THE IMPACT OF ELECTRONICS ON MODERN INSTRUMENTATION

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The application of the newest achievements of physical sciences to the field of measurement and instrumentation has in recent years gained more and more recognition as an independent science of its own. [1, 2, 3, 4.] The wide range of new measureables and the complexity in applying the recent technical achievements to the design of technical and scientific instruments amply justify such a view. Few will disagree with the renowned scientist Dr. WILDHACK of the US Bureau of Standards, when he writes [2] :

"It is easy to foresee an increased recognition for the science of instrumentation. Expect for atomic energy, the development and application of instrumentation probably have greater potential material significance for our age and our civilization than any other factor on the contemporary scene. This seems valid militarily, industrially, and scientifically."

The significance of the new science of "instrumentation" has increased with particular rapidity since the spectacular growth of electronics during the past decade. A row of ingenious scientific devices came into being as a result of combining modern physics with the newest technique of electronic circuitry. With the help of the achievements attained in the field of instrumentation, entire new branches of science were established in some cases. This in itself is not new in the history of natural sciences — let us only remember the tremendous impact given to the science of geophysics by the discovery of the gravitational torsion balance by ROLAND EÖTVÖS. Or, has the simple device known as the Wilson-chamber not revolutionized our knowledge of the nucleus and started an entirely new branch of atomic science? The same may be said of the effect of such instruments as the X-ray powder spectrograph, the mass-spectrograph of Niehr or the n. m. r.-spectrometer — all of which have opened up new chapters in physics and physical chemistry.

Electronics, however, seem to hold an especially valued place in up-to-date development of scientific and industrial instruments. The ratio of devices employing some application of electronics is continuously growing, even in such "conservative" fields as that of spectroscopy, with spectrophotometry and quantometry taking an ever greater share. Knowing the numerous shortcomings and complexities of electronic components and circuits, due in part to the relatively large manufacturing tolerances and limited service life of electronic tubes and other components, as well as the not too exact methods of eletronic circuit design — one may wonder about the factors which justify the wide use of electronics in modern instrumentation, despite these shortcomings. It is the aim of this short study to systematically expose some of these factors.

What does electronics offer to instrumentation?

The electron tube — or, as the British usage more figuratively says: the electron valve — constitutes a current-valve of exceedingly small inertia, requiring minute controlling power. These two properties determine its great value for the instrument designer whose primary aim is to interfere as little as possible with the process under measurement (i. e. not to draw any power from it) and to obtain practically momentary response. Three further characteristic features offered by electron tubes: large amplification, high input impedance and the ability to generate high-frequency voltages or short pulses, are closely connected with the two basic properties mentioned and the combination of these characteristics cannot be found at present in any other device. Let us see how these properties are applied to the measurement of various data.

a) The *amplification* obtainable with electron tubes enables us to measure *voltages* down to a *few microvolts* or — in the case of a very restricted frequency range — voltages as low as 10^{-8} *Volt.* Such an amplification is usefully employed in certain magnetometers for the precise measurement of the earth's magnetic field, in radiation detectors for infrared spectrophotometers, and in such special devices as the microwave power-level-meter developed by the Hungarian Telecommunication Institute. This instrument, using a thermistor to transform the microwave energy of a few microwatts into a resistance variation, uses a bridge-detector amplifier with a gain of 10 million and a sensitivity limit of 10^{-7} Volt. Obviously, only the application of electronic tubes can serve to solve such a problem.

b) The *lack of inertia*, inherent to electron tubes, enabled us to follow events of extremely short duration, such as those associated with nuclear fission. The "piece-meal" counting of hundred thousand pulses per second — accomplished in up-to-date high-speed scalers, as those manufactured by the Hungarian industry, as well as the observation of milli-microsecond (10^{-9}sec) fission processes, a daily routine in our Central Physics Research Institute, are good examples for the use of electron tubes as switching and amplifying devices, almost free of inertia. Another application of the fast-action feature of electron tubes is to be found in the field of microwave technique where precision signal generators are used for producing billions and ten billions of oscillations per second. The 10cm ORION—EMG Signal Generator is another good example of how this feature of modern electronics can be applied to scientific instrumentation.

