COMPARISON OF DIFFERENT TIME SYNCHRONIZATION TECHNIQUES

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ABSTRACT

The Van Swinden Laboratory (VSL) of the National Service of Metrology in the Netherlands has recently been moved to a new laboratory at Delft. The section Time and Frequency of the Division of Electromagnetism and Time is now housed in a laboratory, built as a cabin of Faraday, with well-maintained environmental conditions and equiped with different other provisions.

The cesium atomic clocks are put on heavy concrete blocks which are placed vibration free at sufficient distance from other objects to avoid mutual disturbing influences.
A microprocessor provides the automatic data registration of the complete system. The main international synchronization link is the Loran-C system.

Initially it was planned to set up an international TV-synchronization network between NPL/RGO, LPTF, PTB/DHI and VSL. For this purpose three 3 m-parabolic antennas should be placed at 90 m height on top of the main building of the Department of Electrical Engineering of the Technical University Delft.

A preliminary experiment between NPL and VSL during the years 1976 - 1978 showed the possibilities. The accuracy is 500 ns during most of the time. The link is about 240 km long, mainly across the North Sea. Also good reception of TV-syncpulses was found of a German TV-transmitter at a distance of 170 km from our laboratory. NPL is going to propose a new, improved TV-synchronization experiment. An accuracy of better than 200 ns seems to be possible. In both cases the receiver has been equiped with a phase locked loop TV-sync pulse detector.

However, instead of the planned three parabolic antennas, in the meantime the new laboratory has been equiped with a system of satellite receivers. A 3 m-parabolic antenna receives signals above 4 GHz and other antennas can receive signals in the frequency bands from 100 - 500 MHz and 1 - 2 GHz.
Close co-operation has been established within the Netherlands between the VSL and the laser-satellite groundstation of the Geodetic Department of the Technical University Delft at Kootwijk and the radio-astronomy station at Dwingeloo.

The mutual links make use of the TV-synchronization techniques, with which we can achieve an accuracy of about 8 ns to 10 ns (1 σ) over links of 140 km.

It has been planned to join the ESA (European Space Agency) two-way laser satellite synchronization technique experiments -- where the Netherlands' ground station is one of the most powerful ones in Western Europe -- and to co-operate in VLBI-measurements. A proposal for such a VLBI-experiment between the UK and the Netherlands may be realised in 1980.

In this way a good comparison and synchronization can be performed between the different methods.

INTRODUCTION

The Van Swinden Laboratory (VSL) of the National Service of Metrology in the Netherlands has recently been moved from The Hague to Delft. In the old laboratory at the Hague the section Time and Frequency of the Division of Electromagnetism and Time was equiped for the reception of VLF/LF-, Loran-C- and TV-transmissions. In particular the standard frequency signal transmissions of DCF 77 (Mainflingen, FRG) were monitored daily. Daily measurements were done on the Loran-C transmissions of Ejde (7970-M and 7930-X) and Sylt (7970-W). Also every day measurements were carried out on the TV-synchronization system, in which way other laboratories in the Netherlands are synchronised to the VSL.

The new laboratory at Delft, about 17 km south of the Hague, also possesses the possibilities for receiving satellite transmissions, while by further co-operation with other institutes different techniques -- e.g. laser-synchronization and VLBI -- can be used and compared.

INTERNATIONAL TV-SYNCHRONIZATION NETWORK

Originally, it was planned to set up an international TV-synchronization network between NPL/RGO, LPTF, PTB/DHI and VSL.
For this purpose three 3-m parabolic antennae should be placed at 90 m height on top of the main building of the Department of Electrical Engineering of the Technical University Delft, directed to TV-transmitters in the UK, France and Germany. A special low attenuation coaxial cable of about 800 m should connect the antennae with the measuring equipment in the time and frequency standards laboratory of the VSL.

PRELIMINARY EXPERIMENT BETWEEN NPL AND VSL

An experiment between NPL and VSL during the years 1976 - 1978, when the VSL was still in The Hague, showed the possibilities.
The TV-transmitter to be received by the NPL as well as by the VSL, was located at Sudbury (Suffolk, UK), 85 km north-east of London. In this case no TV-relay stations should be involved. In principle NPL could receive this station without any special measures.
The transmitter frequency is 715 MHz (BBC 2).
The VSL, at a distance of 240 km of the transmitter and a transmitting path mainly over sea, installed a 21 element, 14 dB gain Yagi-antenna on the roof of a 60 m tall building next to the laboratory.
The NPL used a broad band antenna with broad band amplifier.
Because the transmission link from the TV-studio to the Sudbury transmitter is often different, it is strictly necessary to do the measurements at the same moment.

