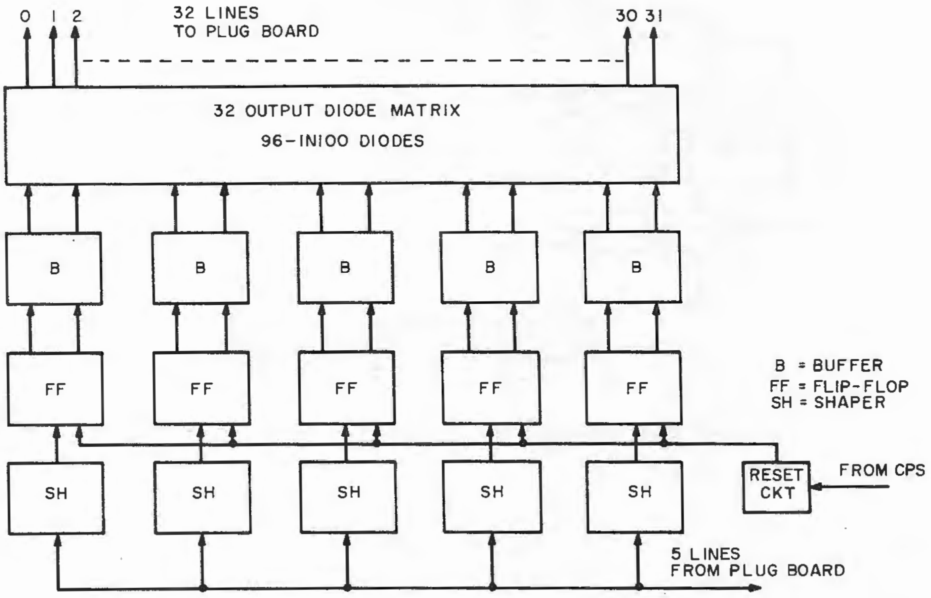

Fig. 19 - 5-level to 32-level translator

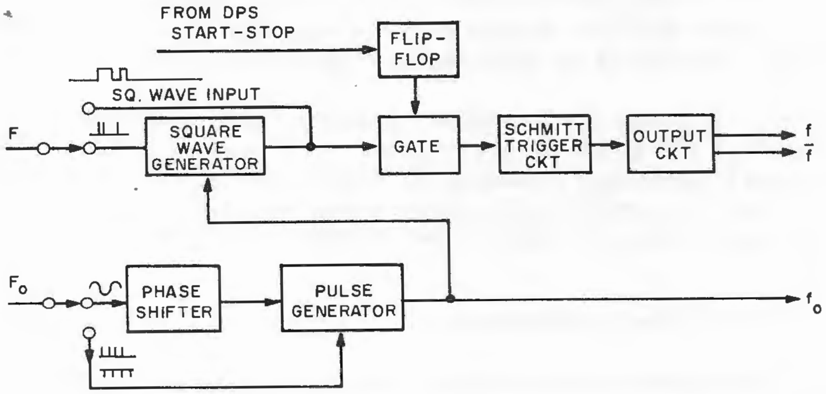

Fig. 20 - Input shaping and timing circuits

wave, or either positive or negative pulses. Provisions are made for shifting the phase of the input clock information. The clock output is in the form of two out-of-phase positive pulses (even and odd), which are used in the system for sampling, for operating the shift register advance circuits, and for operating the interval timing equipment.

The shaping unit accepts binary information in the form of pulses, positive or negative, or in the form of a square wave. The information is then gated on and off under the control of a dual preset scaler and is converted into a standardized square wave by means of a Schmitt circuit, since the internal operation of the system is based on a square wave. A complemented signal $\bar{f}$ is also available.

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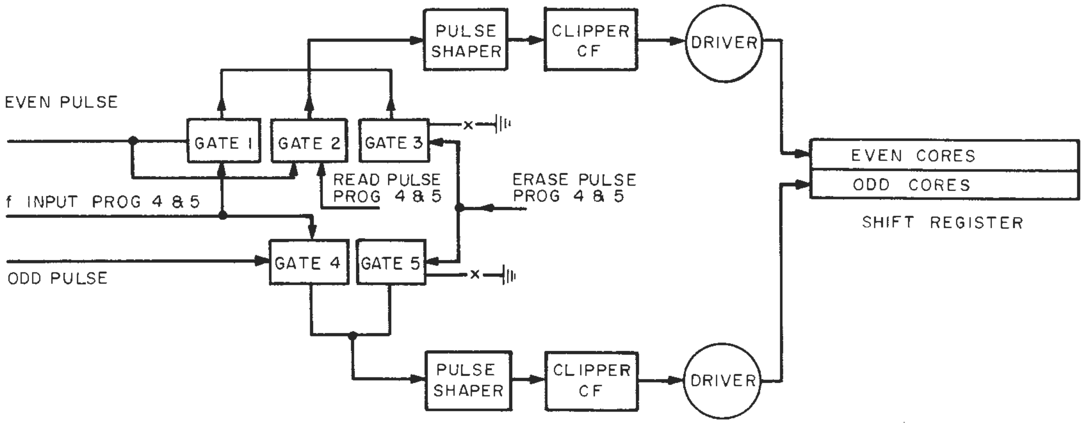

Fig. 21 - Detail of advance drivers for shift register showing control gates

Advance Drivers

The advance drivers (Fig. 21) are used to drive the magnetic core units of the shift register. Two pulses generated in the input timing unit are used to drive this circuit. These two pulses, the even and odd pulse, are not in time phase. The pulses feed a network of gates which in turn generate pulses of the proper amplitude, width, and rise times. The drivers are power pentodes capable of delivering large current pulses for the core advance windings. Each bit of the shift register has an even and an odd core.

In programs 1, 2, 3, and 6, all gates are gated on. In programs 4 and 5, the advance is gated on in gates 1 and 4 with the $f(t)$ marks. At the proper time, an erase pulse is fed simultaneously to both lines through gates 3 and 5, and erases all information in the shift register. Gate 2 is used for gating on the even advance for obtaining a signal from the proper register bit when the special read circuit of the equipment is triggered.

Plugboard and Interval Timing Equipment

A standard IBM plugboard is used in the Astre equipment. It is permanently wired into the circuits. The internal interval-timing generators in the Astre are commercial Berkeley dual preset counters, model 5446.

Display

Work has been done on devices suitable for a normalized display, an instantaneous plotting board, which may ultimately take the form of a special gas-tube or cathode-ray-tube display to present at cinematic speeds short-time probability estimates produced by the Astre equipment. The equipment as now constituted, if compared with manual speeds, is capable of condensing processing time from man-years to minutes. The display as contemplated will condense the time further from minutes to some minimum time determined by the user's assimilation rate and the sample size.

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CONCLUSIONS

The six programs designed for noise analysis have been instrumented and have produced useful information. The device has been designed for computer reliability, and together with preliminary checks, cross checks on the output data reveal readily if errors have been made and, if so, a probable trouble location. The device is in use a considerable amount of time and will see more use as soon as new magnetic-core shift-register units are delivered which promise to result in increased reliability and flexibility.

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