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# A NEW EQUIPMENT FOR MEASURING STOCHASTIC PROCESSES: STATISTICAL ANALYZER

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"A NEW EQUIPMENT FOR MEASURING STOCHASTIC PROCESSES:
STATISTICAL ANALYSER"

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ABSTRACT

The concept of a new statistical measuring set-up is presented. A family of plug-in instrument modules will be developed in the near future in our Laboratory. With the set-up one will be able to perform all the typical statistical measurements, such as signal recovery, amplitude and time analysis, correlation computing, etc. In the following the most important types of statistical measurements are summarized, the aimed performances of the equipment are presented, and its application to statistical measuring problems is discussed.

РЕЗЮМЕ

В статье описывается новая система приборов, служащая для проведения статистических измерений. Наша лаборатория в ближайшем будущем начнет разработку этих модульных приборов. Система приборов пригодна для проведения всех типичных статистических измерений (например, усреднения сигналов, амплитудно-временного анализа, вычисления корреляционных функций и т.д.). После описания важнейших методов статистических измерений излагаются основные технические параметры, а также важнейшие области применения системы приборов.

ÖSSZEFOGLALÁS

Alábbiakban bemutatjuk egy uj, statisztikus mérések elvégzésére szolgáló készülékrendszer főbb vonásait. A moduláris készülékek kifejlesztését Laboratóriumunk a közeljövőben megkezdi. A müszer-együttes lehetővé teszi az összes tipikus statisztikus mérés elvégzését /pl. jelátlagolás, amplitudó- és idő-analizis, korrelációs függvények felvétele, stb./. A fontosabb statisztikus mérési módszerek bemutatása után ismertetjük a készülékrendszer fő müszaki jellemzőit, majd a statisztikus mérések területén történő alkalmazhatóságát.

# I. INTRODUCTION

There are a number of fields where the information to be measured may have statistical, stochastic character, e.g.:

- nuclear research
- nuclear reactors
- plasma physics
- automation, electronics
- hydrodynamics
- geophysics
- acoustic analysis
- biology
- physiology
- neurophysiology
- space-research
- telemetry
- noise studies
- vibration studies, etc.

For handling and processing the measured data there are some commonly used methods, which - by integrating one or more quantities - permit the study of features "buried" in a noise. Some examples:

□ <u>signal-averaging</u>
by storing successive sample values of a repetitive signal in successive channels of a memory, the integrated pattern permits to be detected the significant features of the signal to be detected

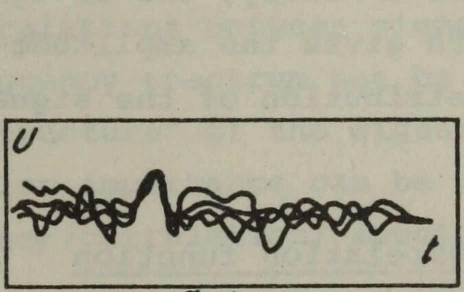


fig.1

□ <u>pulse-rate vs. time distribution</u>
by registering the number of pulses per time increment in the channels of a memory, the integrated pattern permits detection of the significant features of the distribution

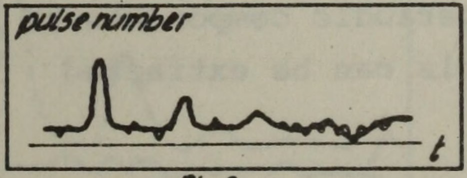


fig.2

pulse-to-pulse time interval distribution
by registrating time distances between pulses in the corresponding channels of a memory, the integrated pattern permits the detection of the significant features of the distribution

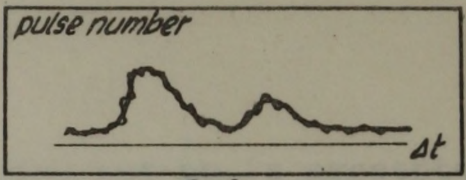


Fig.3

amplitude distribution /integral/
by registering the number of samples higher than a discriminator-level proportional to the actual channel number of a memory, the integrated pattern gives the amplitude distribution of the signal