The difference in propagation delay between the transmitter and the respective laboratories showed up to be about 2200 μs, what is much more than the theoretically calculated difference of 480 μs.
It came out that the transmissions of Sudbury (at a distance of 100 km from NPL) were overruled by the transmission of a local transmitter at the same frequency and with the same program in Hemelhempstead (35 km from the NPL).
NPL could, however, very well receive another BBC 2 transmitter at Crystal Palace in South-London.
Taking into account that the BBC-program comes from studios in London and then is transmitted via a detour of about 500 km to the Sudbury transmitter, after which reception in The Hague is possible, the overall correction, which one has to apply, is 2470 μs.

In figure 1 the result of the measurements UTC(VSL) - UTC(NPL) via TV is plotted over a period of 3 months (May - July 1978). For comparison is also plotted UTC (VSL) - UTC(NPL) via Loran-C (Sylt).
Except for throw-out measurements the average over these 3 months seems to be well within 500 ns.
The uncertainty in each measuringpoint is ± 1 μs as a maximum.

The VSL-measurements were carried out with the application of a phase locked loop, locked to the received synchronization signals. The variations in field strength in the troposphere over this distance can be 60 dB.

As a check a portable clock measurement was carried out between NPL and VSL on June 27, 1977. The difference UTC(NPL) - UTC(VSL) = (30,05 ± 0,05) μs. Calculations in 1978 taking into account this value confirmed the delay of 2470 μs.

Also experimental TV-measurements were done between PTB and VSL.
The VSL could receive the German ZDF-transmitter at Wesel, 166 km away from our laboratory. The measurement data were calculated with the help of the measurements data UTC(PTB) - ZDF as published weekly by the PTB in their Time Service Bulletin.
The TV-measurements were compared with the calculated time difference UTC(PTB) - UTC(VSL) out of the Loran-C measurements.
Also in this case a correction had to be applied which was calculated out of the comparison of Loran-C differences and the averaged TV-differences.
The results are plotted in figure 2.
The dispersion over about 2 months is less than 1 μs.

CONCLUSION

The throw-out measurement results are mainly due to the fact that for direct TV-synchronization over such large distances there can be much disturbance, by which the signal levels can strongly change and thus the receiver will be upsetted and extra uncertainties of 1 to 1,5 μs are introduced.
Improvement for this can be achieved by applying a better antenna with a higher gain and a more narrow beam and placed on a greater height.
In this moment it is believed that in an international TV-synchronization network, as thought, one can achieve an accuracy of 500 ns, which possibly may be improved to 200 ns.

PROPOSAL

With respect to the feasibility study on long distance international TV-synchronization networks the NPL is proposing a continuation of the work in the year 1980.

THE NEW VSL - LABORATORY AT DELFT

In the mean time the VSL has been moved to a new laboratory at Delft, 17 km south of The Hague.
Instead of the intended three 3-m parabolic antennae, one has installed on the highest point of the roof of the VSL satellite receiving antennae, so to have a good opportunity to link in in these synchronization systems.

INSTALLATION

The section Time and Frequency is now housed in a laboratory, built as a cabin of Faraday with a 135 dB screening up to 10 GHz. The environmental conditions are (23 ± 0,3) $^{\circ}$C and (45 ± 5)% R.H. An extra emergency air-conditioning is available.
The laboratory has been equiped with automatic fire alarm and halogen extinguisher.
The power supply consists of two different networks. One is a stabilized mains; the other network is connected via an emergency power generator. Further, an open NiCd battery power supply guarantees continuous and undisturbed functioning of the clocks and the other main electronics.

The cesium atomic clocks are put on heavy concrete blocks which are placed vibration free at sufficient distance from each other (1 m) and other objects to avoid mutual disturbing influences. Also was looked for a minimum magnetic field (< 25 μT).

All the measuring equipment, receivers, digital clocks, counters, microsteppers and other electronics are brought together in a large console.
A microprocessor provides the automatic data registration of the complete system.

The switching between the different standards and receivers is done by means of TTL-integrated switches.

