tijdschrift van het

nederlands elektronica- en radiogenootschap

deel 38 - nr. 6 - 1973

Nederlands Elektronica- en Radiogenootschap
Postbus 39, Leidschendam. Gironummer 94746 t.n.v.
Penningmeester NERG, Leidschendam.

HET GENOOTSCHAP

Het Genootschap stelt zich ten doel in Nederland en de Overzeese Rijksdelen de wetenschappelijke ontwikkeling en de toepassing van de elektronica en de radio in de ruimste zin te bevorderen.

Lidmaatschap

Voor opgave lidmaatschap wende men zich tot de secretaris. Het lidmaatschap staat -behoudens ballotage- open voor academisch gegradueerden en hen, wier kennis of ervaring naar het oordeel van het bestuur een vruchtbaar lidmaatschap mogelijk maakt.

Studenten aan universiteiten en hogescholen kunnen bij gevorderde studie in aanmerking komen voor een juniorlidmaatschap, waarbij 50% reductie wordt verleend op de contributie voor gewone leden. Op aanvraag kan deze reductie ook aan anderen worden verleend.

HET TIJDSCHRIFT

Het tijdschrift verschijnt zesmaal per jaar. Opgenomen worden artikelen op het gebied van de elektronica en van de telecommunicatie.

Auteurs die publicatie van hun wetenschappelijk werk in het tijdschrift wensen, wordt verzocht in een vroeg stadium kontakt op te nemen met de voorzitter van de redactie commissie.

De teksten moeten, getypt op door de redactie verstrekte tekstbladen, geheel persklaar voor de offsetdruk worden ingezonden.

Abonnementen

De abonnementsprijs van het tijdschrift bedraagt ƒ 35,-.
Aan leden wordt het tijdschrift kosteloos toegestuurd.

Advertenties

Tarieven en verdere inlichtingen worden op aanvrage verstrekt door de voorzitter van de redactiecommissie.

DE EXAMENS

De examens door het Genootschap ingesteld en afgenomen zijn:

a. op lager technisch niveau: "Elektronica monteur NERG"
b. op middelbaar technisch niveau^x : Middelbaar Elektronica Technicus NERG"
x. Voor het oude examen "Elektronica Technicus NERG" kan volgens de beeindigingsregeling nog slechts tot en met 1975 worden ingeschreven.

Eisen en reglementen

De brochures waarin de exameneisen en het examenreglement zijn opgenomen kunnen schriftelijk worden aangevraagd bij de Administratie van de Examencommissie.

Deelname en inlichtingen

Voor deelname en inlichtingen wende men zich tot de Administratie van de Examencommissie NERG, von Geusaustraat 151, Voorburg, gironummer 6322 te Voorburg.

De Vederprijs 1972 is toegekend aan de Telecommunicatie Werkgroep Indonesia-Nederland (TWIN).
De feestelijke uitreiking door Mevrouw C.E.van Hoboken-Veder vond plaats op 19 juni 1973 gedurende de 231e werkvergadering van het Nederlands Radio- en Elektronica Genootschap in het Gebouw van de Afdeling Elektrotechniek te Delft. De considerans werd uitgesproken door Dr. Ir. K.Teer. Het technisch ontwerp "Het elektronische schoolbord", waarvoor de prijs werd toegekend wordt besproken in de vier artikelen van dit nummer.
Op deze pagina zijn afgedrukt de oorkonde, de considerans en een foto van de uitreiking.

CONSIDERANS

Mijns inziens kunnen vier belangrijke en aktuele elementen in het projekt worden onderkend.
In de eerste plaats een bijdrage aan het technisch wetenschappelijk probleem van de bandbreedtebeperking bij overdracht van informatie. Bij alle soorten van informatie is men al heel lang op zoek naar methoden om de overdracht tot de essentiële inhoud van de informatie te beperken. Dat is een zeer centraal probleem in de telecommunicatietechniek. In het TWIN projekt heeft men op zeer doeltreffende wijze de minimaal benodigde bandbreedte voor grafische communicatie toegepast.

In de tweede plaats het probleem van infrastruktuur en investering. Het is een uiterst belangrijke zaak om in de wereld van de materiële dingen die met veel moeite en kosten is opgebouwd de gedane investering zo breed en effektief mogelijk te benutten, respectievelijk een uitbreiding zo harmonisch mogelijk bij het bestaande te laten aansluiten. In dit projekt is een voorbeeld gegeven hoe men over de bestaande verbindingen en met de bestaande middelen nieuwe vormen van communicatie kan bedrijven. Zonder de geluidsoverdracht per kabel of radio te hinderen kan men daar een hoeveelheid "wordende" grafische informatie bijvoegen.

In de derde plaats is er het element van het samenwerkingsverband. Meer en meer zal de technische faciliteit voor de gemeenschap tot stand komen in een complex samenwerkingsverband van zeer verscheidene groepen. In dit projekt is op bewonderenswaardige wijze een voorbeeld gegeven hoe mensen die geografisch ver van elkaar verwijderd waren en mensen die qua discipline ver van elkaar afstonden zeer consistent en voortvarend kunnen samenwerken.

Als vierde element tenslotte de relatie tussen het technisch produkt en het maatschappelijk belang. Dit zeer aktuele onderwerp is hier inhoud gegeven niet door manifesten, toespraken of vergaderverslagen maar door werkelijk een stukje van het grote edukatieprobleem aan te pakken en er een duidelijk omlijnde oplossing voor te presenteren.

Oorkonde

behorende bij

GOUDEN VEDER MEDAILLE

door het Bestuur van de

STICHTING WETENSCHAPPELIJK RADIOFONDS VEDER

toegekend aan

TELECOMMUNICATIE WERKGROEP
INDONESIA-NEDERLAND

als blijk van waardering voor

"GEZAMENLIJK BETOOND INITIATIEF EN REALISATIEVERMOGEN TEN AANZIEN VAN EEN SYSTEEM VOOR GRAFISCHE COMMUNICATIE, DAT MET EENVOUDIGE MIDDELEN BINNEN BESTAANDE TELECOMMUNICATIESTELSELS KAN WORDEN UITGEVOERD."

Rotterdam, 17 juni 1973.

De Voorzitter:

De Bestuursleden:

THE ELECTRONIC BLACKBOARD

Ir. A. Kegel
Delft University of Technology

This introductory article is intended to give an over-all impression of the features of the electronic blackboard. The electronic blackboard is a graphic communications device which can be used within the framework of existing telecommunication systems. In particular, the electronic blackboard permits handwriting to be displayed on the screen of a normal TV set via an audio channel. After a historical survey of the development of this system and a brief description of its construction, some educational applications are given; special stress is placed on the low software costs. Applications in the fields of TV broadcasting, (medical) instrumentation, telephony and computer techniques are also mentioned.

1. HISTORY

It has so far proved impossible to introduce compulsory education throughout the Indonesian archipelago, with its vast extent (roughly 3000 x 1000 miles), its many islands and its great shortage of well qualified teachers. The Institute of Technology, Bandung (ITB), has been working for some time on the introduction of an economically feasible educational broadcasting system, which they see as a way out of this impasse.

During a meeting between Prof. I. Alisjahbana (ITB) and Prof. J.L. Bordewijk (Delft University of Technology = DUT) in Bandung in November 1968, this idea was further worked out. It was concluded that school radio alone is not enough, while school television will be too expensive for many years in the absence of a national TV broadcasting network. A broadcasting satellite, which is technically the best solution for such an island state, is also financially out of the question at present. The meeting resulted in a provisional agreement, where the development of an educational broadcasting system formed one of the topics to be dealt with in a cooperative development programme to be set up between Indonesian and Dutch technological universities.

The coordination and financial supervision of this project have since come into the hands of NUFFIC (Netherlands Universities' Foundation for International Cooperation) and CICA (Committee for International Cooperation Activities), Delft.

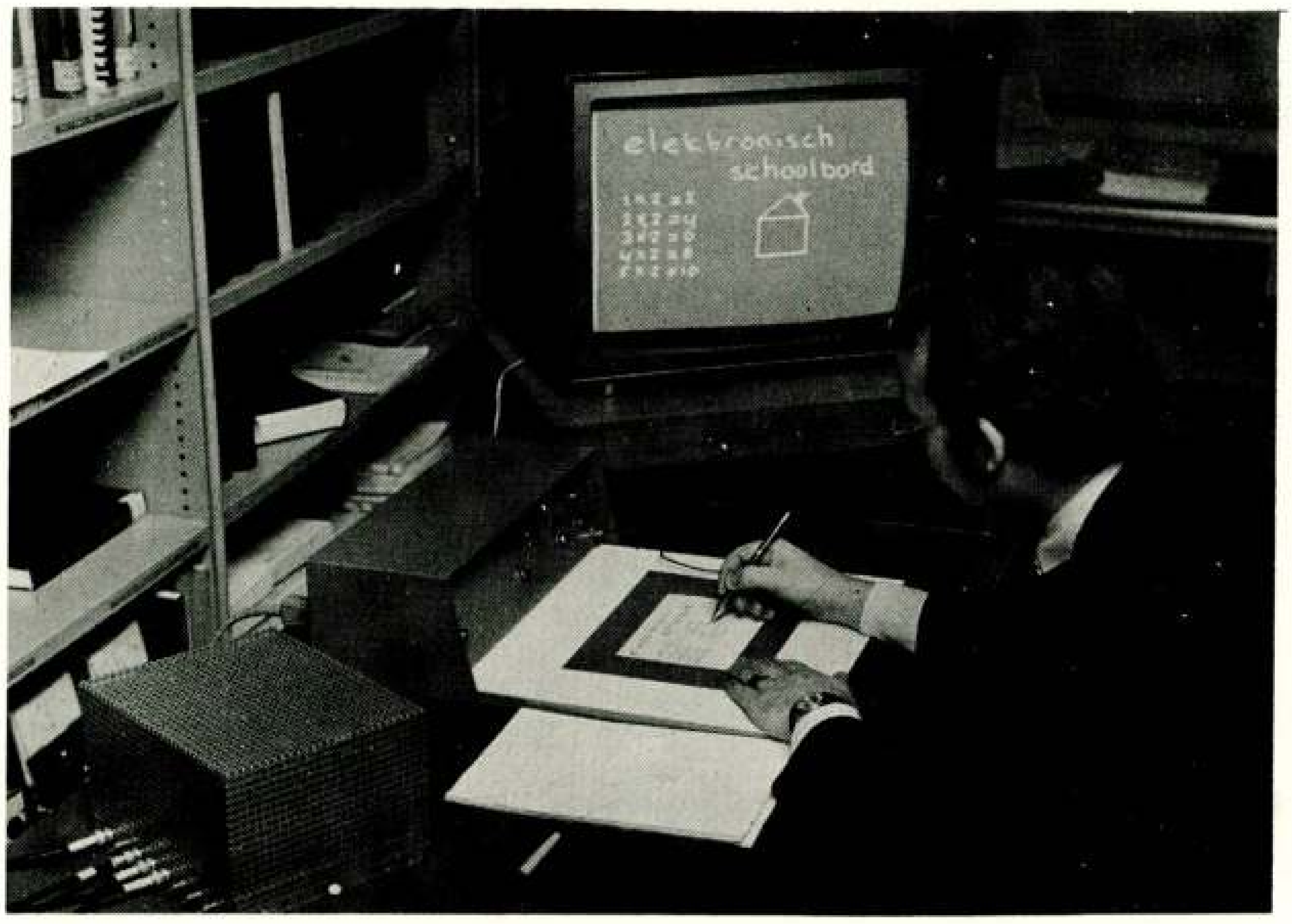

Fig. 1. Preparing a lesson on the electronic blackboard.

A year after this provisional agreement had been made, two students from Delft, D. Los and J.J. Koudstaal, put forward the idea of bridging the gap between school radio and school TV by complementing school radio broadcasts with images restricted to handwriting and line drawings, which required such limited bandwidth that they could be transmitted via the sound broadcasting network.

After a study of existing systems and technical developments, the Telecommunications Working group Indonesia-Netherlands (TWIN), which was set up to deal with this task, decided to try to develop a system themselves which would satisfy quite strict requirements as regards price, simplicity of operation and robustness. The working group arrived at the system described in this article, which they consider to be a reasonable solution to this problem.

The system was demonstrated to President Suharto during an exhibition in Jakarta in November 1971. The president displayed a very positive attitude towards the development of the electronic blackboard.

The first teaching experiments took place in Holland on 13 March 1972. The headmaster of a primary school in Zevenhuizen gave a number of arithmetic lessons to pupils of his 6th grade from a studio in Delft University of Technology, 8 miles away as the crow flies. A 300-watt FM transmitter was loaned by Philips' Telecommunication Industries Hilversum for this purpose, and was adjusted for these trial broadcasts by post-office engineers. This first experiment demonstrated the usefulness of the electronic blackboard.

A year later (in March, April and May of 1973) a second experiment on a wider scale was carried out in the Dutch province of Friesland; 20 schools took part. Ten lessons, each 20 minutes long, on Frisian culture and the Frisian language were broadcast. This experiment was also a success, and the experience gained could be used for further development of the system. A broadcast experiment in Indonesia and a number of broadcast and closed-circuit experiments in Holland are planned for the near future.

2. SYSTEM CONSTRUCTION

The block diagram of the electronic blackboard is shown in fig. 2. The writing tablet is shown on the left in this figure. The user writes on a normal sheet of paper on this tablet with a normal-looking ball-point pen which is connected to the tablet by a flexible cable. The "pen" is in fact a receiver which picks up a signal transmitted through the paper. With the aid of the signal received by the pen, the position of the latter during writing can be defined by two coordinate voltages. With an analog output, normal writing requires a bandwidth of about 15 Hz for each coordinate signal. With a digital output and time coding (PCM), the upper limit of the data rate is about 1000 bit/s. By making use of positional coding and a suitable buffer system, the data rate can be reduced to 300 bit/s and maybe even to 200 bit/s without giving an impermissibly large delay of the output with respect to the spoken text.