c) The possibility of a *high input impedance* as mentioned above further adds to the versatile application of electronics in scientific measurement. The well-known glass electrodes for pH measurement were of as little use to the chemist, as the photo-tubes to the physicist, were it not for the ability of electron tubes to amplify voltages with almost no power drawn from the circuit under measurement. A voltage measuring circuit with an input resistance of ten billion ohm is now a matter of industrial routine, as for instance in the ORION electronic pH-meter. Moreover, in the continuous radiation meter Model GK—4 using a GM tube, an electrometer-tube circuit having an input resistance of 10^{14} ohm, enables, the measurement of currents as low as 10^{-14} ampère. No other non-electronic device can accomplish this with such simplicity, ruggedness and speed.

d) The *ease of data-transmission* over long distances is another merit of electronic measuring circuits. A combination of high-frequency technique with the inherently high sensitivity of these circuits has very recently rendered a splendid performance of electronic telemetry in combination with the IGY satellite program. A less spectacular, but more practical example of "wired" electronic telemetering is the radioactive prospecting equipment developed by our Geophysical Institute, which is capable of measuring minute traces of radioactivity (as well as a number of other data) at a depth of 2—3000 meters. It is possible by means of minute electronic components to sense only these variables in a bore hole 2 miles deep and of a diameter not over 5", and to transmit them with the accuracy of a precision measurement to the amplifying and recording mechanism above. A similar accomplishment can be seen in the famous "Laterolog" enabling the specific resistance measurement of a soil-layer not more than 20 cm in thickness at a depth of 2000 meters below the surface (shaded area of Fig. 1). This is achieved by setting up a current and potential pattern as shown in Fig. 2, and electronically stabilizing this distribution against wide variations in the resistivity of the surrounding material. The shown potential distribution assures an accurate measurement of the resistivity of the lateral earth sheet, with the unshaded areas bearing no influence on the measurement. Recent improvements made by our Geophysical Institute in the electronic amplifying and stabilizing circuitry have further added to the simplicity and accuracy of this ingenious method; a simplified reproduction of the results is shown in Fig. 3. As against the "averaged" data obtained by classical resistance measuring methods(left-hand) curve, the electronic logging system yields accurate data of the resistivity of a layer one tenthousandth as thick as its depth below the point of measurement — with the probe often being surrounded by a mud of high electric conductivity (right-hand curve) [5].

In the many different geophysical instruments produced by our industry for the accurate mapping of mineral resources, electronics is widely used for the telemetered scanning of bore holes and for the registration of artificial shock-waves in the well-known seismic investigations. Again, the fast-acting electron tube comes as an aid to accomplish what no other device can do for the prospector — the divining rod of bygone days has found its more reliable successor in the complex electronic equipment of our seismometric geophysical field laboratories (Fig. 4).

e) An entirely new aspect of instrumentation is the great increase in accuracy, accomplished through the *digital technique of data processing*. In the past, the accuracy of measurement was greatly limited by the use of scales and dials, which permit an accuracy of reading around 1% in industial devices and 1‰ by the most accurate laboratory methods, requiring laborious precaution and much time. To-day, with the use of binary and decade switching and counting circuits and special indicating tubes (decatrons, etc.), this limit no longer exists. The measurement of time-intervals and frequencies to an accuracy of *one part in a million* can now be achieved in a fast and direct way, the result being presented within a second's time on appropriate meter scales or counter tubes. The same holds true in the counting of swift events — such as cosmic showers of high-energy particles — or the revolutionary method of counting millions of red blood cells in the viewing field of a microscope — all within a matter of seconds. The so-called "cycle counter" or digital frequency meter, shown at a Hungarian Instruments Exhibition last year, is a good example of such a type of equipment. Thanks to the unique speed and versatility of electronics, the results of such digitalized precision measurements can now be further processed without loss in accuracy by the most advanced electronic tool, the *digital computing machine*, capable of handling a million binary digits per second.