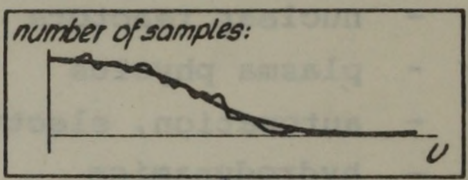


Fig.4

amplitude-density distribution /differential/
by registering the number of samples within a swept discriminator window in the corresponding channels of a memory, the integrated pattern gives the amplitude-density distribution of the signal

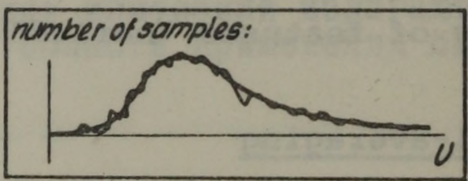


Fig.5

autocorrelation function
by calculating an estimate of tne autocorrelation function

$$C^{xx}(\tau)=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}x(t)x(t-\tau)dt,$$

the periodic components of noisy signals can be extracted

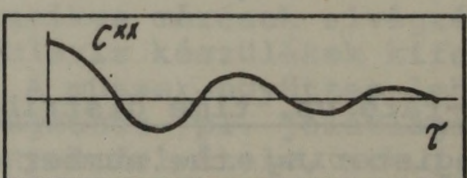


Fig.6

cross-correlation function
by calculating an estimate of the cross-correlation function

$$C^{xy}(\tau)=\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}x(t)y(t-\tau)\,dt,$$

the relations between the two signals can be studied

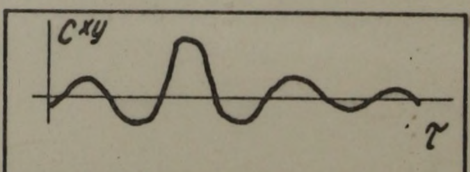


Fig.7

<u>pulse-response determination by stochastic modulation</u> when the system under test is randomly excited, the cross-correlogram between input and output is proportional to the pulse-response /weight/ function of the system

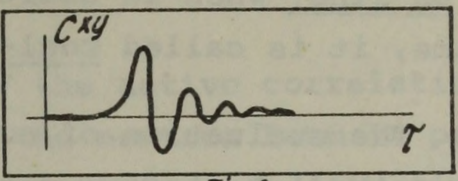


Fig.8

## II. WHY MAKE CORRELATION MEASUREMENTS ?

As the correlation method is a relatively new technique in the analysis of stochastic processes, it may be of use to the reader to have a short glossary of correlation terms.

The evaluation of correlation functions is based on integration, and thus it is a fairly good method for "extracting" interesting information from a random fluctuation.

In the <u>correlation function</u> one has a /delay/ time variable: signal values of a source are compared /multiplied/ by delayed, shifted ones of another source. In the case of an <u>autocorrelation</u> function the two sources are identical. With the aid of the method one can study the internal correlations of a signal or the correlations between signals. From the <u>correlogram</u> the <u>power density</u> - frequency spectrum can be calculated by <u>Fourier transformation</u>, i.e. the "structure" of the signal/s/ can be studied. In such a way, events of particular importance can be identified easily from the change of the frequency /correlation/ spectrum, e.g. water-boiling in a nuclear reactor [1], etc.