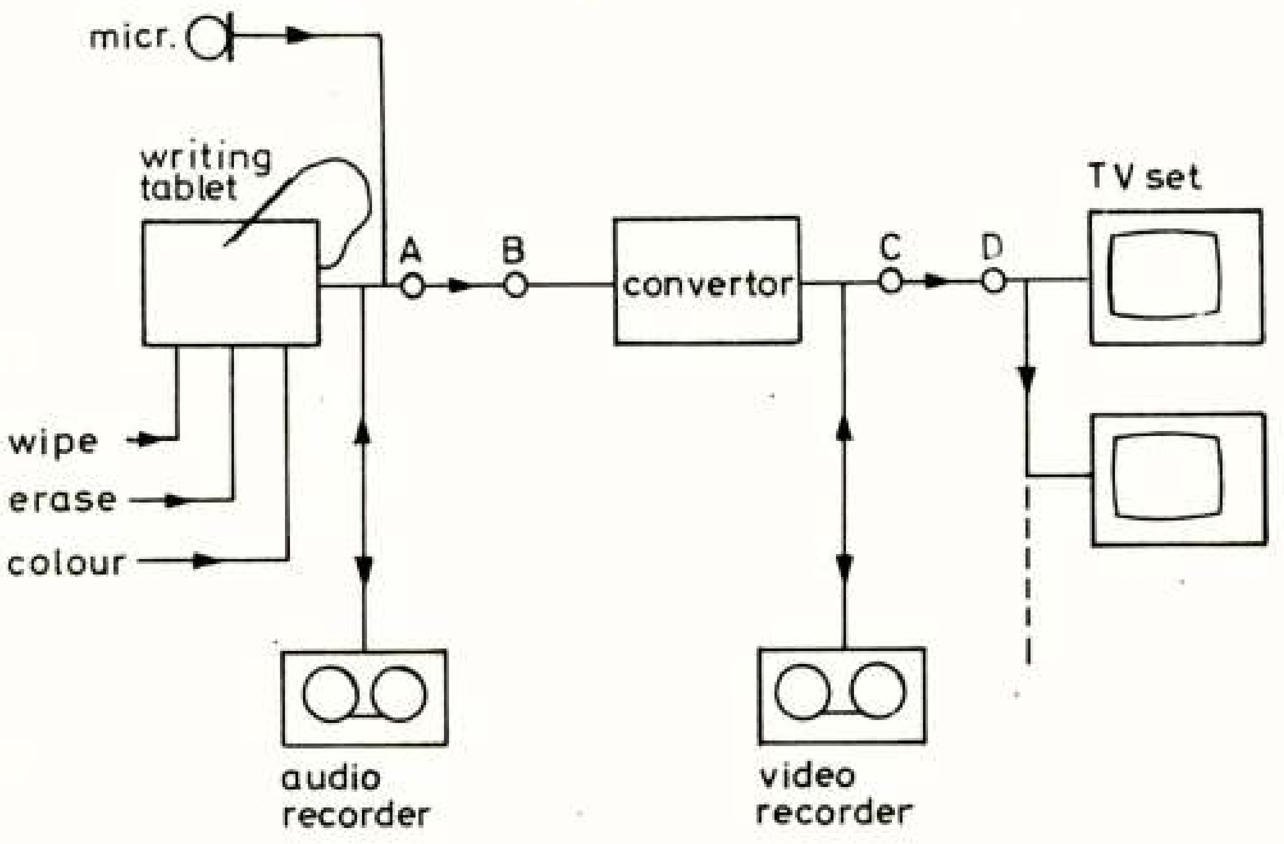

Fig. 2. Block diagram of the electronic blackboard system.

The writing tablet is connected via audio channel A-B with the converter, which transforms the output of the tablet into a video signal complying with CCIR standards. This video signal, together with the accompanying sound signal, is passed to a normal TV channel in the VHF or UHF band. Via the TV channel C-D the output of the converter is transmitted to the antenna input of a normal TV receiver. The choice of a TV screen as display is based on the arguments of low price, high light yield, low energy consumption an commercial availability.

A memory is essential for the conversion process, since each 1/25 second the screen of the TV receiver must reproduce a complete picture of all positions occupied by the pen tip since the writing started.

It is important to note that of the roughly 300.000 possible image points present on the TV screen, at most 2% are used for line drawings or handwriting. Thanks to the use of suitable coding and interpolation, a memory capacity of about 30 K bit has proved sufficient.

The nature of the memory makes it possible to erase part or all of the image and to build the image up of different colours, by means of simple commands from the transmitter side. When a colour receiver is used, the image can be literally multi-coloured; with a black-and-white receiver, colour differences can be suggested by lines of different shades varying from very light grey to black.

The low bandwidth of the writing signal has led to the development of a modem (modulator-demodulator), which can be used together with a system of differential phase-shift keying (DPSK) to record the writing information on one of the tracks of a simple audio cassette recorder. The other track is used for the sound recording.

This makes it posssible to produce programmes without synchronization problems caused by stopping or erasing the tape, or by re-takes of certain scenes. After the audio tape has been completed, the whole programme can be recorded on a video tape via the converter, if desired.

3. APPLICATIONS

The most striking feature of the electronic blackboard system is the low cost of making programmes with this system. The only persons involved in the production of an educational programme are the text reader, the person who writes and makes the drawings, a stage manager and an audio technician. Problems associated with decor, lighting or shooting of the scene do not arise.

Fig. 3. Recording a lesson intended for local transmission in the Dutch province of Friesland.

For broadcasting applications, the cable link A-B is replaced by a radio link. In FM transmitters, one of the store-casting channels above the stereo base-band is the suitable channel for the image transmission. In medium-wave or short-wave transmitters, one suitable multiplex method is to use PM for the image and AM for the sound. It goes without saying that the rate should be sufficiently low if transmission via the ionosphere is used. This is yet another reason for finding a suitable source coding technique for the writing information. This is also of importance if the image and sound are transmitted simultaneously via a telephone circuit instead of by a radio link.

For local broadcasts, the link C-D is broken and a TV transmitter is used. In this connection, the audio channel A-B can be used for the transmission of programmes from distant audio studios (up to e.g. 1000 miles away) to the TV transmitter.

In this section we shall mention, in addition to educational applications, some applications from the fields of TV broadcasting, studio techniques, instrumentation, telephony and computer techniques {4}.

3.1. Education

Apart from the broadcasting of educational programmes via AM and FM transmitters in various frequency bands, it is also possible to broadcast programmes via satellites. Use of the entire transmitter power and the entire available bandwidth for the transmission of a narrow-band "scribosony" (combined writing and sound) signal can permit the use of receiver antennae of small dimensions (e.g. 50 cm ϕ).

Another interesting possibility is the multiple use of a TV transmitter. The image part of a normal standard video signal has enough room for about 30 scribosony signals. If time-multiplex code modulation is used, these signals can be transmitted at the same time without modification to the existing TV transmitters.

Apart from the broadcasting applications considered so far, the electronic blackboard can also be very useful for closed-circuit applications within the school building or classroom. One possibility is to give a group of pupils a writing tablet each, in addition to the one for the teacher, so that they could all write messages for display on the TV screen. Such a set-up could be used e.g. for scribosony "brainstorming" sessions, where the whole process can be recorded with a cassette recorder for play-back later.
Another possible application is in the field of programmed instruction and self-study. The combination of written and audio-visual presentation can help to make self-study courses for e.g. adults more attractive and effective too.

3.3. (Medical) instrumentation

The combination of a converter and a TV receiver forms a "memoscope" with the special features of partial erasure and colour presentation. This can be very useful, e.g. for the display of cardiograms.

Another interesting application is the control of tools or other equipment by indicating the point of interest on a drawing placed on the writing tablet. Suitable modification of the writing tablet would make it possible to carry out coordinate transformations in this way. This last-mentioned possibility is at present being used for point-by-point scanning of the sensitivity of the retina.

3.4. Telephony

The narrow bandwidth makes it possible to transmit speech and writing together over one telephone channel. This makes such applications possible as scriptophones, girophones (transmission of signatures to authorize payments, etc.), telecopy or data display.

Teleboard	Short-wave or FM broacasting Multiple use of TV transmitter (e.g. 30 channels) Singel channel satellite and small receiver antenna
Electronic blackboard	Programmed instruction (with audio cassettes) Collective writing on TV screen (brain storming) Self-study
TV broadcasting	Writing, drawing or erasing in TV images Subscripts at will Time-tables, news
Telephone	Scriptophone Girophone (for signatures) Telecopy
(Medical) instrumentation	Memoscope Cardiography Retina sensitivity test
Computer	Man-machine interface

Fig. 4. Survey of applications of the electronic blackboard system.

3.2. TV broadcasting and studio techniques

A need is often felt to mark existing TV images (both live and recorded on video tape). This can be done with the aid of the electronic blackboard system, by adding the image output of the converter to the video signal to be marked. This provides a simple method of writing words or drawing pictures on a TV image, and of erasing parts of the image if desired.

A recent topic of discussion is the possibility of transmitting all kinds of information via the sync and blanking intervals of the video signal. The memory in the converter of the electronic blackboard makes it possible to store this relatively slow information flux, and to play it back later at any desired moment. This provides a simple means for flexible sub-titling, services for deaf people, electronic time-tables and "stop-press" TV news.

3.5. Computer techniques

One possible kind of coupling between man and machine is provided by using the writing tablet for input of hand-written or drawn information in the computer. The output can be displayed on the TV screen with the aid of the converter. Since the converter stores the information for one complete TV image, the load on the computer memory is reduced.

4. TEAMWORK

The electronic blackboard was produced in response to the recognition of a social need. Many persons have made a contribution to the technical development of the system.

Moreover, many teachers have helped to extend its applicability. It goes without saying that the development team would be most grateful for suggestions concerning further applications.

A system like that described in this paper cannot be produced today without close teamwork. The author therefore feels obliged to mention that the electronic blackboard in its present form was realized with the aid of the following persons:

Institute of Technology,Bandung:
Prof.dr.-ing. I. Alisjahbana, Ir. Darminto Tjitrokusumo, Ir. Ketut Karsa.
Delft University of Technology:
J.H. Bons, Prof.dr.ir. J.L. Bordewijk, R. Hak, F. van 't Hof, Ir. A. Kegel, C.M. v.d. Knaap, Ir. J.J. Koudstaal, Ir. A.S.T. Kruijf, D. Los, Ir. L.R. Nieuwkerk, W.C. van Spronsen, P.J. Tanis, C.P.J. Wester.
Utrecht University: Dr. H.S. Verduin-Muller.

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4) "Scribosony" developments in the Netherlands, to be published in "Communication for EBU-working party S".
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7) C.P.J. Wester, Tape Recording of Scribosonic Signals, Tijdschrift van het NERG, this issue.

Lecture held on June 19th 1973 at the Delft University of Technology, Department of Electrical Engineering, at meeting no. 231.

A WRITING TABLET FOR CONVERTING CURRENT HANDWRITING INTO ELECTRICAL SIGNALS

Ir. L.R. Nieuwkerk
Delft University of Technology

A writing tablet designed for "Electronic Blackboard" and "Writing Telephone" purposes and consisting of two mutually orthogonal printed wiregatings capacitively coupled with an almost normal ball-point is described. An interpolation mechanism ensures a better than 1 $^{o}/_{oo}$ accuracy in measuring the position of the pen.

INTRODUCTION

The transmission of handwriting or drawing can best be done, from a bandwidth point of view, by transferring the coordinates (x,y) of the position of the pen with which is written. The frequency content of the coordinate or writing signals $x(t)$ and $y(t)$ lies below 15 Hz {1} and is essentially limited by the dynamical characteristics of the human body. Due to the narrow bandwidth of the writing signals, it is possible to transmit the writingsignals together with the eventual corresponding audiosignals over an audiocircuit.

The coordinate signals can be generated by means of a writing tablet. Writing tablets are a.o. in use as peripherical equipment to computers and are used as a graphical information input to a computer. If one has to design a writing tablet for purposes of an "Electronic Blackboard System" or "Writing Telephone" the tablet should be cheap, easy in operation and reliable. The first two requirements are not entirely met by most of the existing equipment.

The conversion of the pen-coordinates into electrical signals can be done mechanically, optically, acoustically and electrically or by a combination of these. The mechanical converters known are the "XY-mouse" {2} and the "Electrowriter" {3}, the latter of which makes use of a pantograph. An optical system,the so called lightpen {2},optically detects the passing of the light-spot writing a frame on a cathode ray-tube. The position of the lightpen is determined by the time elapsing between the beginning of the frame and the passing of the light-spot along the lightpen (detector). Recent publications by Siemens {4} and Bell Laboratories {5} mentioned the use of the propagation of sound waves in a plate for the generation of the pencoordinate signals. In the first system a tablet of piëzo-electric material is activated on the edges by sound pulses and the moving voltage-front generated in the material is capacitively detected by a pen, whereas in the second system the tablet is activated by the pen, by means of sound pulses, and the sound-fronts are detected on the edges with the aid of bar-shaped microphones. Also in these cases the coordinates can be determined from the time interval elapsing between the start and the detection of the pulse.

The detection of electric fields generated on the writing tablet can take place conductively, capacitively and inductively. In the conductive case {2} the writing surface generally consists of resistance material, connected to a voltage-source. The magnitude of the voltage detected by the pen is a measure for the location on the tablet. The great disadvantage of the conductive method is that it is not possible to put a normal sheet of paper on the tablet. By applying a source of alternating voltage, it is possible to detect capacitively; however, the magnitude of the detected voltage depends on the thickness of the sheet of paper to be laid on the tablet. When using the writing tablet for the transmission of handwriting, this is a drawback. All the systems here described have their pros and cons. In the case of the "Electronic Blackboard System" or "Writing Telephone" it is rather unhandy to work with the mechanical converters, and then there is the hinderance of parallax in the optical method, and the vulnerability possible in the acoustical methods. In the following paragraphs the design of a simple and ruggedised writing tablet is described which has turned out to be adequate for the transmission of handwriting.

PRINCIPLE OF OPERATION OF THE TABLET

The writing tablet consists of a non-conducting plate on which a number of "horizontal" and "vertical" wires are placed. These wires are isolated with respect to each other and connected to shift-registers (see fig. 1). The shift-registers are clock-controlled. At the first stroke of the clock on the input of the first shift-register a pulse is fed in, which at the same time activates the

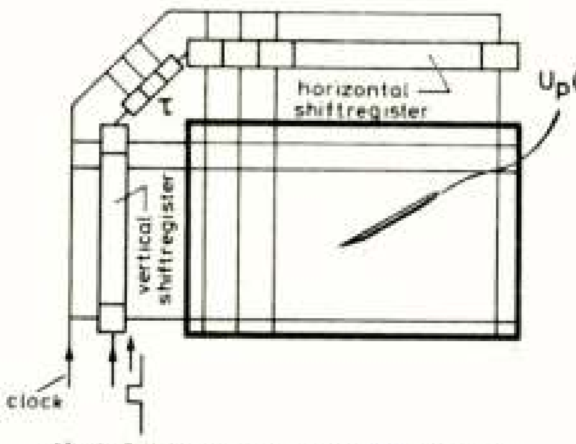

fig.1 Schematic representation of the writing tablet

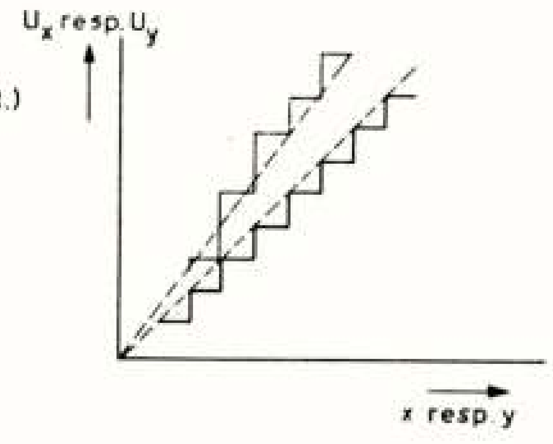

fig.2 x resp. y co-ordinate signal as a function of the position of the pen

first horizontal wire.
At a following stroke of the clock-generator, the pulse in the shift-register is shifted to the next element of the shift-register and then appears on the second wire. After thus activating sequentially the horizontal wires, the vertical set of wires is activated sequentially thus concluding the first clockcycle. A pen, capable of detecting the electric or magnetic field caused by an activated wire, in any given position (x,y) on the tablet will detect a pulse twice in one cycle; the first time at the moment the horizontal wire under the pen is activated.