The overall reproducibility in this switching system is about 1 ns.

The on tape gathered measurement data are further processed with the help of a microcomputer.

Further improvements on the system can be achieved and have been planned by providing a microprocessor controlled surveillance system.
The number of cesium atomic clocks, taking part into the BIH-program has been increased to four, while a fifth clock is under study.
Three of the clocks are located in our own laboratory.

The fourth clock is located at the European space Technology Center (ESA-ESTEC) at Noordwijk, Netherlands.

LORAN-C, VLF/LF AND DOMESTIC TIME SIGNALS

Also in the new laboratory the main international synchronization link is still the Loran-C system.
Received are the transmissions of Ejde (7970-M, 7930-X) and Sylt (7970-W).
The measuring data are sent by telex once a week to the USNO in Washington D.C. for keeping track on the North Atlantic and Norwegian Sea chains, and every period of 30 days to the BIH.

The standard frequency transmissions of DCF 77 are monitored as also the domestic time signals, which are disseminated by the telephone PTT, ± 10 ms, and the radiotransmitters Hilversum III, ± 1 ms.

TV-SYNCHRONIZATION

Daily measurements on the TV-synchronization system guarantee a very accurate synchronization of the time and frequency standards in other laboratories.
For the synchronization signal (point) one uses the middle of the trailing edge of the first field synchronization pulse.

The day by day variance in the difference UTC(VSL)-UTC (ESTEC) is about 15 ns, and is mainly limited by the instability of the standard tube of the cesium atomic clock used by the VSL.
Figure 3 shows the stability UTC(VSL)-UTC(ESTEC) via TV.

The variance of 6 measurements, spaced by 10 s each, is about 8 ns. This is mainly due to receiver noise.

TV-synchronization measurements done at other locations in the Netherlands show that over distances of 180 km, where one measures via other TV-relay transmitters, about the same variance of 15 ns can be expected.

A weekly time service bulletin is published by the VSL.

LASSO

For the succesful operation of the two-way laser satellite synchronization technique, one needs very powerful laser ranging ground stations, which can give very accurate timed single shots and can detect the shot again after having been reflected by the satellite at a distance of 36000 km. One of the most powerful stations is located in Kootwijk, Netherlands.
After having applied some modifications and adaptations it is planned to join the BIH-ESA-Sirio II laser synchronization experiments, where we hope to achieve an uncertainty in the synchronization of 1-10 ns as a maximum.
The Kootwijk laser ranging station is linked to the VSL by means of TV-synchronization and portable clock measurements.

VLBI

Another possibility for time scale synchronization is to make use of the VLBI-technique.
The radio-astronomy station at Dwingeloo, Netherlands is located at a distance of 173 km from the VSL and has also a TV-synchronization link with the VSL.
An experiment which will make use of the VLBI technique has recently been proposed by the NPL and the VSL making use of the radio-astronomy stations in Chilbolton (UK) of the Appleton Laboratory and in Dwingeloo.

SYNCHRONIZATION VIA SATELLITE

The new VSL-laboratory at Delft has been equiped with different antennae.
It is now possible to receive signals in the frequency band from 100 MHz to 500 MHz. The antenna gain is 8 dBi; RH or LH circular.

Another antenna gives the possibility for receiving signals in the frequency band from 1 GHz to 2 GHz. The antenna gain is 8dBi; RH or LH circular.
Also a 3 m-parabolic antenna has been installed, which at present has been equiped with a receiving system for the frequency band 11 GHz - 12 GHz.
The noise figure is 4,5 dB. It gives the opportunity for looking into the time synchronization possibilities at a high accuracy level by receiving FM-TV-broadcasting.
The parabolic antenna as also the 100-500 MHz antenna are remote controlled in azimuth and elevation from the console in the time standards laboratory.

At present apart from the 11 - 12 GHz receiver no other receivers has been installed or are available for measuring on other satellites.

The VSL might have also access to very large parabolic telecommunication satellite antennae of the PTT at Burum, Netherlands, 188 km north of our laboratory.

In the mean time the coordinates of the VSL as also of Kootwijk are together with the coordinates of other laboratories and institutions determined by means of simultaneous Dopplerobservations.

CONCLUSION

We hope to be able with the help of all the combined facilities to compare the different synchronization techniques among each other.