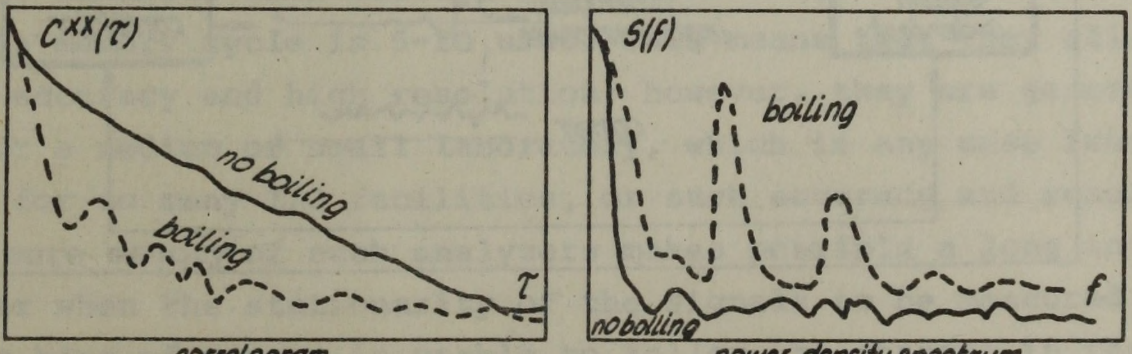
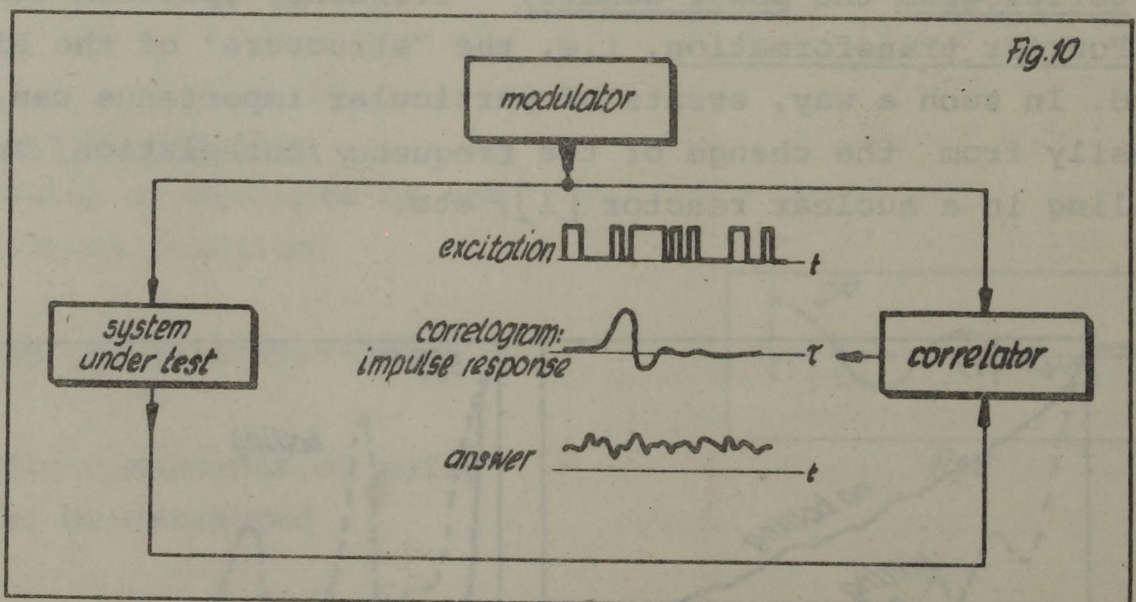


Fig.9.

With regard to the technique of correlation function evaluation, there are a great number of approximation methods. When the signals are binary <u>sampled</u>, one gets a <u>polarity correlation</u>; when one of the signals is binary while the other is analog sampled, a relay correlation is obtained, etc. When the calculation is made during the measurement, it is called on-line; when in addition all shifts of all samples are taken during this time, it is called real-time.

The evaluation of auto- or cross-correlation functions is a passive method. An active method of correlation measurements is used when the system under test is stimulated or excited and the answer is compared to the stimulation itself. Mathematically the correlation function between the random /or pseudo-random/ modulator function and the answer must be calculated. Their cross-correlation function is directly related to the system's pulse-response, i.e. to the signal detected as answer when the system is stimulated with a narrow pulse.