The first pulse in a cycle detected by the pen resets a flip-flop that was set at the beginning of the cycle. In this manner in a series of cycles a pulse-width modulated train of pulses is obtained when the pen is moving vertically. The width of the pulses and therefore by constant height their d.c. component is a measure for the position of the pen in vertical (y) direction. The second pulse in a cycle, detected by the pen, is used for measuring the position in horizontal (x) direction. The set-pulse for the horizontal direction is derived from the first element of the shift-register connected with the vertical wires. As the number of wires must be limited (horizontally 56, vertically 80), the coordinate signals obtained are quantized. The maximum number of levels of the coordinate signals is equal to the number of wires of the corresponding direction related to.

A wiregrating as described is a.o. used in the "RAND TABLET" {6}. In order to obtain a good resolution (small quantization errors) 100 wires per inch have been applied to the writing tablet. Each wire carries a unique code by which the position of the detecting pen on the tablet can be determined. The manufacturing of such fine wiregratings might be difficult and the necessarily thin writing surface vulnerable.

It is wellknown that the resolution also may be improved by interpolation between two wires. In {7} a method is described in which, instead of one pulse, a series of five pulses with a pulse duration of twice the clock-period is fed into the shift-registers. The basic frequencies of two adjacent wires at the moment the series of pulses pass, have a "phase" difference of $\pi/2$. The pen detects the presence of a pulse (course information) and the phase information relating to the position of the pen between two wires. The relation between the pen-position between 2 wires and the phase detected is non-linear, but can be compensated for.
In {8} another method related to {7} is described.
In the following paragraph an alternative interpolation method is introduced, which is principally linear and of great simplicity.

THE INTERPOLATION

In fig. 3 a cross-section of the tablet is drawn in such a way that the wires on the tablet are perpendicular to the drawing. The figure has been drawn for the case that the n-th wire at a distance of x_n = na from the origin is activated. The remaining wires are earthed. In fig. 4 the output signal $u_p(x)$ of the pen has been

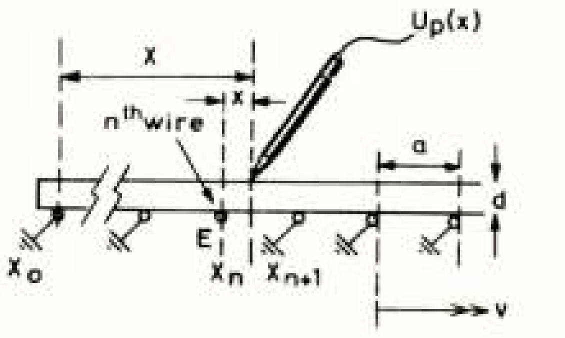

fig.3 Cross-section of the tablet

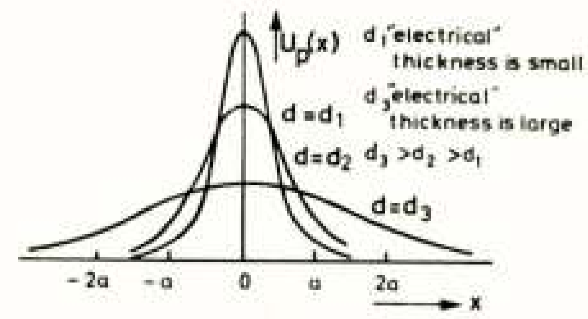

fig.4 Pensignal as a function of the distance x between the pen and the activated wire

drawn as a function of the displacement x with respect to the activated wire. The "electric" thickness d of the dielectricum is thereby taken as parameter.

The thinner the tablet or the lower the dielectrical constant, the "sharper" the $U_p(x)$ function. Moreover the $U_p(x)$ function is determined by the shape and the construction of the pen (parasitical capacities) and the thickness of the wires of the tablet; the funcion however will always be symmetrical around x=o and maximal at x=o, if we take care to provide for a sufficient number of matching wires at the edges of the tablet.

In order to understand the interpolation principle, consider the case where the wiregrating moves at a constant speed in the direction indicated by the arrow v in fig. 3 and that now x_o is the activated wire instead of x_n. Also assume that on both sides of the wire x_o there are wires. The expression of the pensignal then becomes $U_p\ (x_n+x-vt)$. In fig. 5 the pensignal $U_p(t)$ is represented as a time function with the position of the pen on the tablet as the parameter. If the wiregrating moves at a constant speed v, there is a linear relation between the time the pulse reaches the pen and the position of the pen. The spectrum of $U_p(t)$ is represented in fig. 6. As the capacitance between pen and wire increases monotonously reaches a flat maximum and decreases monotonously again the time-signal is bell-shaped. The spectrum will also be bell-shaped and by proper design it is possible to obtain a Fourier spectrum that is sufficiently bandlimited.

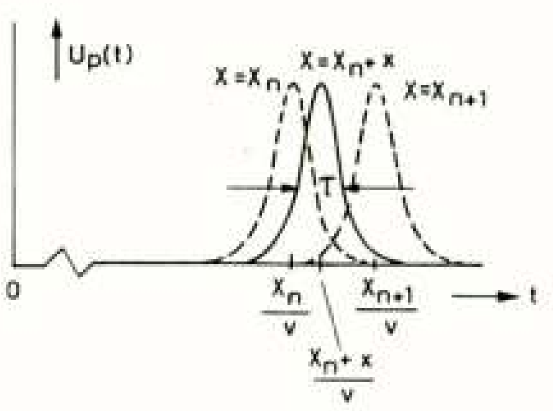

fig.5 Pensignal when wiregrating is moving at a constant speed v

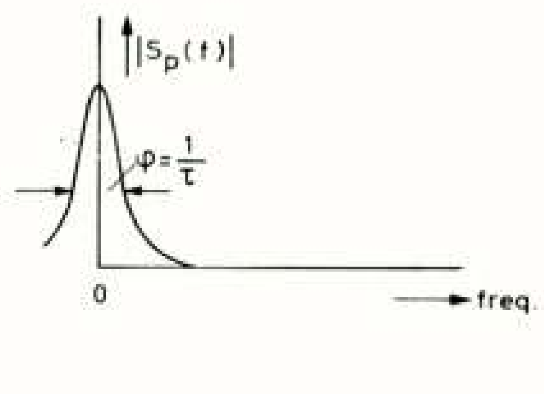

fig.6 Spectrum of the signal as drawn in fig.5

According to the Fourier-analysis for these non-oscillatory functions the width of the spectrum will relate to the width of the time-signal according to $\phi\tau = 1$, if we define τ and ϕ as the average function widths of s(f) and U(t). As for a practical realization the movements of the pen have to be followed, the wiregrating ought to move along the pen ever again. Should this occur periodically, the spectrum (fig. 6) will consist of a line spectrum with the spectrum lines at the distances $f_1 = 1/T_{per}$, in which T_{per} is the period time (practically $f_1 << \frac{1}{\tau}$) and in which $|s_p(f)|$ is the envelope of the line spectrum.

When the pensignal $U_p(t)$ is sampled according to Shannon's theorem, the sample frequency f_s ought to be twice the highest frequency occurring in the pensignal; then the original pensignal can be regained from the sampled signal. Satisfying the sampling theorem means no overlap in the spectrum (see fig. 7), so that the original signal can be registered by filtering.

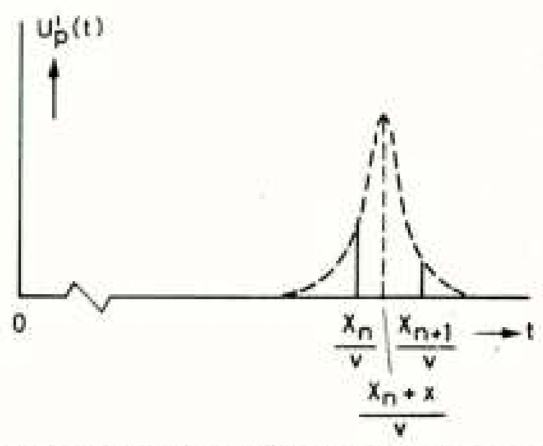

fig.7 Sampled pensignal when wiregrating is moving at a constand speed v

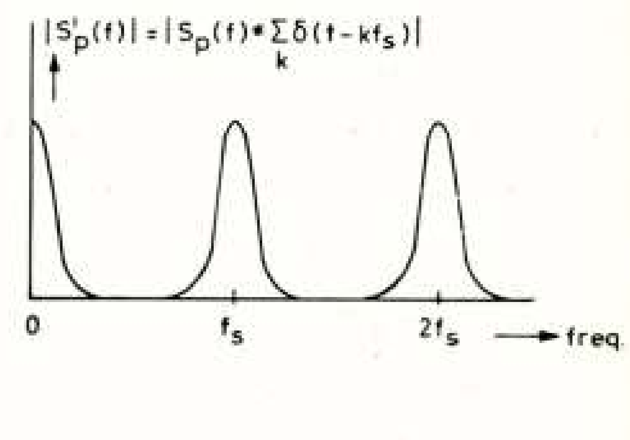

fig.8 Spectrum of the signal as drawn in fig.7

When the sampled signal is supplied to a holding circuit the spectrum of the sampled signal is multiplied by si $(\pi f/f_s)$ (si (x) = sin x/x) in which f_s is the sampling frequency. So:

$S''_p(f) = \{ S_p(f) * \sum_k S(f-kf_s) \}.\ si\ (\pi f/f_s)$, in this $S''_p(f)$ is the spectrum of the "sample-and-hold" signal, $S_p(f)$ is the spectrum of the pensignal with moving wiregrating and f_s is the sampling frequency.

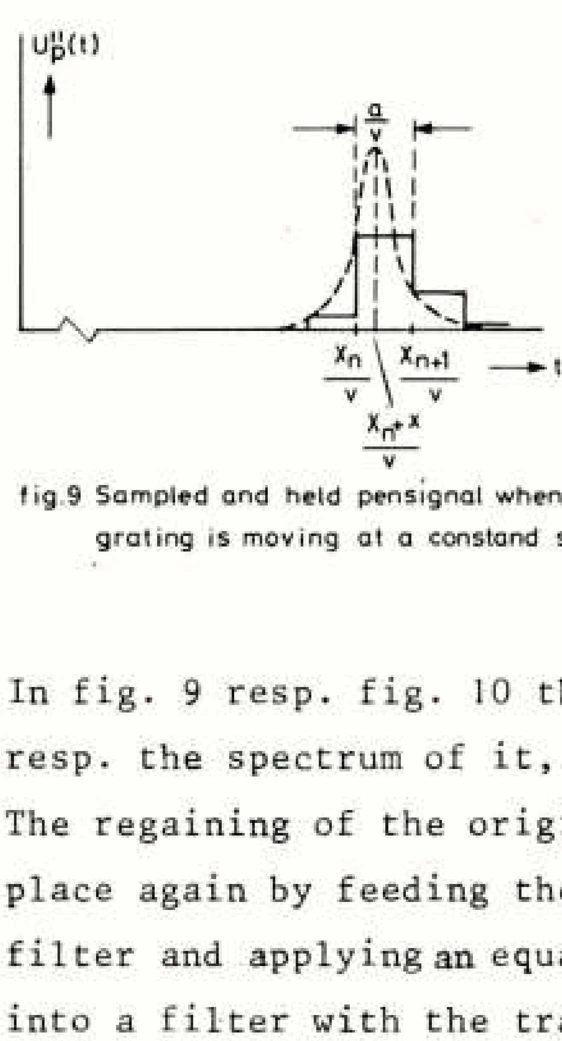

fig.9 Sampled and held pensignal when wiregrating is moving at a constand speed v

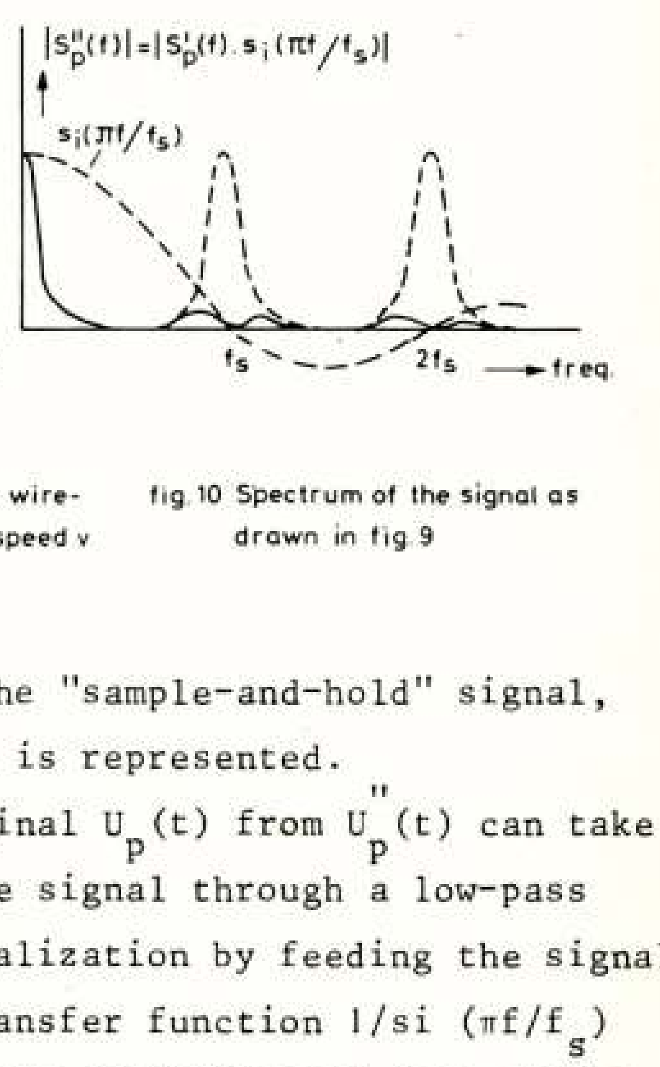

fig.10 Spectrum of the signal as drawn in fig.9

In fig. 9 resp. fig. 10 the "sample-and-hold" signal, resp. the spectrum of it, is represented.
The regaining of the original $U_p(t)$ from $U''_p(t)$ can take place again by feeding the signal through a low-pass filter and applying an equalization by feeding the signal into a filter with the transfer function 1/si $(\pi f/f_s)$ for $f< f_s$. This operation is admissible as long as the demands of the sampling theorem are met. In fig. 9 the signal has been drawn for the case the sample frequency is f_s=v/a (v is the velocity of the wiregrating and a is the distance between two adjacent wires).
The signal described can be obtained in a simpler manner by fixing the wiregrating to the table and connecting the wires of the gratings to the elements of a shift-register controlled by a clock with a frequency $f_k=f_s$ as described in the second part of this article (fig.1). The value of $f_s=f_k$ must be chosen sufficiently high in order to be able to convert the quickest movements of the pen into electrical signals.

REALIZATION

By carefully choosing the design parameters of which the most important are the "electric" thickness of the tablet and the distance between the wires, i.e. by choosing such a function of $U_p(x)$ that after the quasi-sampling and holding-operation there is no overlap in the spectra, it is possible to generate an output-signal of the tablet for which the d.c. component is proportional to the displacement of the pen.