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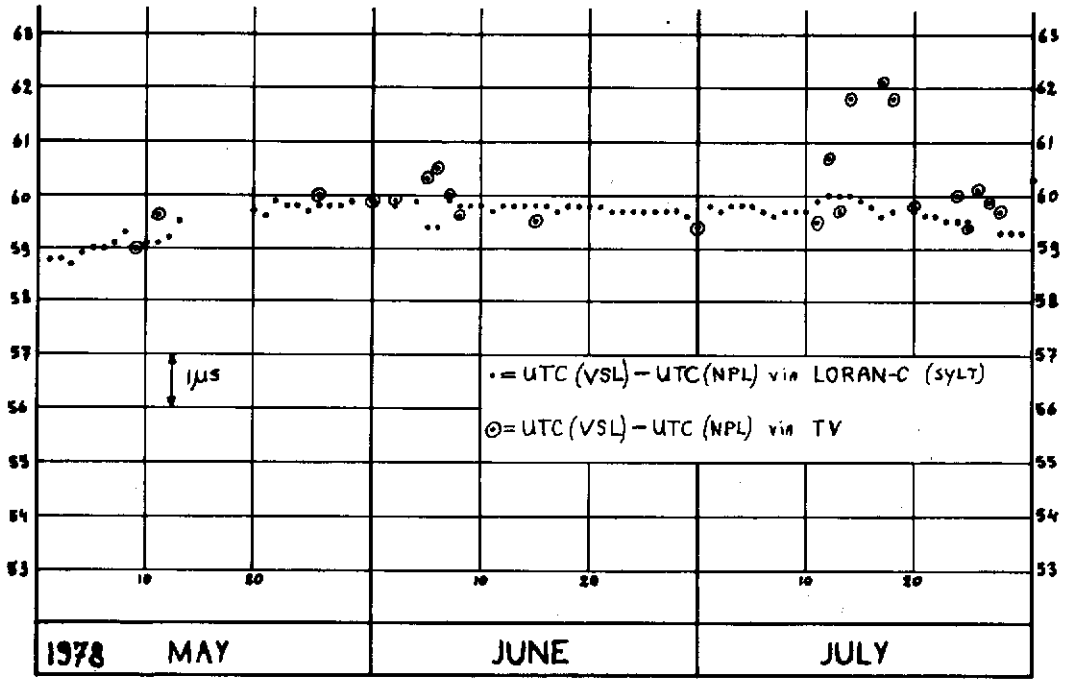