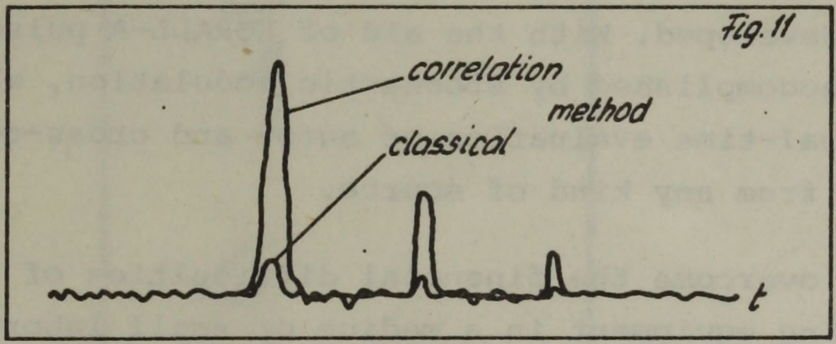
This method has a number of great advantages over the classical one of simple pulse excitation. Since the background or noise /additional signals superimposed on the signal to be measured/ is not correlated with the excitation, it will be automatically eliminated /or strongly reduced/ in the result. Another advantage is given by the fact that the number of stimulation pulses per unit time is much greater in random excitation than in a classical experiment, i.e. measuring time can be spared or statistical accuracy increased.




Such measurements can be performed during the normal operation of the systems. The modulation can be of low level and it does not disturb the normal operation. Because the signals coming from normal operation are not correlated with the modulation, they will be automatically eliminated from the result.

Technically the modulator is generally an integrated part of the correlation measuring instrument. The modulator is in most cases realized as a binary pseudo-random generator.

To illustrate the wide application of the active correlation method, we mention neutron spectrometry. Here the neutron beam is pseudo-randomly chopped, the neutron counting rate is detected, and the time-of-flight spectrum of the neutrons is obtained as a correlogram /e.g. [2]/.




## III. MULTICHANNEL ANALYZERS

Many of the tasks described in section I /but generally not all/ can be accomplished digitally by the so-called multichannel analyzers often used in experimental nuclear research. Such equipments have several sophisticated input facilities for analog-digital conversion /time-digital, amplitude-digital, etc. converters/ and provide many possibilities for the output of results /digital-analog converters, internal oscilloscope, external printer, punch, tape, recorder, etc./. As for memory, they normally have 400-4000 channels with storage capacities of $10^5$-$10^7$ pulses per channel; the time of a memory cycle is 5-20 μsec. This means that they allow work to a fairly good accuracy and high resolution; however, they are generally too expensive for a medium or small laboratory, which in any case frequently has no need for so many I/O facilities, or such accuracy and resolution. Lastly, the core memory of such analyzers makes possible a long integration time. However when the stationarity of the signals to be measured is not assured this kind of memory is unable to follow the changes in the measured spectra.

The NTA-1024 and NTA-512M multichannel analyzers developed and produced at the Central Research Institute for Physics, Budapest, are typical examples of this type of equipment [3]. Their main data include:

| | | | |
|---|---|---|---|
| number of channels | : | 1024 | 512 |
| storage capacity per channel | : | $10^5$-1 | $10^5$-1 |
| storage-cycle | : | $<16\ \mu$sec | $<16\ \mu$sec |
| price of the basic unit only | : | 456,000 Ft | 345,000 Ft |

Some types of multichannel analyzers have been equipped with special units in order to be able to perform correlation analysis. For the NTA analyzer two correlator plug-in units, named KORALL-A and KORALL-B [4], [5], have been developed. With the aid of KORALL-A pulse-response measurements can be accomplished by stochastic modulation, while KORALL-B makes possible the real-time evaluation of auto- and cross-correlation functions of signals from any kind of source.