In fig. 11 a block-diagram showing the operation of the writing tablet has been drawn. As the x and y coordinates are generated in an identical manner, the block-diagram has been restricted to the measurement of one coordinate signal only. Directly based on the "sampling theorem" the circuitry is of astonishing simplicity. The signal picked up by the pen is sent through a low-pass filter in order to get the desired lower frequency part of the spectrum only. The compensation with the transfer function $1/si(\pi f/f_s)$ is hardly necessary, because the value of the correction factor at $f=f_s/2$ is only $2/\pi$. After the signal has been differentiated a zero crossing detector determines the zero crossing of the signal after differentiation and supplies the reset-signal for the flip-flop which received a set-signal at the moment the first wire was activated. The signal pulsewidth modulated by the displacement of the pen can now be fed into a second low-pass filter in order to regain the coordinate-signals. From a physiological point of view the bandwidth of this second low-pass filter can be limited to about 15 Hz.

A digital coordinate-signal can simply be obtained by feeding the pulsewidth modulated-signal from the flip-flop drawn in fig. 11, together with a clock-signal with a sufficiently high frequency into an and-gate.

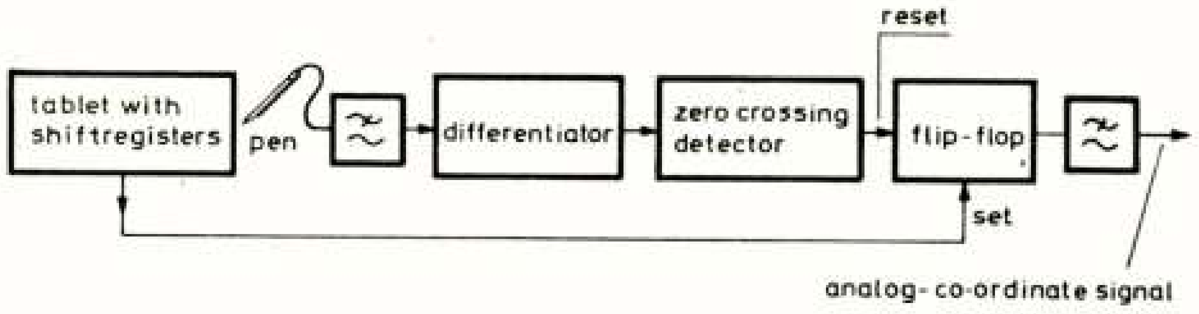

fig.11 Blockdiagram of the writing tablet

The output of the and-gate is fed into a binary counter. If required, the parallel output of the binary information of the counter can be converted in series. The necessary low-pass filtering can now take place digitally.

In order to arrive at a reliable definition of the coordinates it is essential that the pen-signal be sufficiently high with respect to interfering signals. The pen-signal can be enlarged by deminishing the thickness of the dielectricum of the tablet. However, in this case the number of wires ought to be enlarged to satisfy the sampling theorem. Consequently a well-considered pen design is important. The sensitivity to interference can be improved considerably by applying a time-window. The output of the zero crossing-detector is therefore only connected to the reset input of the flip-flop when it is clear from the output signal of a special treshold-detector that the signal picked up by the pen is the desired one and not an interfering signal. A useful criterion can be derived from the difference in spectral content between the desired pen-signal and the interference.

Since 2 mutually orthogonal wiregratings are used and the upper grating slightly shields the underlying grating, the wires ought to be kept as thin as possible. As the gratings are mutually orthogonal, there is no interference between the two gratings in establishing the

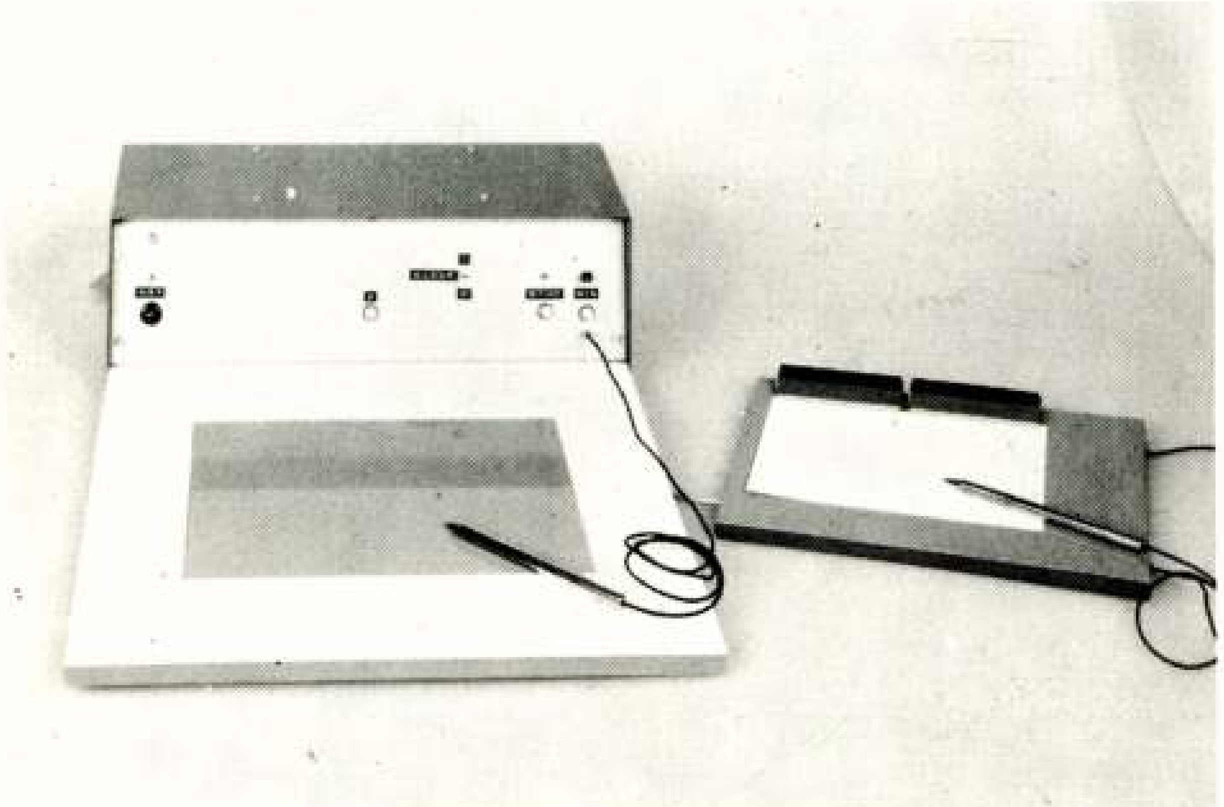

fig. 12. Tablet 1 and tablet 2.

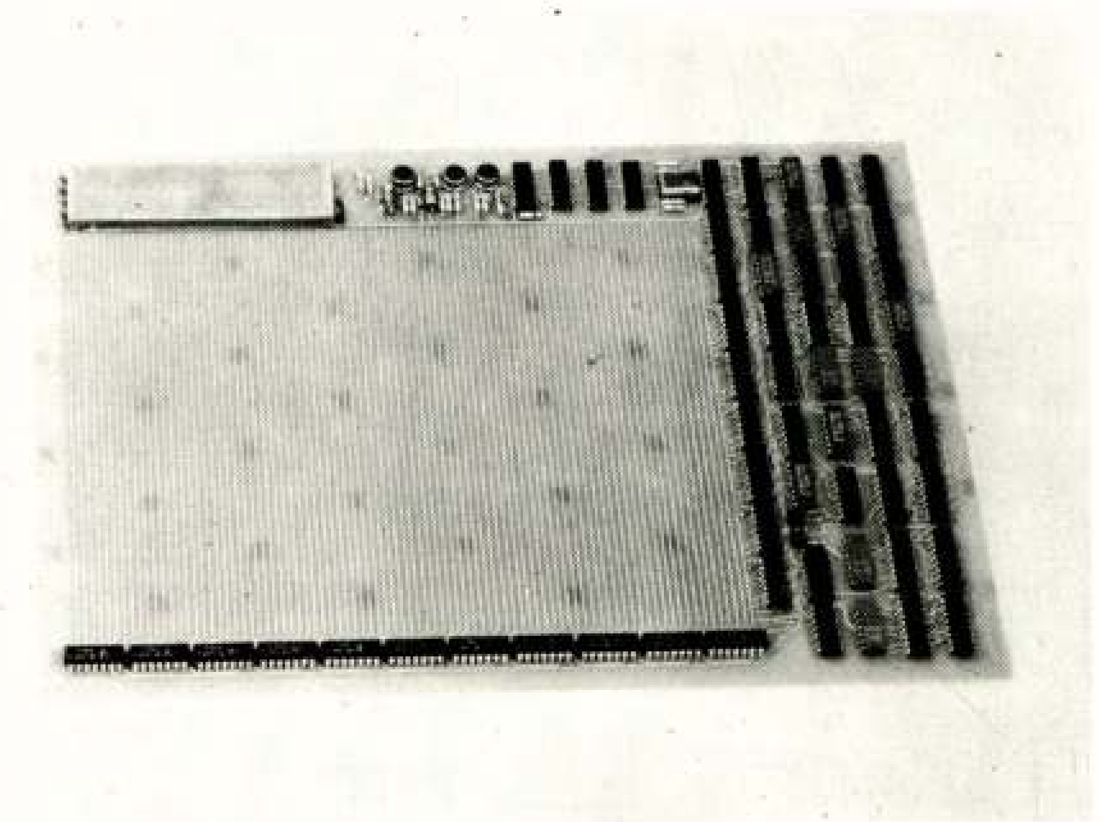

fig. 13. The assembled print of the small writing tablet.

position of the pen.

The wiregratings of the writing tablet, together with the wiring of the shift-registers in the case of the small tablet, are executed as one printed circuit, which makes it possible to manufacture the writing tablet easily and inexpensively. In table 1 some particulars of two different tablets are mentioned. The two tablets are shown in fig. 12 and the assembled print of the small writing tablet in fig. 13.

	Tablet 1	Tablet 2
Overall dimensions	45 x 55 x 15 cm	21 x 30, 5 x 4 cm
Dimensions of writing surface	A 4	A 5
Number of wires	56 hor., 80 vert.	58 hor., 83 vert.
Distance between the wires	4 mm	2,54 mm
Output	Analog	Digital (1000 bits/sec)
Scanning frequency	1,5 kHz	1,8 kHz

Table 1

Our experiences have shown that with careful construction an accuracy better than 1 o/oo over the total area of the tablet is attainable.

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ACKNOWLEDGEMENT

The author is indebted to Prof. Bordewijk for his suggestions and encouragement, to Mr v.d. Knaap for his intuitive approach of the interpolation mechanism and the realization of the analog version of the tablet, to Mr Tanis for the realization of the digital tablet and to Mr van 't Hof for his preliminary investigations.

Lecture held on June 19th 1973 at the Delft University of Technology, Department of Electrical Engineering, at meeting no. 231.

THE DISPLAY OF THE ELECTRONIC BLACKBOARD SYSTEM

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A description is given of the conversion of narrow-band handwriting signals from the writing tablet described by Nieuwkerk |2| into a video signal complying with CCIR standards. A memory unit plays an essential part in this process. Special attention is paid to the development of a simple, inexpensive coding system.

1. INTRODUCTION

The narrow-band transmission of handwriting (script) signals as described by Kegel |1| requires the presence of a display with a memory. The following devices come into consideration for this application:

a. memoscope
b. XY recorder
c. oscilloscope with external memory
d. TV receiver or TV monitor with external memory.

There would be little point in considering experimental display systems such as plasma layers, liquid crystals or diode mosaics within the framework of the article, since there is little prospect that such systems could be applied in practice in the near future.

In view of the fact that the display unit for the electronic blackboard system should be cheap and should also permit the use of classical teaching methods, d. is the obvious choice. It has the specific advantages:

1. low price of the TV receiver (Thanks to series production)
2. high light yield
3. relatively large picture
4. simple reproduction of sound
5. simple coupling with existing TV systems (transmitters, video recorders, etc.).

For reasons of economy, a MOS-FET shift register (which passes a complete picture to the TV receiver each 1/25 second) was chosen as the external memory.

The electronic blackboard system works with 625 lines and 512 possible image points on each line, making a total of about 300.000 image points. A typical line drawing or handwritten text only makes use of about 2% of the total number of image points. If a suitable coding system and interpolation are used, a memory capacity of 30kbit will be adequate for this application.

This type of memory makes it quite easy,with the aid of binary control signals from the transmitter, to modify the display in e.g. the following ways: clear the whole screen; clear part of the screen (e.g. the right-hand half, or the part to the right or left of a specified position); "rubbing out" a relatively small portion of the display for correction purposes; colour information (which may be provided by various shades of grey in black-and-white receivers).

Apart from the transmission equipment (FM, medium- or short-wave, telephone link, etc.), the TV receiver and the external memory, we need a "scanner" which converts the signals received (X and Y coordinate signals and control signals) into the image signal. We shall refer to the combination of the scanner, external memory and synchronization unit as the "converter". The audio channel of the TV receiver will be used for the reproduction of sound. It is a simple matter to connect several receivers to one converter.

For individual instruction, and possibly also for applications such as the "scriptophone" |1|, display unit c. (oscilloscope with external memory) would seem to be very suitable, largely because of its low price. A system using such a display is being developed at present; the size of the memory in this system is very appreciably reduced by means of special positional coding and analog interpolation.

2. SYSTEM DESIGN

A block diagram of the electronic blackboard in a closed-circuit version is shown in Fig. 1. On the left in this figure we see the writing tablet which has already been described by Nieuwkerk |2|, and on the right the TV receiver and the converter (the latter consisting of a

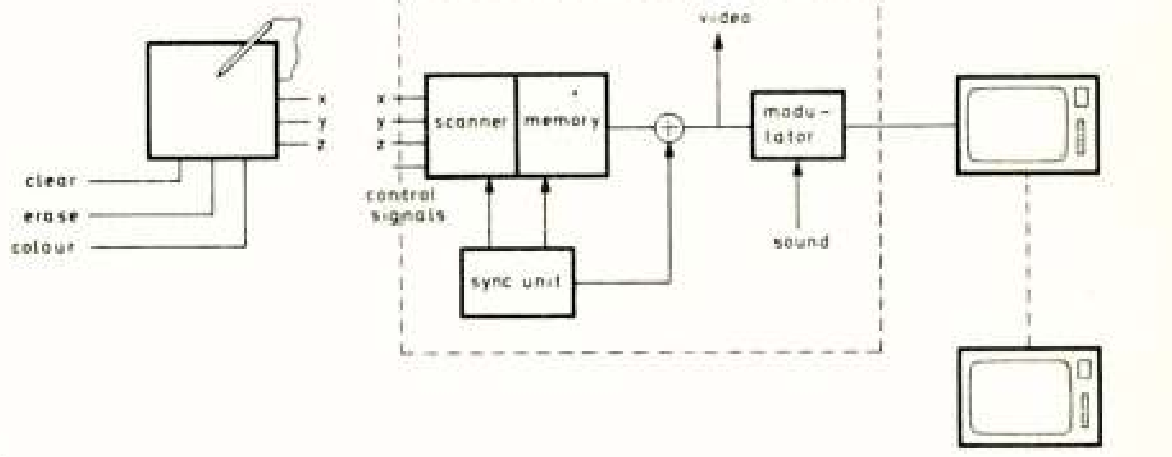

Fig. 1. Block diagram of the electronic blackboard system.

scanner which converts the X and Y coordinate signals and the control signals into the image signal, a memory in which this image signal can be stored and a sync unit which generates e.g. the frame, line and sync pulses for the control of the scanner and the memory). The memory delivers a complete image signal each 1/25 second, and this signal is combined with the total sync signal to give the video signal. The video signal is combined with the audio signal in a channel in the VHF or UHF band. It will be clear that several TV receivers can be used in combination with one converter.