Figure 1

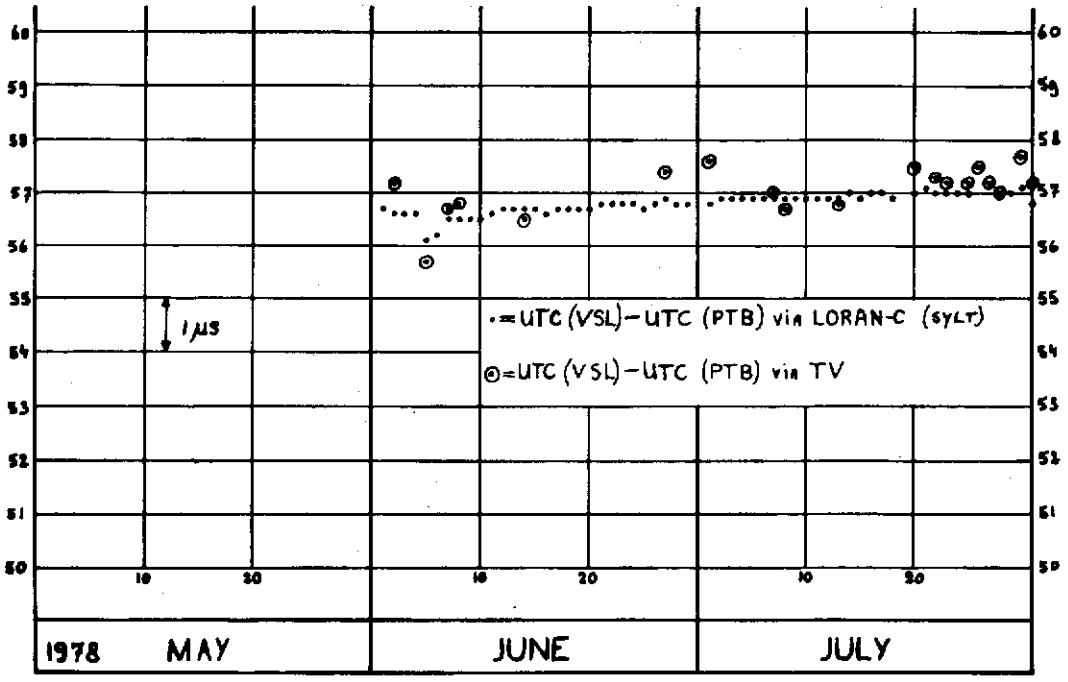

Figure 2

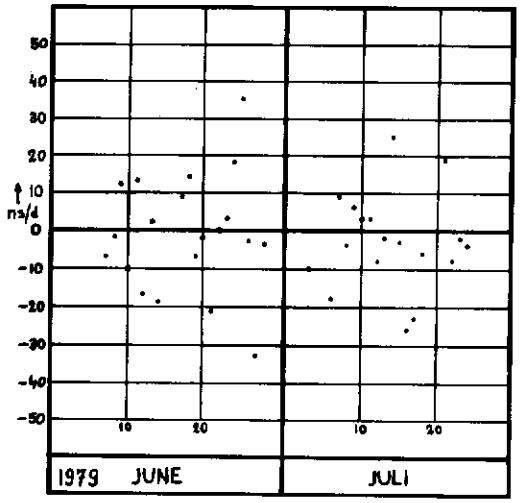

Figure 3. Stability of