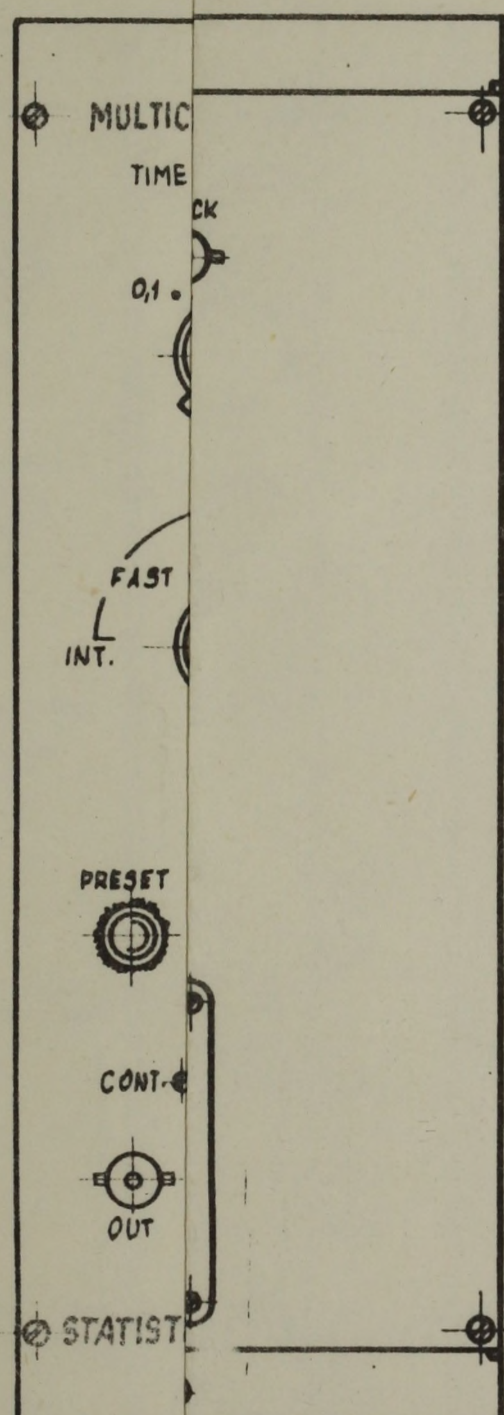
In order to overcome the financial difficulties of installing a statistical measuring equipment in a medium or small laboratory, further to provide a fast and very flexible instrumentation set with specifications well suited to the actual needs of comparative and not too high precision measurements, a new statistical measuring set-up, named the STATISTICAL ANALYZER, is presented in the following. The units of this analyzer are to be developed in the Laboratory of Measurement and Automatization of this Institute in the near future.

## IV. WHAT IS THE STATISTICAL ANALYZER ?

The STATISTICAL ANALYZER will be a set of instrument modules purchaseable separately or as an assembly, as desired. The complete assembly will fit into a standard 19" mechanical crate. The different measuring set-ups are created by appropriately combining the basic modules. The system permits you to optimize your instrumentation in relation to the size of your budget. From our point of view it means that we can extend the range of the system by producing new modules. There is usually no need for amplifiers or compensation for the signal sources, as these are built into the first module. For the output all that is required is a simple, ordinary oscilloscope connected to the last module. If you have an oscilloscope with a storage-screen or camera, this will give you a permanent record of the results. A pictorial record can also be obtained by connecting a simple graphical recorder to the output.

If you need an accuracy of $10^{-4}$, or 1000-channel resolution, then

From Rear panel



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clearly you will require a multichannel analyzer*, but if only a few percent accuracy and 50- to 100-channel resolution are sufficient, then it may be worth considering what our STATISTICAL ANALYZER can offer. We think that this analyzer is as useful and as simple a device for measurement of stochastic signals as an oscilloscope is in the world of electronics.

STATISTICAL ANALYZER units will be available for resolving all the measurement problems described in sections I and II. A more detailed list of acceptable problems is given in section VII.

In the following we present our basic set-up of four modules. With the aid of this instrumentation a wide range of typical problems is covered. In the future we intend to complete the family with new elements, such as a Fourier transformer, etc. The modular system of the instrumentation greatly simplifies service and maintenance.When new circuit components or an important new field of application call for the revision of technical specifications, it will not be necessary to change the complete apparatus but only to modify single plug-in units. The modular system offers an economical way of installing a statistical measuring equipment and maintaining it at a state-of-the-art level.

## V. STATISTICAL ANALYZER UNITS

On the next page the front and rear panels of the basic units are shown. They are built in standard sub-rack mechanical system and are compatible with each other in electronic and mechanical parameters.

### 1. SAMPLING

The sampling unit is generally the first element of a measuring set-up. It has two channels: Channel A always takes an Analog, Channel B a Binary sample when a clock-signal arrives at the rear panel clock sockets. Each channel has an amplifier /GAIN/, a compensator /BASE-LINE/, DC or AC operation mode and also a lamp for checking that no overload is present /OVER/.