3. PRINCIPLES OF OPERATION

In this section we shall discuss in turn how the scanner and the memory work.

a. Scanner

The block diagram of a scanner is shown in Fig. 2. It will be seen that this unit has two saw-tooth generators, the top one being triggered by the frame sync pulse (50 Hz) and the bottom one by the line sync

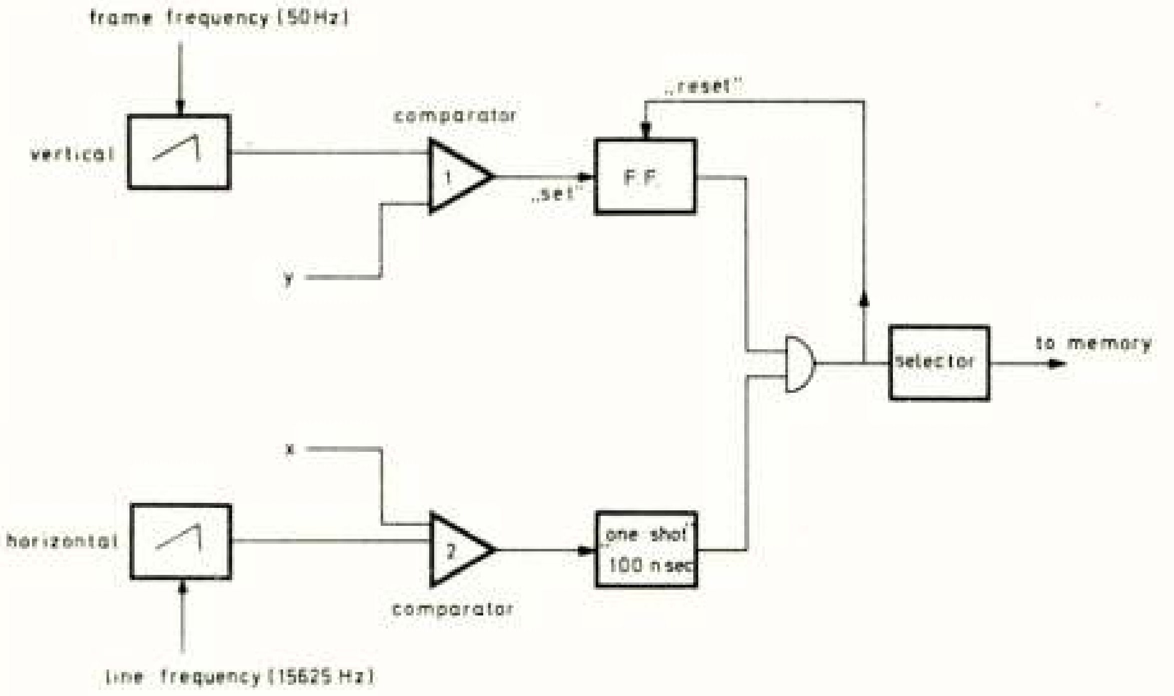

Fig. 2. Scanner

pulse (15.625 Hz). These saw-tooth voltages are thus synchronized with the horizontal and vertical deflection voltages respectively of the picture tube in the TV receiver. The incoming coordinate signals are now compared with the sawtooth voltages, with the aid of comparators 1 and 2. When the vertical saw-tooth voltage has the same amplitude as coordinate signal Y, comparator 1 will pass a "set" pulse to the flip-flop (FF), thus opening the AND gate. Similarly, comparator 2 passes a control pulse to the monostable multivibrator ("one-shot") when the horizontal saw-tooth voltage is equal to coordinate signal X. The one-shot then produces a pulse of length 100 ns, which passes the AND gate and then resets the flip-flop. If we add the output signal from the AND gate to the total sync signal and pass the result to a TV receiver, we will see a spot of light on the screen, which is situated on the right image line and at the right position along this line. The width of the spot can be adjusted by means of the one-shot. Changes in X and Y lead to corresponding changes in the position of the spot of light on the screen, so that this spot follows the movement of the pen over the writing tablet. The positional information is in fact passed to the memory before being displayed, via a selector which will be described below.

The circuit discribed above has the advantage of great simplicity, but the disadvantage that only 50 image points can be scanned per second: while the horizontal scanning rate is quite adequate, the vertical scanning frequency is only 50 Hz which means that only 50 vertical positions can be determined per second. The maximum permitted writing rate is thus low. An image line contains 512 points, which means that the writing of a horizontal line should be extended over 512/50 ≈ 10 seconds. If the line is written faster than this, it will appear on the screen as a broken line.

The system can be appreciably improved by speeding up the vertical scanning (see Fig. 3). The vertical

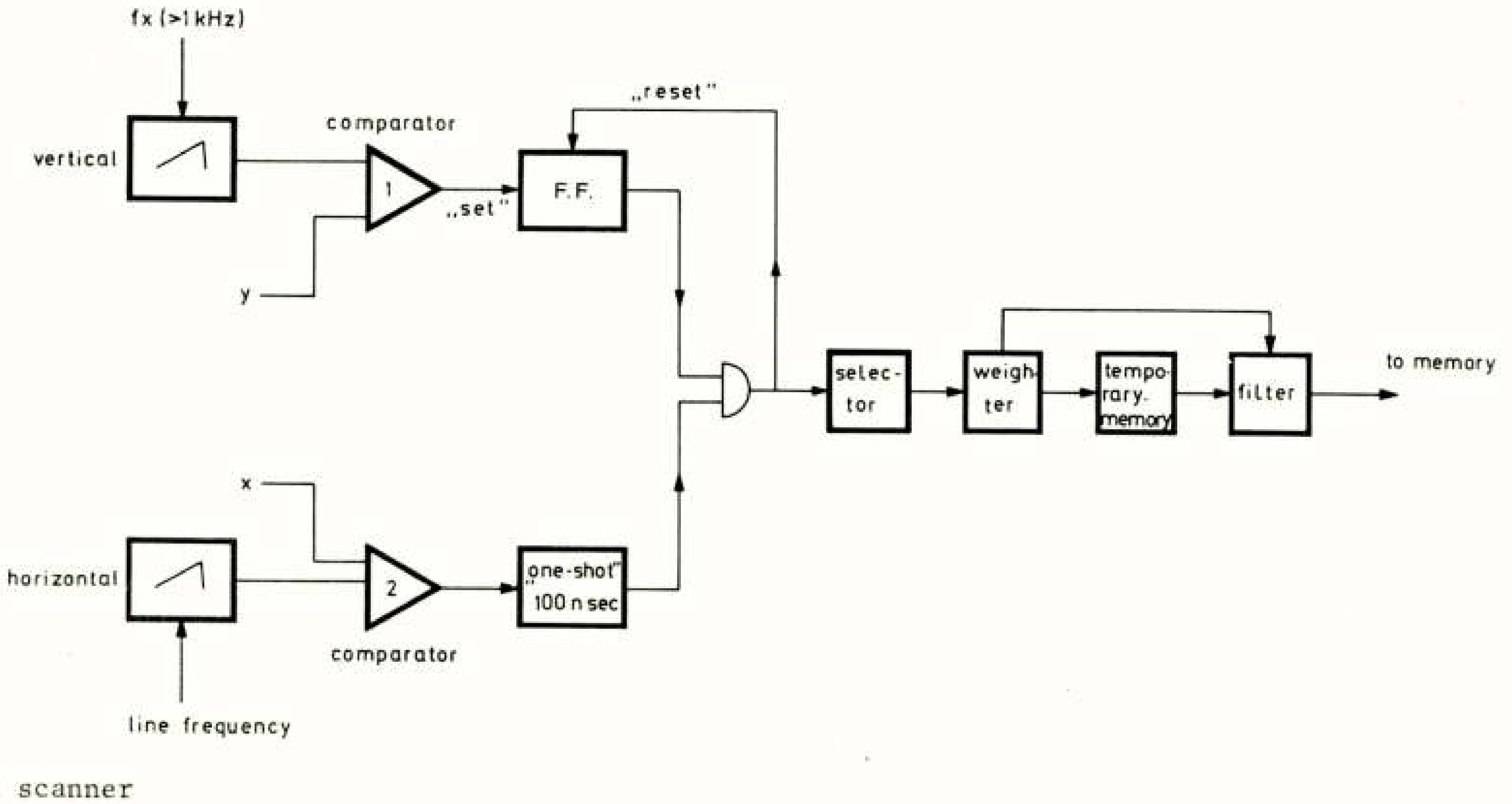

Fig. 3. Fast scanner

positions can now be found much more quickly, and after combination with the horizontal position, selection and weighting the information can be stored in a small temporary memory. This sytem makes use of the experimentally determined fact that the image points occurring during one frame period (20 ms) all lie quite close to one another (within a group of 32 image lines). This makes it possible to process the image information in two phases. In the first phase, the five least significant bits of every 9-bit word, used for storage of the vertical position, are compared with the corresponding five bits of a 9-bit counter which counts the line sync pulses. If these two sets of 5 bits are identical, the vertical position is combined with the horizontal position and passed to the temporary memory. This memory is designed so that the points stored in it appear at the output at intervals of 32 line periods; in other words, the position of the points is determined within a group of 32 image lines.

In the second phase, the right group of points is filtered through a "strip" the position of which is determined by absolute position of the last point determined (comparison of all 9 bits). Fig. 4 shows how this group of points appears on the monitor.

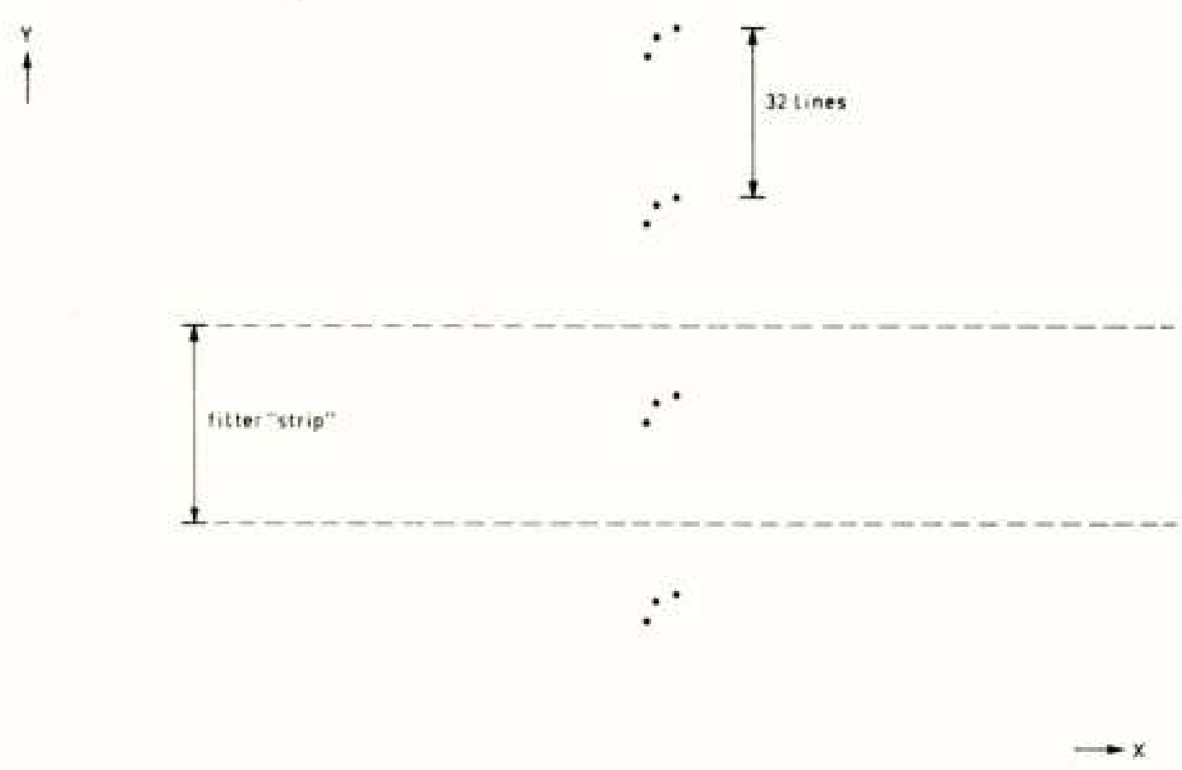

Fig. 4.

It will thus be clear that these positions are determined independently of the TV synchronization system. One group of points can now be processed in one frame period (20 ms). With this scanning method, 500 spots of light can be processed per second.

The selector

As we have already indicated the positions of the image points are quantized both horizontally and vertically. There are 625 lines, and the horizontal position along each line is also quantized; the memory in use at the moment can distinguish 512 possible positions. If we were now to reproduce a line making use of all possible image points, we would not get a very nice-looking result; this is illustrated in Fig. 5. Fig. 5a shows

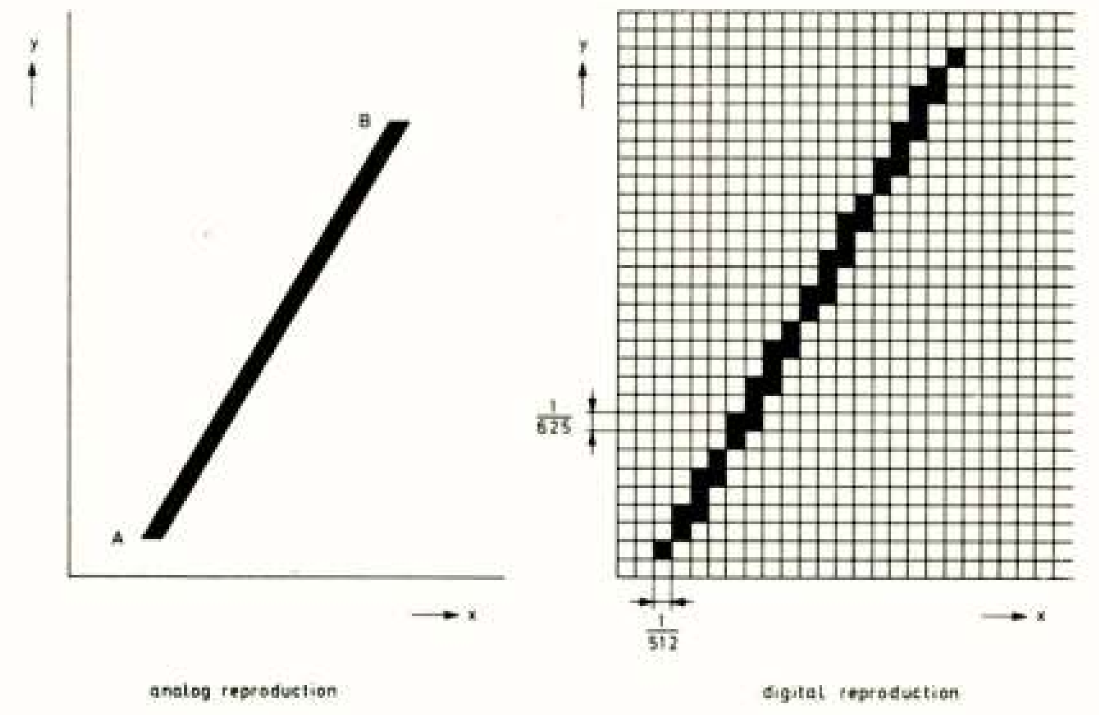

Fig. 5.

a line A, B reproduced by an analog display (no quantization), and Fig. 5b shows the same line reproduced with quantization of X and Y. In the latter case, each intersection of the line A, B with a rectangle (1/625 x 1/512) gives a point in the memory. The result is a jagged line; and, moreover, points are stored in the memory which do not give relevant information. The final effect is even worse if interference signals are present in X-Y information.