UTC(VSL)–UTC(ESTEC) Via TV

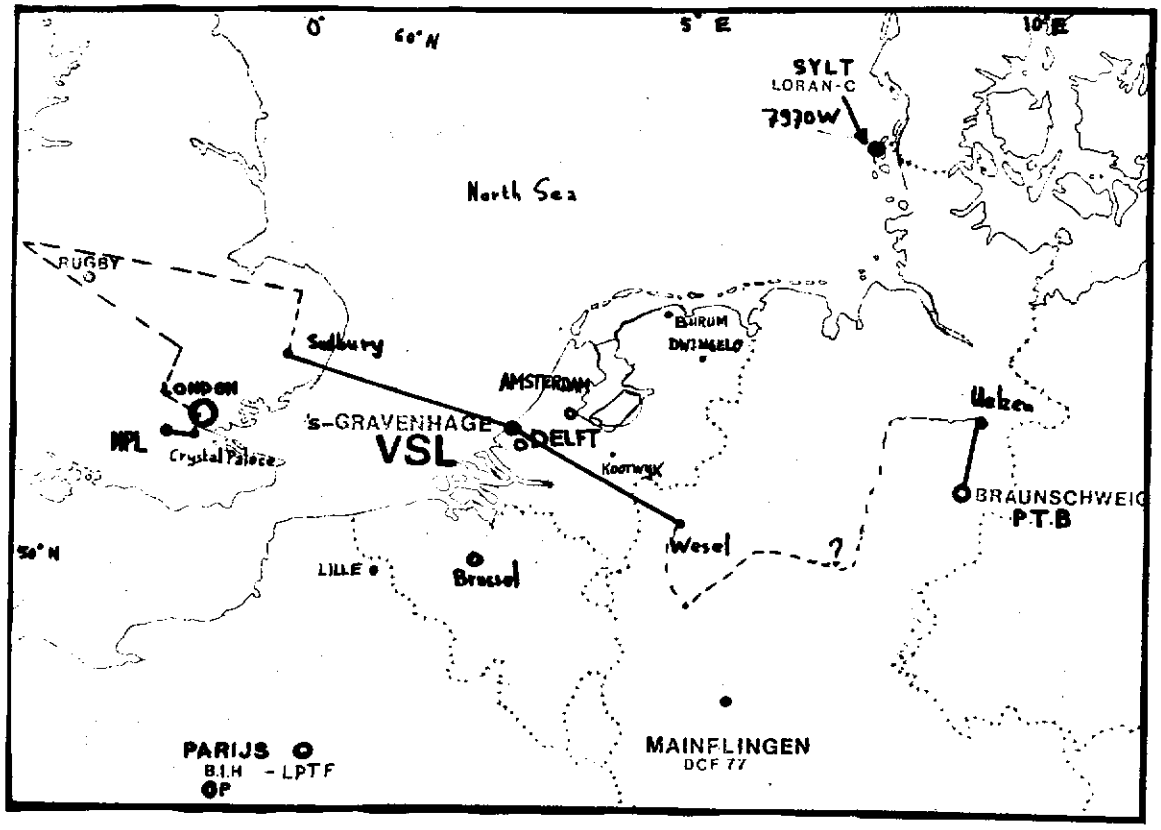

Figure 4

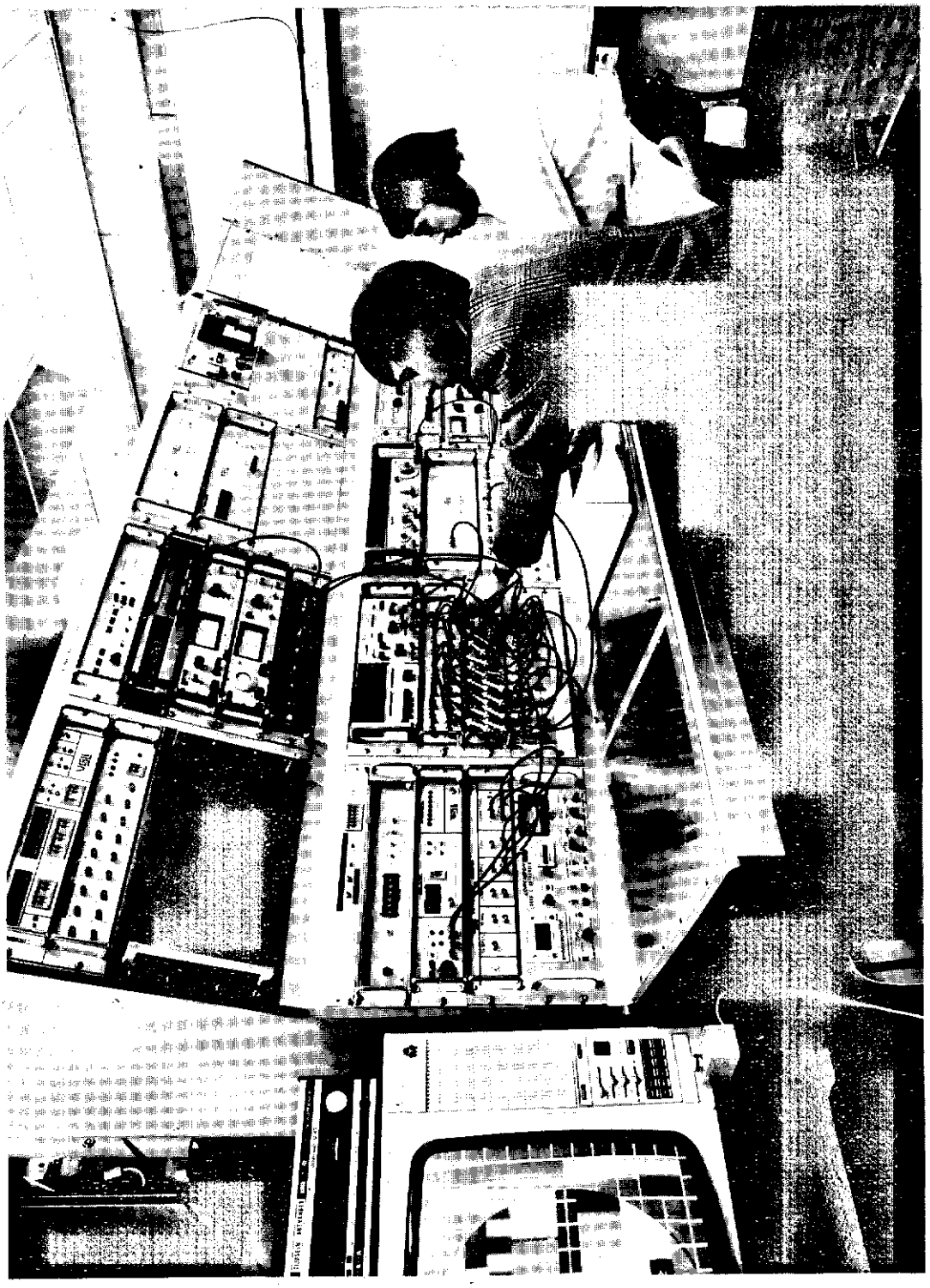

Figure 5