In this manner the *high amplification* at almost no input power, *speed of action*, high input impedance, ease of *data transmission* and the possibility for fast *digitalized data processing*, add up to a combination of features which evidently can hardly be matched by any other means known to instrument-physicists. No wonder then, that despite its apparent drawbacks and complexity, electronics are constantly gaining space in up-to-date instrumentation.

New data-transducers for electronics

The characteristics of electronic circuitry opened up entirely new possibilities for measuring certain variables, too small, too fast changing, or otherwise not accessible to "classical" measuring methods.

Certain fundamental physical phenomena such as the changing of a wire's resistance to its physical dimensions, or the electrolytic semiconductivity of glass, suddenly find their "renaissance" in the strain gauge, using an electronic bridge indicator for measuring a dimensional change of 0,0001% — or in the glass electrode of an electronic pH meter having an input resistance of over ten thousand megohms. Minute voltages raised in a conductor moving by a few microns through a magnetic field suffice to detect and measure —

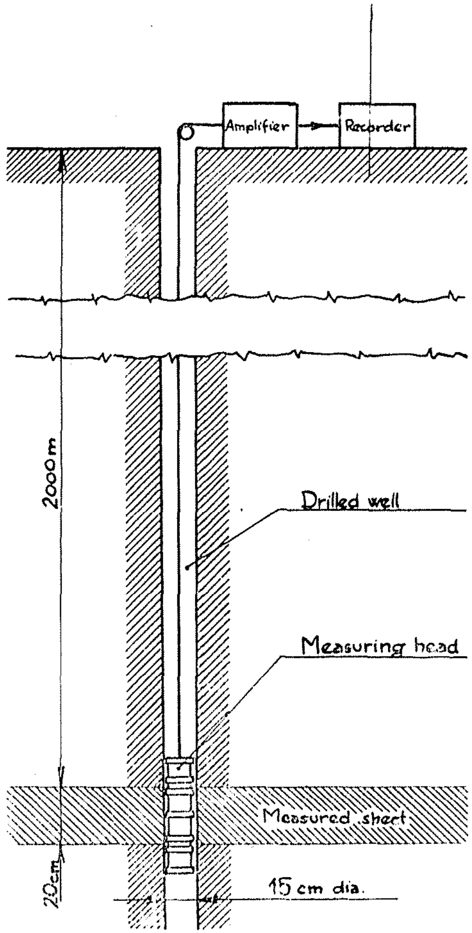
Amplifier
Recorder
2000 m
Drilled well
Measuring head
Measured sheet
20cm
15 cm dia.

Fig. 1

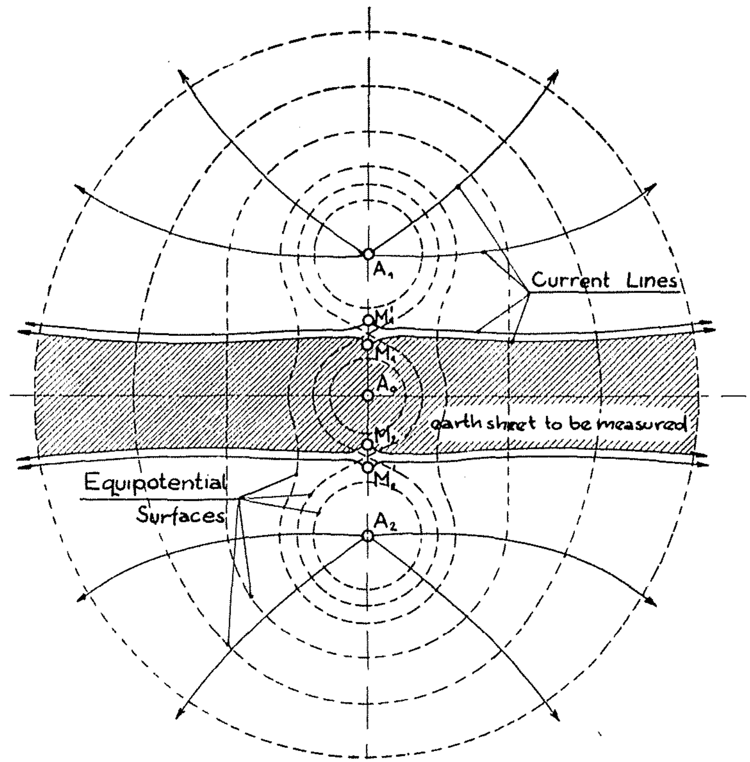
A1
M1'
M1
A0
M2
M2'
A2
Current Lines
earth sheet to be measured
Equipotential
Surfaces