Better results are obtained if the points stored are selected first, in accordance with some suitable criteria. One possibility is, after one relevant point has been stored, to reject all points immediately adjacent to this (see Fig. 6) by means of a selector. The result of this type of selection is shown in Fig.7a. It will

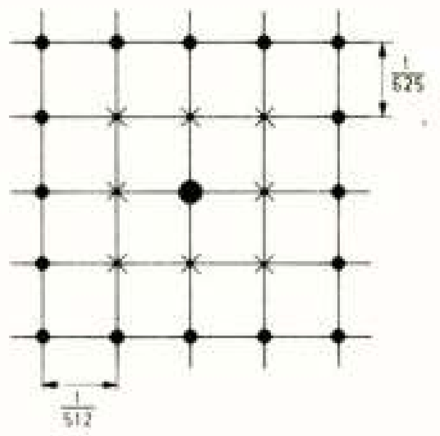

Fig. 6. Operating principle of the selector.

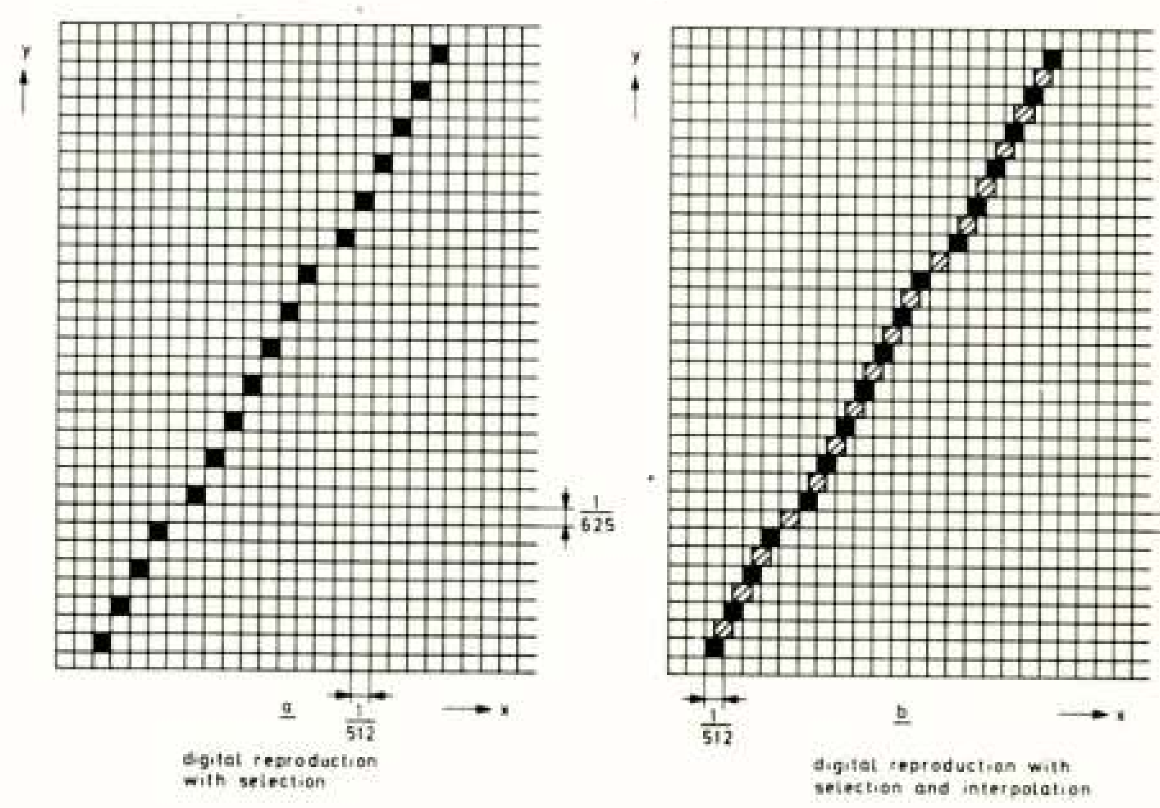

Fig. 7.

be seen that the line reproduced is indeed smoother, while this selection further gives a memory saving of at least a factor 2. In addition, the permissible writing rate is raised by a factor 2. The selector can be used in combination with both the simple and the fast scanner, so that the advantages of both systems are retained. During the read-out from the memory, the points which were omitted are reconstituted by linear interpolation. The result of selection and interpolation is shown in Fig. 7b.

The scanning method described above has been designed for use with analog narrow-band X and Y coordinate signals.

In case of digital transmission, selection can occur at the transmitter end, the selected points being coded in a special code. At the receiver end, the output signals from the decoder can then be passed directly to the temporary memory. The amount of equipment required at the receiver end is appreciably reduced in this way. With the aid of suitable buffering at the transmitter end, a transmission rate of 200 - 300 bit/s should be quite possible.

A system working on this principle is at an advanced stage of development. The preliminary results obtained with it are highly encouraging.

<u>b. The memory</u>

The memory occupies a very important place in the converter. It not only determines the quality of the TV picture but is also the most expensive part of the converter and thus largely determines the over-all price.

As mentioned above, the memory proper is built up of MOS-FET shift registers, for reasons of price, ease of handling and space.

With the present resolution, the TV image consists of an array of about 300.000 points. It would be possible in principle to design the memory as one big shift register with a capacity of 300.000 bits, but in practice such a solution would give a memory which was much too big and expensive and dissipated much too much power.

Since however a line drawing or handwritten text only makes use of a few percent of the total number of image points, it would seem possible to realize a very appreciable reduction in memory capacity.

Before looking for a method of achieving the desired reduction, it is advisable to list the demands to be made of such a method. These are:

1. Large reduction in the number of memory places required.(It can easily be shown with reference to a few simple examples that compressed written texts generally make much higher demands on the capacity of a memory than drawings, so a reduction system should be designed to deal with the former).
2. Simple control circuit for the reduced memory.
3. Read-in and read-out of the image points should be very fast, in connection with the use of the TV receiver as display. For example, in the case of a horizontal written line, the points on this line from left to right should be stored and recovered at intervals of about 200 ns. This implies that the sequence in which the points of the text are stored in the memory should be the same as that in which the points appear on the screen during the display. This greatly reduces the number of types of memory reduction which come into consideration for this application.

In general, the first and second requirements will not be optimally satisfied at the same time; these means that we have to look for a compromise solution giving the best possible reduction in memory capacity combined with the simplest possible control circuit under the circumstances.

Analysis of a large number of TV images of written texts and line drawings led to the following findings:

1. The <u>average</u> number of intersections per image line is generally less than 10 (in case where selection - i.e. reduction in the number of image points - has been applied).
2. The frequency of point pairs on a given image line with a given distance between the pair increases as the distance between the pair decreases.
3. The distance $l_i = 2$ (i.e., where two image points on a line are separated by only one quantized space) occurs relatively much more frequently than any other distance.

After some investigation on the basis of the above three findings, it was concluded that two reduction principles came into consideration for further study.

a) Each image line is split up into segments containing <u>k</u> successive image points (see Fig. 8); it was found empirically that the best results were obtained when <u>k</u> lay between 8 and 12.

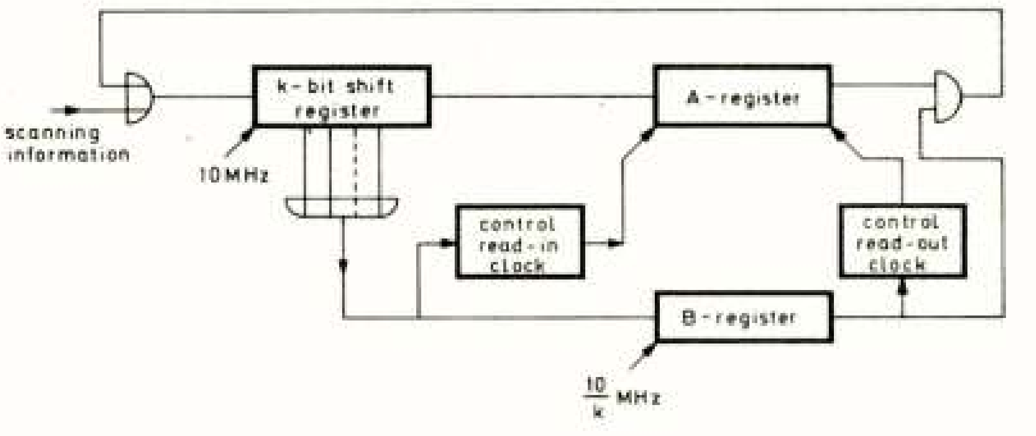

Fig. 8.

Each group of <u>k</u> points is then tested in turn in a buffer register to see whether it contains any points of the text to be displayed. If not, a "0" is stored in a register called the "B" register. If a point from the image is found, a "1" is stored in the "B" register and the entire group of <u>k</u> bits is stored in the "A" register.

It was found that the control circuit required for realization of this principle was quite simple. The read-in and read-out rates never represented problems in the application of this circuit. The worst-case reduction factor was about 6.

The read-in and read-out control signals for the A register are not always synchronized. In order to uncouple the read-in and read-out processes completely, the A register was split up into segments. With the exception of the first segment (which always follows the read-in pulse), each segment can be connected to follow either the read-in or the read-out instruction. The price (in memory capacity) to be paid for this improvement is only one segment.

b) In each image line, the distance from the left-hand edge of the screen to the left-hand text point on the line (l_1) is measured in binary code, followed by the distance between this point and the next text point to the right (l_2), and so on; see Fig. 9.

Fig. 9.

In view of the high probability of occurence of short distances, a variable-length coding is likely to give the best results.

However, it is difficult to give a cut-and-dried procedure for this coding, since at the moment we have no exact data on the relative frequencies of occurence of the various lengths. Moreover, it is doubtful whether application of a fixed coding procedure of this type would be compatible with requirements 2 and 3 mentioned above.

After careful consideration of all requirements, also the following system of reduction was selected for further study:

The distance between two successive points on an image line is in the first instance determined as a 9-bit code word. However, only the part of the code word actually required for the coding of the distance is stored in the memory. Fig. 10 gives a number of examples.

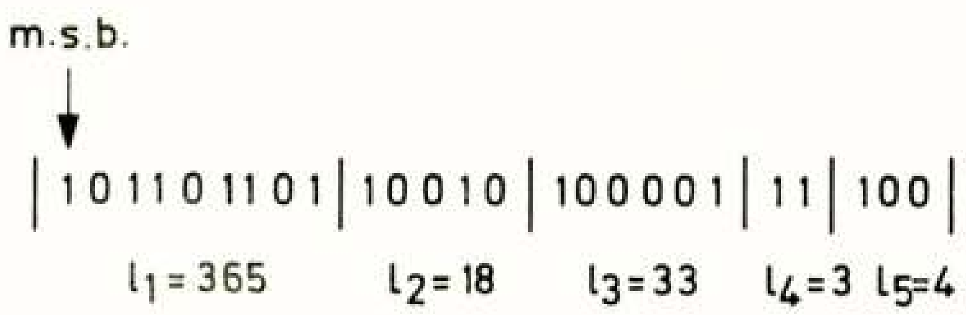

Fig. 10.

Of course, it is not enough simply to store the appropriate parts of the various code words; in order to decode the information later, we also have to store data concerning the lengths of the various code words recorded. Now the length of a code word can be recorded in various ways, the most obvious one being the use of 4-bit words for coding the number of symbols in each code word. However, in view of the very high frequency of occurence of short distances, it was decided to use variable-length coding of the length of each code word, as follows (see Fig. 11). A secondary code word is

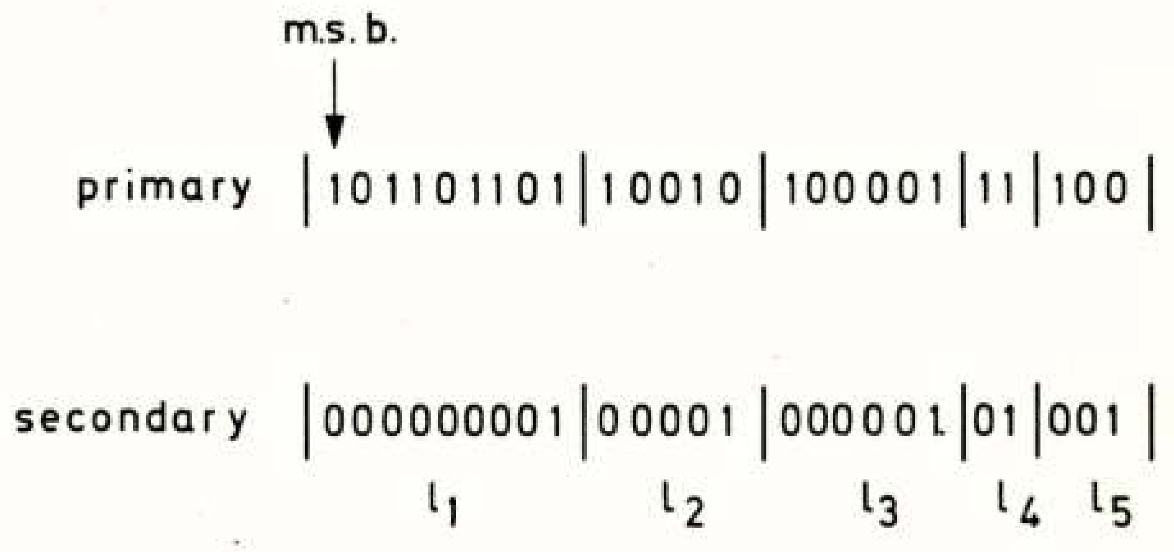

Fig. 11.

generated for each (primary) code word representing the length of a line segment. The secondary code word has just as many bits as the primary one, but only the least significant bit of the secondary code word is a "1". The secondary code words are stored in a separate register. We now have all the information we need about the length of the various code words, so the stored data can be unambiguously decoded.

It might be thought that the introduction of a second shift register would represent an unacceptable waste of memory space, but fortunately this is not the case.

Each scanned point fed to the input of the memory which is horizontally adjacent to a point already stored in the memory will be rejected. As a result, the shortest distance which can occur is $l_i = 2$, and the most significant bits of the primary and secondary code words will always be "1" and "0" respectively. We can thus omit the most significant bit of each code word when storing it in the memory, whithout losing any information. Fig. 12 gives a survey of the code words for the various distances, compressed according to this principle.