The sampled signal obtained from channel A is an analog voltage proportional to the actual value of a signal source /CONT/ or to the number of pulses arriving between two clock pulses /PULSE+ or PULSE-/. /The latter modes make possible counting-rate analysis./

*Are you sure that it is not worth-while to have a relatively simple and cheap device in the preparatory period or for checking your measurements?

Channel B gives one-bit information, i.e. indicates whether the signal value on + B is greater than the external reference level on -B /INT.DISCRIM./ or whether it is within a narrow voltage-window at the reference level /DIFF.DISCRIM./. The reference level function can be given e.g. by the FUNCTION GENERATOR unit corresponding to the character of the measuring problem /see VII./. When instead of CONTINUOUS the PULSE mode is selected, the signal to be analyzed is a voltage level proportional to the peak-value of the highest pulse between two consecutive clock pulses /possibility of pulse-height analysis/.

Channel B possesses two other useful features. With the DELAY switch an additional delay of 100 clock periods can be applied /increased time -lag in e.g. correlation measurements/. Samples can be taken for every clock signal /SAMPLE INCR./ or for every trigger /SAMPLE TRIGG./. The latter is used in amplitude-analysis.

CLOCK A, CLOCK B, CLOCK DELAY, TRIGGER inputs, SAMPLED A, and SAMPLED B outputs are placed on the rear panel.

## 2. PROCESSOR

In the operation mode AVERAGE the processer takes consecutive samples from Ch A or Ch B of the SAMPLING unit and gives them to the MULTICHANNEL INTEGRATOR unit. In the operation mode CORRELATION the processor takes the samples from both channels, performs the required shifts for the one-bit samples, multiplies the sample values A and B and gives the results consecutively to the MULTICHANNEL INTEGRATOR. The unit does not evaluate polarity- but relay-correlation functions.

The INCREMENT of the delay time-variable /channel-width in the correlogram/ can be selected between 100 nsec and 20 msec. The TIME-LAG can be plus or minus oriented in cross-correlation measurements.

The operation of the unit can be gated with an external signal /GATE IN/ or switched ON or OFF by the CYCLE switch. In AUTO mode there is a continuous operation from the internal clock, in TRIGG. mode an external signal /TRIGG. IN/ starts a complete cycle. In mode FRACTION a new cycle is started each time a new pulse appears on TRIGG. IN socket.

The unit delivers clock signals /CLOCK A, CLOCK B, DELAY CLOCK, TRIGG.OUT/. It requires samples A and B, and it is connected to the integrator /socket: TO INTEGR./.

As a correlator, the processor performs the needed calculations on-line in the increment range 100 nsec - 50 μsec, or real-time in the range above 50 μsec.

## 3. MULTICHANNEL INTEGRATOR

The multichannel integrator has an analog RC integrator system of 100 capacitors. Access to the "channels" is made in a serial way, consecutively and periodically for each one. The TIME-CONSTANT of the channels /averaging time/ can be set to 0.1, 1, 10, 50 seconds. The sweep must be synchronized with that of the processor /CLOCK: EXT.; MODE: TRIGG.; IN connected to TRIGG. OUT of the processor; CLOCK IN connected to CLOCK OUT of the processor/ when measuring. If only display is wanted, either the internal FAST CLOCK of 100 Hz or the SLOW CLOCK of 0,1 - 1 Hz can be used in MODE CONT. or TRIGGERED. In the latter case a manual start can also be provided for starting a single cycle.

The accessed channels are continuously reset for as long as the push-button RESET is pressed.

The channel contents of the integrator can be visually displayed on a normal oscilloscope /consecutively and in the rhythm of the sweep/ when the socket OUT is connected to the Y-input of the device. The rear panel socket Z MOD delivers a brightness-pulse each time a channel is accessed.

The oscilloscope can be swept internally when triggered from the processor or externally by using the saw-tooth voltage given by the FUNCTION GENERATOR.