Fig. 2

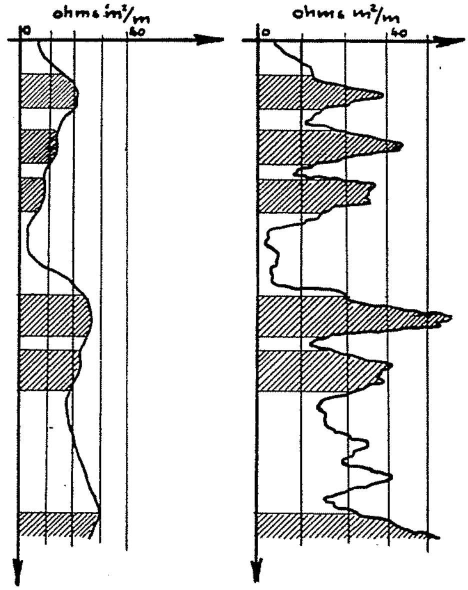

Fig. 3

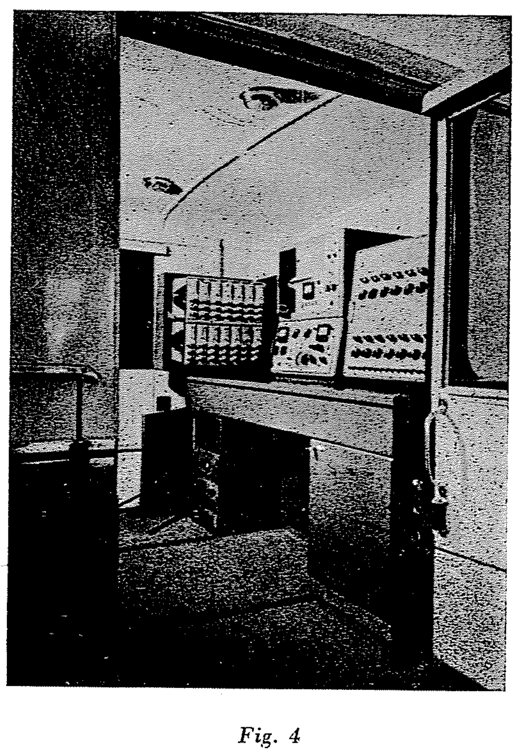

Fig. 4

with the aid of electronic amplifiers — seismic shockwaves propagating through miles of geological strata.

Beyond the revival, however, of classical physical phenomena, a number of new and characteristic *electronic transducers* have become widely used for measuring purposes. Among these are the *photomultiplier* in optics, the *GM-counters* in nuclear physics, new semiconductor-type transducers as *thermistors*, *photo-resistors* and *photo-transistors* as sensing elements for visible and thermal radiation, to mention but a few. Most of these transducers show a startling feature over the older ones, that is : they combine the sensing and amplifying function into one and the same element, thereby working at a great *power-gain* as against most "old-time" transducers which emparted a *power-loss* upon the quantity to be measured. The "efficiency" of ,,classic' transducers is always a quantity smaller than one, while these most recent electronic transducers operate at a considerable gain even before an additional amplifier is employed. Electron-multipliers with a sensitivy of 60 ampère pro lumen or thermistors and phototransistors, having only slightly smaller figures of merit — not to speak of the G-M tube with an inherent amplification of 10^6 — are good examples of how some of these electronic transducing elements perform.