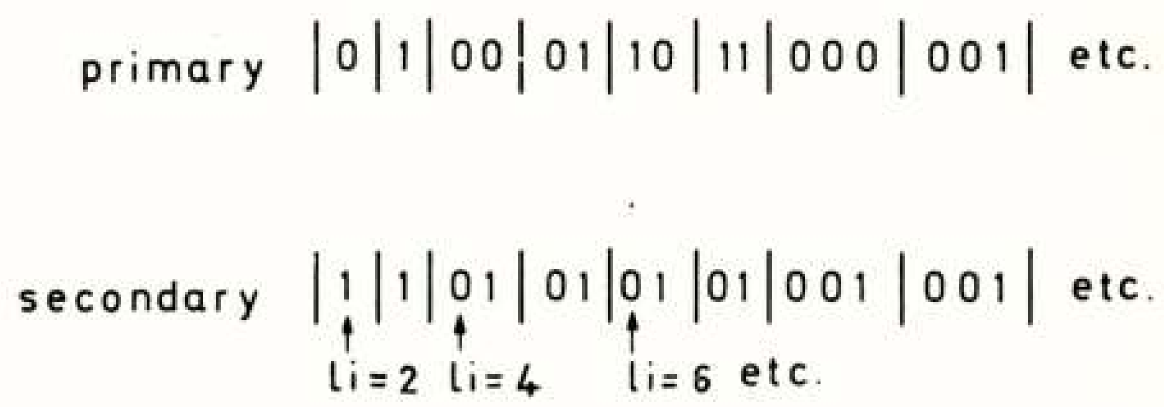

Fig. 12.

Each code word in the memory representing the far right-hand point in a line is followed by a special 6-bit code word.

It can easily be verified that the code described has the desired "prefix property", and that no permitted code-word combinations are unused. Since the exact probability of occurrence of the various distances is unknown, no precise estimate could be made of the extent to which this coding departs from the optimum, but a number of experiments suggest that it is in fact very close to the optimum. The memory capacity required (as determined on the basis of a number of trials of the electronic blackboard system) is about 30 kbit. The reduction factor is thus about 10. (It goes without saying that the selector is responsible for part of the reduction).

As regards the control circuits required for this coding, it may be remarked that both the coding and the decoding process go very smoothly and are easy to follow; and they require a minimum of equipment. The coder proper consists of a 9-bit counter and two 9-bit shift registers, while the decoder proper consists of a 9-bit counter, a 9-bit shift register and a 9-bit digital comparator (see Fig. 13).

It will further be clear from Fig. 13 that the coding and decoding rates will not give problems with the present horizontal definition; with a higher horizontal definition, however, problems will arise.

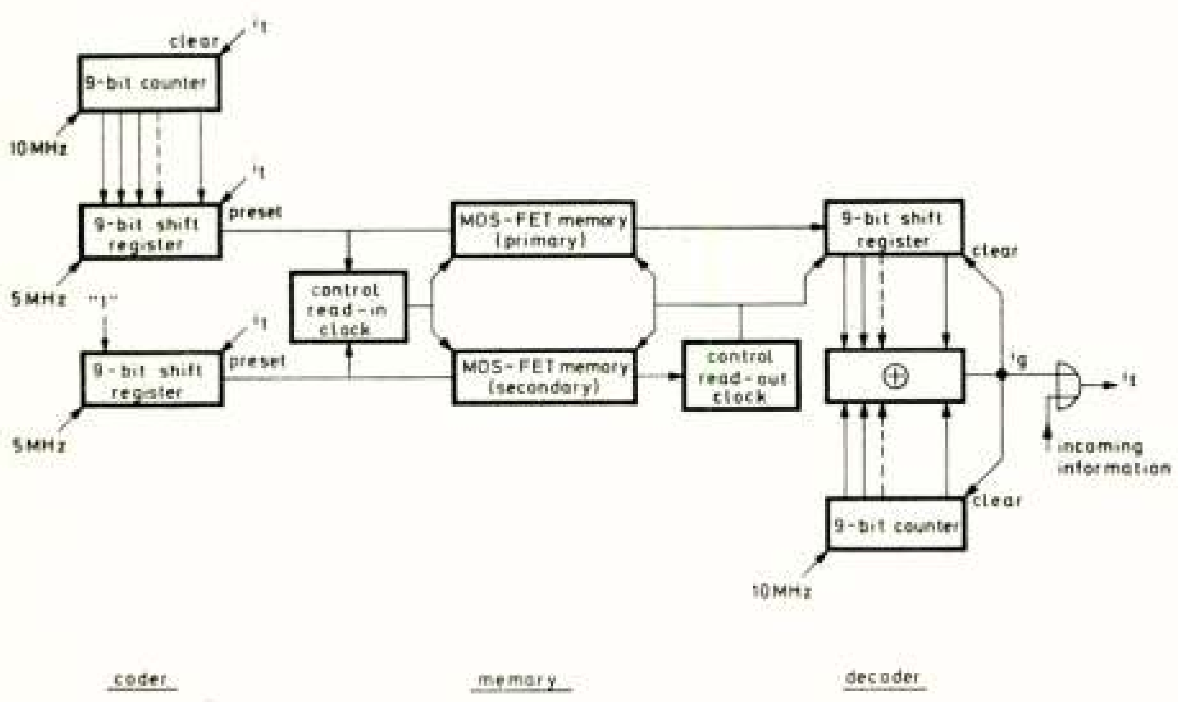

Fig. 13. Block diagram of the complete memory unit.

The reduction method finally chosen was of type b) mentioned above (variable-length coding), because of the greater reduction factor which this gives.

The memory loop consists of the MOS-FET shift registers in combination with the coder and decoder. This makes it an easy matter to insert new information.
An extra register can be added for information concerning the colour of the light spot. If 1 bit per light point is reserved for this purpose, we get a choice between two different colours. The number of possible colours can easily be extended by adding more bits per light spot.

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C.P.J. Wester, Tape recording of scribosonic signals, Tijdschrift van het N.E.R.G., this issue.

Lecture held on June 19th 1973 at the Delft University of Technology, Department of Electrical Engineering, at meeting no. 231.

TAPE RECORDING OF SCRIBOSONIC SIGNALS

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This article gives a survey of the various signal types in the Electronic Blackboard system which are suitable for the combined recording of writing and sound (scribosony). Further details are given of why and how differential phase shift keying is used for recording the digital script signal, how errors are detected and what effects the error detection has on the writing as reproduced. The minimalization of the effects of cross-talk when using cassette recorders is also described.

INTRODUCTION

One of the problems encoutered in the development of the electronic blackboard system for Indonesia was the time difference between the various regions involved.[2] Indonesia extends over about 3000 miles from East to West, so the land is divided into three time zones, each one differing in time by one hour from its neighbour. This makes it difficult to chose a time for the direct broadcasting of educational programmes which is suitable for all three time zones. It is therefore desirable to have facilities for recording the programmes in question, so that they can be re-transmitted at a suitable time for the different time zones. Furthermore, if recording is possible, in cases where long-distance radio transmission is difficult the recorded tapes can be sent to distant regional transmitters which can then transmit the programmes in their turn.

Recording also offers further advantages, such as the possibility of editing programmes and of building up complete courses on tape.

Finally, experience shows that the making of live programmes is attended by great psychic stresses; the recording of programmes on tape can be done in a much more relaxed manner.

SYSTEM SET-UP AND SIGNAL SELECTION

Examination of the block diagram of Fig. 1 shows that the following signals are available for recording purposes:

a. the "source signals" at A_1 and A_2

b. the telephone signals at B_1 and B_2

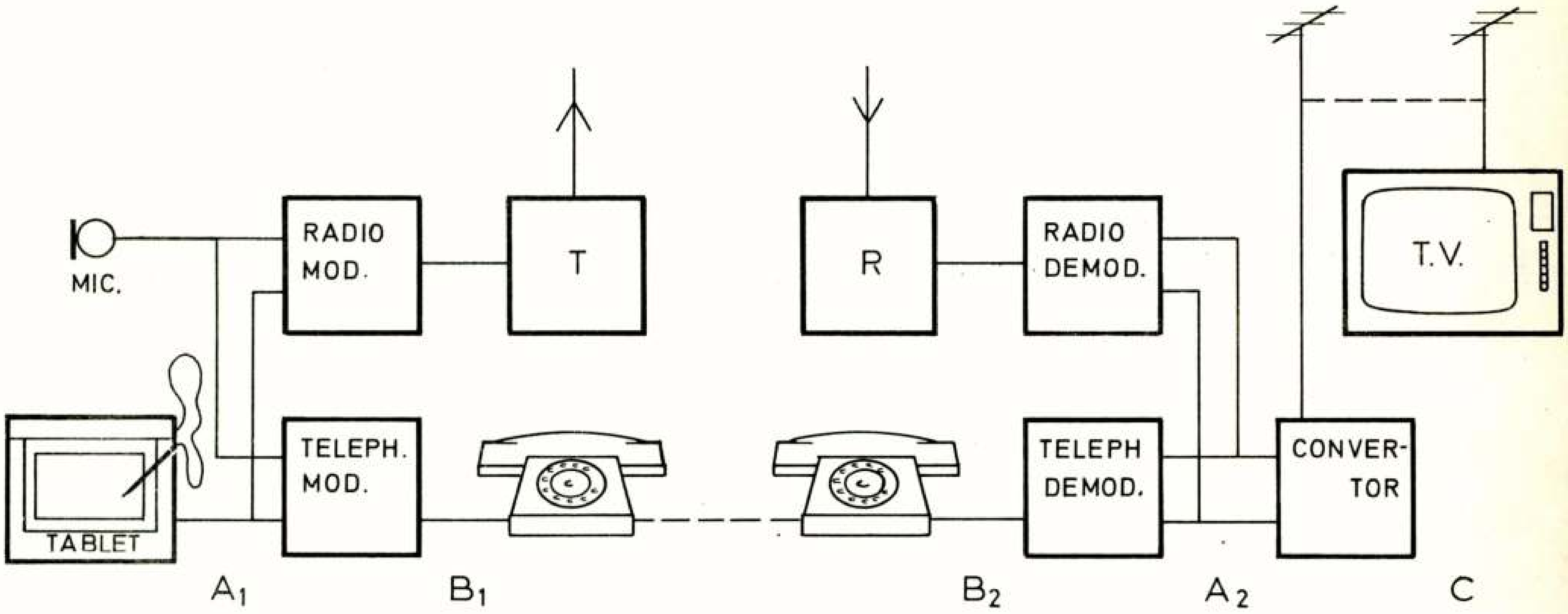

Fig.1 System lay-out

c. the video signal at C.

Technically speaking, there are no problems in the recording of video signals. However, this recording process does have a number of serious disadvantages:

- both the video recorders and the tapes are very expensive
- video recording systems have not been standardized yet
- the systems are easily damaged
- the editing of tapes requires expensive equipment, in connection with synchronization problems
- in the system of Fig. 1, video recording is only possible between the TV receiver and the converter

This last point in particular precludes the use of video recording in Indonesia. It is intended to use radio transmission for scribosony signals in Indonesia, which means that video recording is only possible at the receiver end.

A suitable telephone signal would probably be the most universal signal form, since it could also be used for radio transmission and for recording on tape. However, a system for the common transmission of writing and sound via a normal telephone line is still in the initial development phase. The manner in which the script information will be mixed with the sound, and separated from the latter at the other end, still has to be worked out.

At the moment, therefore, the only signals left for recording purposes are the source signals. The audio signal can be directly recorded on audio recorders, but the script signal has to be processed in some way before recording.

The recording method should be planned in such a way that stereo cassette recorders can be used. These recorders have the great advantages of compactness and simplicity of operation. One stereo channel will then be used for recording sound, the other for the script signal. However, they also have a number of disadvantages:

1. During the play-back of a signal which was recorded at a constant level, the output level will be found to vary considerably (by about 6 dB), while at times the signal actually drops out completely for a few milliseconds.
2. the separation between the two stereo channels is only about 20 dB.
3. the tape speed can vary by about 1%.
4. further variations in tape speed (of about 0.3%) are caused e.g. by the unroundness of the capstan.

Especially in places where the electrical power is supplied by a small (e.g. diesel-operated) power station for a small region, variations in the mains frequency can occur. These frequency variations will intensify the last two disadvantages of the cassette recorder, if the latter is driven by a synchronous or asynchronous motor.

In connection with all these points, it should be remembered that if recording and play-back occur under the same conditions, the effects are about doubled.

SOURCE SIGNALS

We saw from our discussion of the system set-up the source signals come into consideration for recording purposes. These signals are: the audio signal, which can be recorded directly, and the script signal. The latter can exist in two forms, analog and digital.

The analog script signal

The analog script signal consists of two voltages, each of which is directly proportional to one of the coordinates of the instantaneous pen position (with reference to one of the corners of the writing tablet, which is taken as the origin). Each voltage consists of a DC component with a very low-frequency alternating voltage superimposed on it. Apart from these coordinate voltages, there are a number of control voltages required for the transmission of the "write" or "erase" instructions.

Modulation will be required for the recording of the analog signal. Amplitude modulation is not possible in this application. It follows from the properties of the cassette recorder that we will get level differences during play-back which were not present in the original signal. These level differences represent parasitic AM signals as far as the demodulation is concerned, and will give rise to large interference voltages in the reconstituted signal which will cause big "scratches" in the reproduced script. These level variations are frequency-dependent, so compensation with a pilot tone is hardly possible.

Frequency modulation methods are subject to interference from variations in the tape speed. During play-back, these variations lead to a shift in all recorded frequencies. This gives rise to parasitic FM during demodulation. However, these shifts are relatively equal for all frequencies. According to quasi-stationary considerations, therefore, a pilot tone should be able to give complete compensation.

The digital script signal

In its digital form, the signal is modulated in a binary pulse code, with 9 bits for each coordinate. There is also one Z (pen lift) bit, one E (erase) bit, one C (clear) bit and one frame synchronization (Sy) bit, giving a total frame length of 22 bits. The frame synchronization bit is alternately low and high in successive PCM (pulse-code modulated) frames (see Fig. 2). The bit frequency is 1 kHz and the frame frequency is about 45 Hz; the sampling frequency of the script signal

Fig.2 The P.C.M. code

is equal to the frame frequency.

The signal will have to be read in at the receiver end with the aid of a PCM receiver provided with a clock frequency which is accurately equal to the bit frequency of the signal supplied. This is realized with a phase-locked loop oscillator tuned to 1 kHz and synchronized with the PCM signals by the 1-0 and 0-1 transitions in the latter; in general, this gives no problems.

The worst case for synchronization is when all bits in a frame are "1" or "0". The first 1-0 or 0-1 transition at which synchronization is possible is then found in the following frame (since at least the synchronization bit will have changed polarity). In the worst case, there are thus no level transitions in 42 bits. It follows that if the 42nd read-in pulse may have a maximum permissible shift of ± half a bit length with respect to the PCM signal supplied, the clock frequency and the PCM bit frequency may not differ by more than about 1%.

It will be clear that this last requirement can give difficulties when the PCM signal is reproduced from a cassette recorder: the tape speed gives rise to variations in the bit frequency of the PCM signal supplied which can be much greater than 1%. This means that when PCM code signals are recorded, information about the clock pulses must be recorded at the same time.

PRACTICAL REALIZATION OF THE DIGITAL RECORDING SYSTEM

As we just mentioned, clock information must be recorded at the same time as the PCM code. The poor channel separation means that certain demands must be made concerning the ratio of the levels of the recorded audio and script signals and may also lead to errors in the PCM code. Error detection is therefore necessary to keep the distortion of the reproduced script as low as possible.