## 4. FUNCTION GENERATOR

The function generator generates a number of auxiliary signals digitally. It accepts clock signals /CLOCK IN/ delivered either by the processor or by the multichannel integrator /synchronization can be done with the switch MODE: TRIGG./. To obtain only one part of a signal period during a cycle, the external clock frequency can be divided /CLOCK DIVIDER: 1, 2, 5, 10, 20/ before driving the digital function generator.

Five different functions can be obtained from the unit: increasing or decreasing saw-tooth /for oscilloscope sweep or reference function in amplitude analysis/, sine-wave /for Fourier transformation/, modulator signal of pseudo-random distributed pulses of levels /for correlation measurements/.

The POLARITY and the AMPLITUDE of the signals can be modified by front panel manual control.

## VI. MAIN TECHNICAL DATA

As the development of the STATISTICAL ANALYZER units is still in the preparatory period, this permits the parameters and technical data listed below to be changed if required. If you would be interested to have a statistical instrumentation designed to meet your own requirements then please contact us.

At present we are contemplating a main specification along the following lines:

| | |
|---|---|
| input signals peak-to-peak | ± 100mV - 5V |
| compensation possible | max. ± 5V |
| counting-rate /increment | max. 9 pulses |
| logic signals | TTL /0 or +5V |
| resolution /width of increment/ | min.100 nsec |
| time /delay/ variable | max..2 sec |
| time-lag | ± |
| constant delay in increments | 100 |
| integration /averaging/ time | min 0,1 sec, max. 50 sec |
| increments /channel number/ | 100 |
| accuracy/stability | 3% approx. |

## VII. HOW TO MEASURE WITH STATISTICAL ANALYZER

a/ COMPLETE RANGE OF ACCEPTABLE PROBLEMS

With all four basic units the following measurements can be made:

1. Analog signal averaging/*/

SAMPLE: INCREMENT
CYCLE: TRIGGERED
CHANNEL: A CONT.
MODE: AVERAGE A

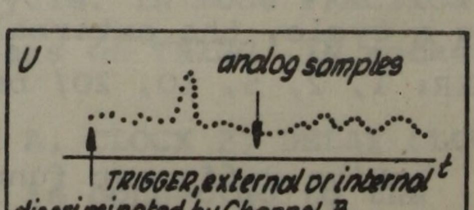

Fig.13

*No FUNCTION GENERATOR needed.

2. <u>Pulse-rate vs.-time distribution/x/</u>
SAMPLE: INCREMENT
CYCLE: TRIGGERED
CHANNEL: A PULSE
MODE: AVERAGE A

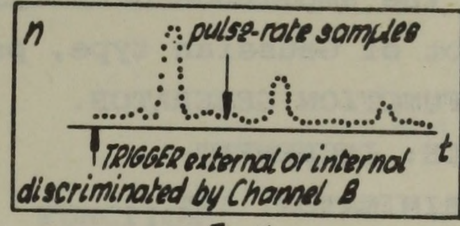

Fig.14

3. <u>Amplitude-distribution /integral/</u>
/for pulses or analog signals/
SAMPLE: TRIGGER
CYCLE: AUTO
CHANNEL: B INT. DISCR.
MODE: AVERAGE B
INCREMENT: fast
PULSE/CONT: as wanted
FUNCTION: saw-tooth
/used as reference on -B/

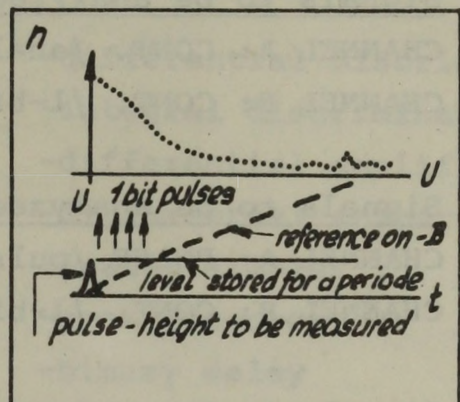

Fig.15

4. <u>Amplitude-density distribution /differential/</u>
/for pulses or analog signals/
as above, but
CHANNEL B in DIFF.DISCR.