The examples mentioned clearly show that electronics not only opened up a new perspective by its speed and sensitivity in conjunction with conservative sensing elements, but it also created new transducers which by themselves out-perform any of their "classical" predecessors by many orders of magnitude. It now remains for the scientists of our days to combine the stability and reliability of those older devices with the sensitivity and speed of action of their electronic successors. It is no secret that much has yet to be done in this direction in the interest of lasting precision and reliability of measurement.

Certain results are scored in this respect by the development staff of our instrument industry, which is steadily growing more "electronics-conscious". In addition to the large size electronic instruments' factory ORION, the Geophysical Instruments' Factory and a score of smaller specialized manufacturers are engaged exclusively in the advancement of the electronic art. Electronics is also at the same time rapidly infiltrating into most other instrument factories — be it in the shape of automatic electronic potentiometers or of electronic surface roughness testers. The greater part of our *Industrial Institute of Instrument Research* is engaged in electronic circuit development and their work is complemented by electronic instrument research made at the *Telecommunication Research Institute*, the *Geophysical Institute* and the *Central Physical Research Institute* of our Academy[6]. The development and research of new transducers for electronics is the primary task of the Academic *Institute for Measurement and Instrumentation*, and certain results in the field of thermistors[7] magnetostrictive torque-transducers and new photomultiplier applications[8] can here be registered.

With so great an effort to keep abreast with the pace of world progress in electronic instrumentation, the training of specialists, obviously, becomes a central problem. It was with this in mind that a special *Electronic Instruments' Branch* was set up within the Instrument Department of our Electrical Faculty. The coming years will show how well the training in general instrumentation and the specialized courses and projects in instrument electronics will be combined to furnish the highly qualified yet universally trained specialists fit for one of the various diverse tasks to be done.

Electron-optical instruments

Without in any way attempting completeness, another important class of electronic instruments should not escape our attention. Beyond the application of circuit-technique and electronic transducers, modern scientific instrumenation is coming to use an ever greater variety of large measuring devices in which the *wave-nature* of accelerated electrons play an important role. We refer here to the wide application of electron optics in such devices as the *electron microscope*, the *electron-diffractograph* or the *microfocus X-ray tube* — instruments yielding data on the submicroscopic structure of materials not obtainable by any other method. Intramolecular spacing of crystal lattices in the order of one angström-unit can, for example, be measured to four decimals. Let us not forget, furthermore, that various kinds of electron accelerators for generating high energy radiation — the *betatron*, *synchrotron* and *synchro-cyclotron* — are also special cases of applied electron optics. Briefly mentioning a few representatives of this important class of electronic instrumentation only serves to round out the picture aimed at by the present review and to prove — should such a proof still be required — how universal a research tool electronics has become in modern science.

Conclusions

The appearance of electron tubes and semiconductors in experimental physics marks — as we have shown — an important milestone in the development of new tools for nvestigating the processes of nature and of technology, as well as for influencing and controlling them. The revolutionary impact of electronics on modern instrumentation has caused a quite sudden „discontinuity" in the orders of magnitude in which man to-day can conveniently obtain data, not only of unbelievably small values of voltage or current, but also those of time and space as well as of most other variables known to physics. The exact scientist whose task it is: "To measure everything measurable and to render measurable all that cannot yet be measured" — has truly received a powerful new tool and it can be safely predicted that electronics will in its daily progress hardly leave any part of experimental science untouched by its magic wand.

In order to meet this challenge, instrument engineers have to join hands with electronic specialits everywhere — and this is also true in our country where a healthy start has been made both in industry and scientific research. Our great traditions of some outstanding past accomplishments in instrumentation and in electronics commit us to a forward looking, high level educational program for training young engineers capable of keeping abreast with world progress.

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