Modulation of the digital signal

The clock frequency (f_k) is transmitted with the aid of the carrier frequency (f_0).

$$f_0 = 6f_k.$$

The clock frequency can then easily be regained in the demodulator by division (Fig. 5):

$$f_k = \frac{1}{6}f_0 = \frac{1}{12} \cdot 2f_0.$$

In this division process, the reconstituted clock frequency can have 6 (12) different phases with respect to the PCM signal. Making use of the 1-0 and 0-1 transitions present in the code, we can ensure that the divider and hence the clock frequency are reset to the right phase.

Two-phase differential phase-shift keying was chosen as the modulation method, because of the low sensitivity to interference possessed by this method.[1] Direct phase-shift keying with two phase states (0 or π radians) cannot be unambiguously demodulated because of the absence of a reference phase: during demodulation, we have no indication of which state represents logic 1, and which logic 0. In differential phase-shift keying the signal undergoes a phase shift of π radians at each logic 1, while logic 0 gives no phase difference.

For the purposes of the modulation, the PCM signal must be coded in a differential PCM code. Each 1 presented to the coder inverts the coder output, while input 0's have no influence on the output signal (Fig. 3 and 4).

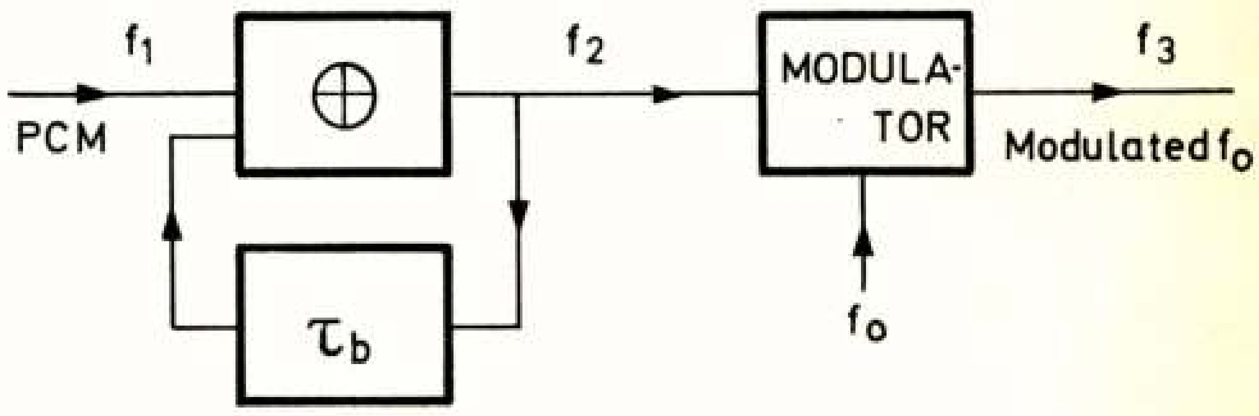

Fig.3 Coder/Modulator

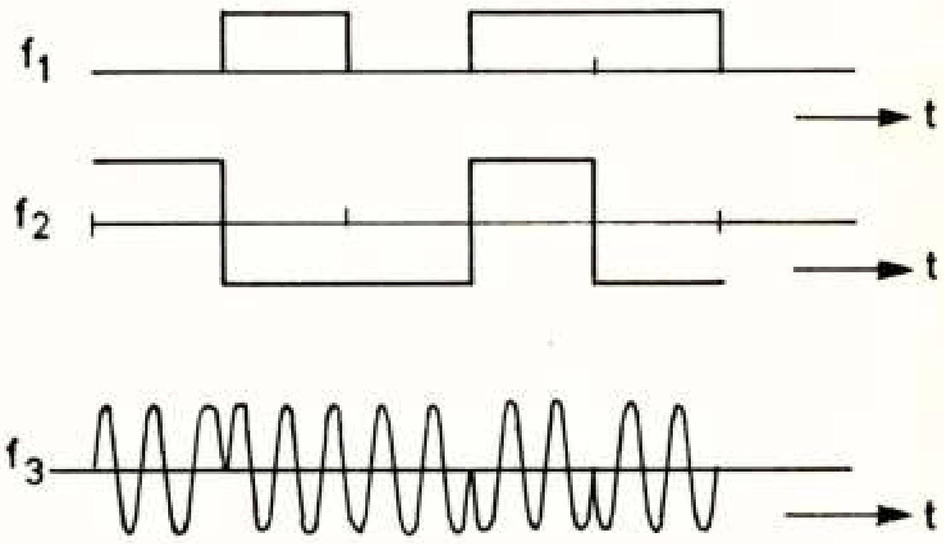

Fig.4 Signal types

Demodulation

In the demodulator (Fig. 5) the differential PCM signal is regained by coherent detection. This process requires the presence of the unmodulated carrier, which is not found in the modulated signal. This can be shown as follows. Let

$$f_3(t) = \sin\{\omega_o t + f_2(t) \cdot \tfrac{\pi}{2}\} \text{ wherein: } f_2(t) = \pm 1.$$

Then $f_3(t) = +\cos(\omega_o t)$ if $f_2(t) = +1$

$= -\cos(\omega_o t)$ if $f_2(t) = -1$.

Thus $f_3(t) = f_2(t)\cos(\omega_o t) = \pm\cos(\omega_o t)$

and $F_3(f) = F_2(f) * \{\tfrac{1}{2}\delta(f_o) + \tfrac{1}{2}\delta(-f_o)\}$.

It will be clear that if $f_2(t)$ is a square-wave voltage this signal will have no DC component, i.e. $f_0(t)$ is absent. When the signal $f_3(t)$ is squared, it loses its information (sign changes):

$$f_3^2(t) = \cos^2(\omega_o t) = \tfrac{1}{2} + \tfrac{1}{2}\cos(2\omega_o t).$$

The carrier frequency can now be regained from $2f_o$ by binary scaling. However, $2f_o$ must be filtered first through a circuit of low Q (10-15). The quality of the filter must be low to permit the demodulator to accept frequency deviations, and to follow changes quickly. A low Q will also cause the amplitude of $2f_o$ to fall off rapidly when interference is present in the incoming signal.

The signal obtained from the detector will have to be decoded again to get the PCM signal. This decoding is done by comparing two signals shifted with respect to one another by one bit period. Like levels give a 0 after decoding, and unlike levels a 1.

Levels and channel separation

In good cassette recorders, the separation between the stereo channels is about 20 dB over a wide frequency band. If the audio signal is recorded in one channel and the PCM signal (modulating a 6 kHz carrier) in the other, the two signals will give cross-talk.

If we assign a level of 0 dB to the maxima in the audio signal, then it is found that interference from the script signal during play-back is acceptable if its level is lower than -40 dB. This means that the script-signal level in the other channel should be -20dB. The interference level experienced during play-back by the script signal will than also be -20 dB at the audio maxima, which will give rise to errors in the PCM-code. For a reasonably small chance of error, the signal-noise ratio should be about 10 dB. This can be achieved by making use of the fact that most high-energy spectral components in the audio signal are in the frequency range from 300 to 3000 Hz. These can be adequately suppressed by placing a 12 dB/octave, 3 kHz high-pass filter in front of the demodulator.

A further improvement in the signal-noise ratio of the audio signal can possibly be obtained by means of compensation with a fraction of the script signal.

Error detection

Despite the low sensitivity to interference of the modulation method chosen, errors can occur during demodulation. If these errors occur in significant bits, they can give rise to large error voltages in the script signal, and hence to "scratches" in the image reproduced. To avoid these errors, error detection is used.

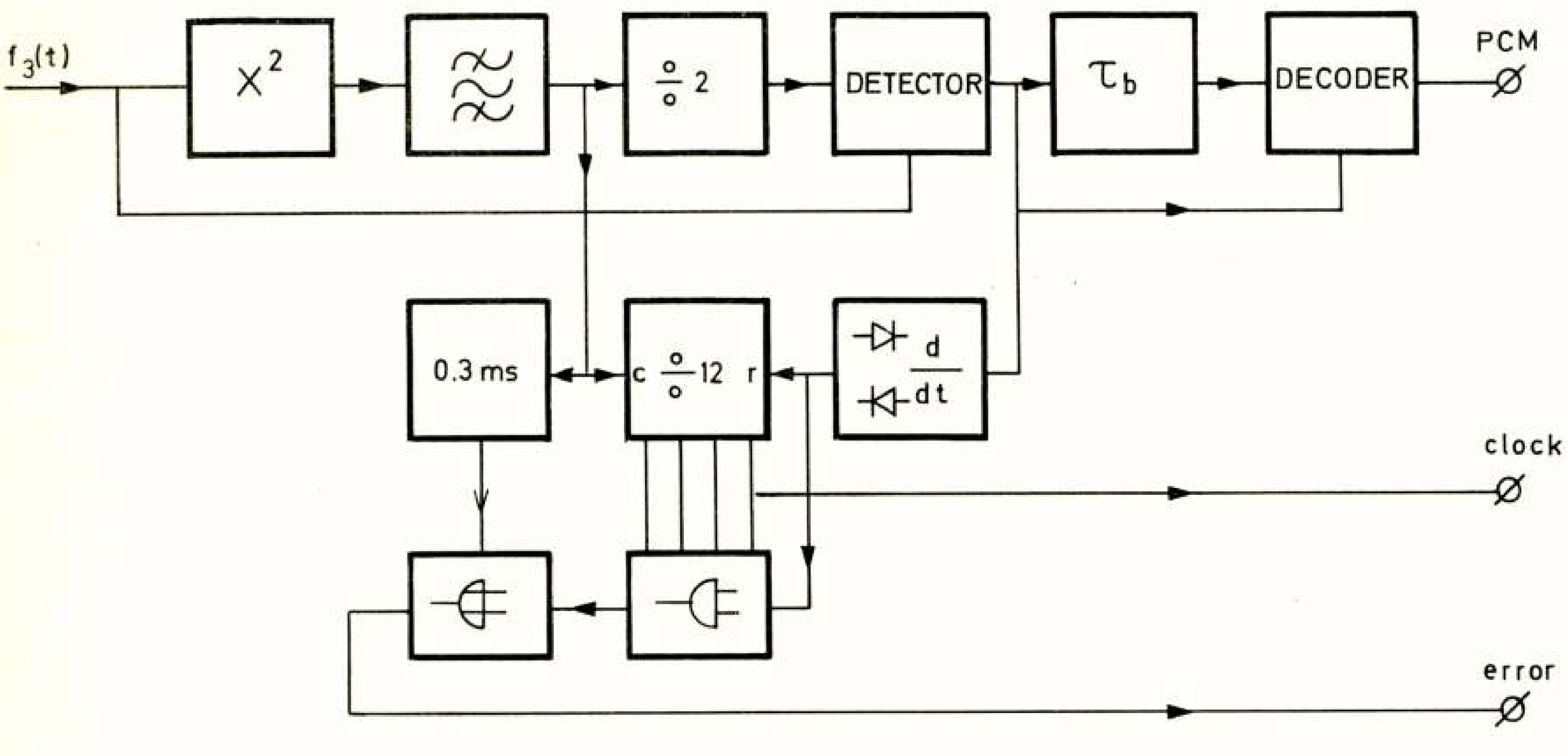

Fig. 5 Demodulator and error detection

The starting point for the error detection is the consideration that errors in the reconstituted PCM signal are due to interference which is already present in the modulated carrier wave during play-back, generally in the form of drop-outs, but sometimes as extreme variations in tape speed due e.g. to a knock against the recorder. These interferences will not vanish in the demodulator, even after squaring, so that the amplitude of the signal $2f_o$, obtained by filtering through the circuit of low Q, will decrease quickly. Thanks to the circuit used, this amplitude has a constant value in the normal situation, except at phase jumps in the modulated signal. The signal is then taken as error-free if $2f_o$ is present with an amplitude above a certain minimum. If $2f_o$ has a smaller amplitude for more than 0.3 ms, an error is signalled to the PCM receiver.

However, during programme editing it may happen that the carrier frequencies of two succeeding script-signal fragments which are joined together match exactly. No error will thus be signalled in this case, though there may be an error in the PCM code at that point. This makes it desirable to have a second criterion for error detection.

This criterion is provided by the differential PCM signal itself. In an error-free signal, the level transitions will always be separated by a whole number of bit periods. Departures from this rule can be signalled as errors. These errors are detected with the aid of the scale-of-twelve circuit also used for reconstituting the clock frequency from the second harmonic of the carrier wave. Once the devide-by-twelve-counter and hence the clock frequency, have been reset to the right phase, then subsequent reset pulses derived from the level transitions of the differential PCM signal should fall at (or just next to) the zero position of this counter.

A gate circuit passes any reset pulses which fall outside the permitted range to the PCM receiver as error indications.

If an error is detected in a PCM frame, the PCM receiver will not pass the analog information corresponding to this frame to the output. The output will then hold the voltage corresponding to the last error-free sample. From this point, the voltages will pass directly to the next error-free coordinate pair received.

Distortion

The distortion in the reprocuded image due to the omission of one sample depends on the form of the smooth curves drawn through the points determined, with and without the sample in question. Let us suppose for example that there is an error in sample number n. Fig. 6 indicates the form of the line actually reproduced, on the assumption that the points before and after the nth sample are free of error.

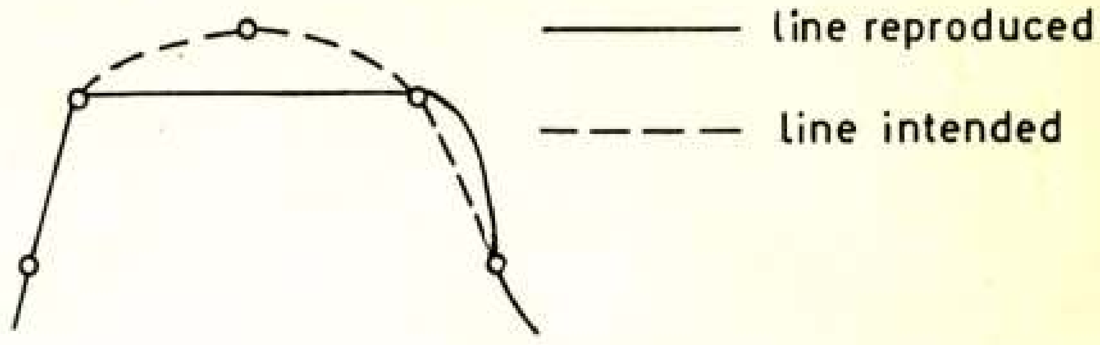

Fig.6 Effect of omission of an image point

The sampling frequency makes it possible to reproduce script signals with a maximum frequency of 15 Hz at maximum amplitude. Such a combination will never occur in practice in the script signal, so that there is a lot of redundancy. The omission of a single sample will therefore not be noticeable at all in practice, since successive samples are so close to one another.

Distortion could also be caused by variations in tape speed, which could influence the coordinate voltages via the PCM receiver. This change in the coordinate voltages as a function of time would give rise to variation in the writing speed. Since however the relation between the coordinates of different samples will not be altered appreciably, the script will be reproduced without distortion.

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Lecture held on June 19th 1973 at the Delft University of Technology, Department of Electrical Engineering, at meeting no. 231.

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Tijdschrift van het Nederlands Elektronica- en Radiogenootschap

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deel 38 - nr. 6 - 1973