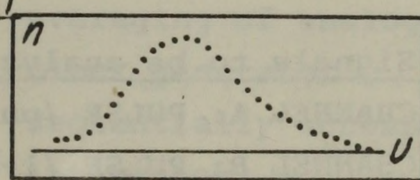

Fig.16

5. <u>Pulse-to-pulse time interval distribution /x/</u>
SAMPLE: INCREMENT
CYCLE: FRACTION
CHANNEL: B PULSE
INT/DIFF: as wanted
MODE: AVERAGE B

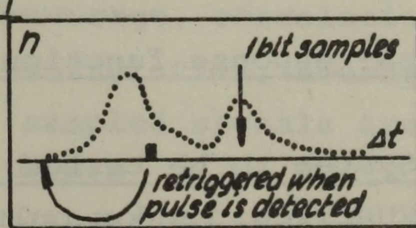

Fig.17

6. <u>Mean value of signals/x/</u>
SAMPLE: INCREMENT
CYCLE: AUTO
CHANNEL: A
MODE: AVERAGE A
MULTICH.INT: only one channel used

7. <u>Mean square value of signals/x/</u>
Maximum value of the autocorrelation function /see 8/

---

x No FUNCTION GENERATOR needed

8. Evaluation of correlation functions/x/

When the amplitude density distribution of the signal/s/ to be analyzed is not of Gaussian type, pseudo-random reference must be given on -B: use FUNCTION GENERATOR.

SAMPLE: INCREMENT CYCLE: AUTO

DISCRIMINATOR: INT. MODE: CORRELATION

8.1. Signals to be analyzed: analog

CHANNEL A: CONT. /analog samples/

CHANNEL B: CONT. /1-bit samples/

8.2. Signals to be analyzed: pulse-rate and analog

CHANNEL A: PULSE /pulse-rate analog samples/

CHANNEL B: CONT. /1-bit samples/

8.3. Signals to be analyzed: pulse amplitude and analog

CHANNEL A: CONT. /analog samples/

CHANNEL B: PULSE /1-bit samples/

8.4. Signals to be analyzed: pulse amplitude and pulse-rate

CHANNEL A: PULSE /pulse-rate analog samples/

CHANNEL B: PULSE /1-bit samples/

9. Impulse-response function by correlation method

9.1. System to be tested: input pulse; output pulse-rate or analog

FUNCTION: random pulses: modulator signal

CHANNEL A: PULSE /pulse-rate analog samples/ or CONT.

CHANNEL B: CONT.

9.2. System to be tested: input analog; output pulse-rate or analog

FUNCTION: random levels: modular signal

CHANNEL A: CONT. /analog samples of modulator/

CHANNEL B: PULSE or CONT.

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x No FUNCTION GENERATOR needed: generally.

b/ <u>APPLICATIONS OF THE INDIVIDUAL UNITS AND THEIR COMBINATIONS</u>

| SAMPLING / PROCESSOR / M.INTEGR. / FUNCTIONG. | OTHER DEVICE TO BE USED | FUNCTION |
|---|---|---|
| x . . . | | -differential discriminator |
| | | -integral discriminator |
| | | -differential amplifier |
| | | -differentiel comparator |
| | pulse-generator | -analog sampler |
| | pulse-generator | -peak detector |
| | pulse-generator | -binary delay |
| . x . . | | -variable clock |
| | | -analog inverter |
| | | -shift register |
| . . x . | | -averaging of analog signals |
| | | -clock generator |
| | pulse-generator | -sequentially accessible integrator |
| . . . x | pulse-generator | -function generation |
| x x . . | multichannel memory | -average, correlation |
| . x x . | | -correlation, average when sampled signals are available |
| x . x . | | -signal averaging with 100Hz clock |
| | pulse-generator | -real-time signal averaging |
| x x x . | | -see items of the complete list marked with * |
| x x x x | | -see the complete list |

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Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szabó Ferenc, a KFKI Reaktorfizikai Tudományos Tanácsának elnöke
Szakmai lektor: Kozmann György
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