A COLOUR DISPLAY UNIT FOR A 21-CHANNEL EEG-MONITOR

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ABSTRACT

A system for the simultaneous display of several functions of one or two variables has been developed. One-variable functions are represented by their graphs, while two-variable functions are displayed by means of contour maps, with a light intensity proportional to the displayed value. By assigning a fixed colour to each contour map, it is possible to superimpose different maps without losing charity. The display unit is connected with a microprocessor system, which allows the real-time calculation and display of time-charging functions.

The primary application of the system is the representation of the distribution of the spectral contents of EEG (electro-encephalographic) signals on the surface of the head.

1. INTRODUCTION

The problem which prompted the development of the system presented here is the display of results of EEG (electro-encephalographic) measurements. EEG potentials vary with time, and are generally measured at several places of the head with multichannel x-t recorders.

The long drawings obtained in this way (typically 100 m for a 1-hour session) are visually analysed and some spectral information is extracted by inspection.

Considerable savings in analysis time and accuracy can be obtained by displaying the energy content of the EEG signals in selected frequency bands, at the different points on the head, and in function of time. This calls for graphs with two independent variables (to represent the surface of the head), which are implemented using contour maps. In order to add the time dimension these maps are displayed on a TV screen.

This visual method of presentation has the advantage of strongly compressing the amount of information, compared to the classical method.

Although the system was conceived with one particular application in mind, it has been kept as general as possible : the system can display contour lines for any twodimensional function. The particular definition of the function for an application is only reflected in the software of the microprocessor system which calculates the contour maps.

2. DISPLAY UNIT DESCRIPTION

The EEG's are recorded with 21 electrodes, arranged according to the international 10-20 system (2), which is shown in a two-dimensional projection in Fig. 1. The different incoming analog signals are filtered, amplified, simultaneously sampled and digitalised, at a frequency of 200 Hz, in blocks of 4 K length.

The FFT, the corresponding power spectrum and the integral over six different user definable frequency bands (e.g. α, β_1, β_2, δ ... waves) are calculated for each channel.

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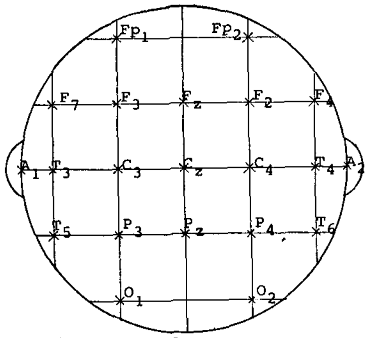


Fig. 1 : two-dimensional projection of the 10-20 recording system.

Using two-dimensional interpolation, one is able to estimate the energy content of the six frequency bands in any point of the head from the 21 available points. Iso-energetic lines for eight different levels are then calculated and displayed on a colour TV-screen, with a light intensity proportional to the displayed level, together with the numerical value (in µV/Hz) of minimum and maximum level.

The distance between the levels can be chosen to be constant or logarithmically variable.

By assigning a fixed colour to each frequency band, it is possible to superimpose different maps on each other, with easy recognition of the different patterns. The user can select at most three maps for simultaneous display, and is allowed to change this selection at any time, with immediate response of the system.

The FFT and energy-map calculations are performed in real-time by means of a parallel system of 8 microprocessors (3). As will be seen in the hardware description of this display unit, one of these 8 processors controls the data flow in the machine, necessary for the display.

As the data are sampled in blocks of 20 seconds, each set of maps can be seen during 20 seconds, and is then replaced by the next set, unless the user wants to hold a particular set of results. The user can also obtain the simultaneous visualisation of the power spectrum of up to ten channels.

A keyboard is provided to allow the user to communicate information concerning the patient, and the required display format. Finally, digital in- and output on a cassette is also provided for recording and re-display of selected measurements.

The whole system is stand-alone, self-contained and easily transportable.

3. THE INTERPOLATION ALGORITHM

Three- and four-point linear interpolation algorithms are used to estimate the energy contents of the six frequency bands in any point (Fig. 2).

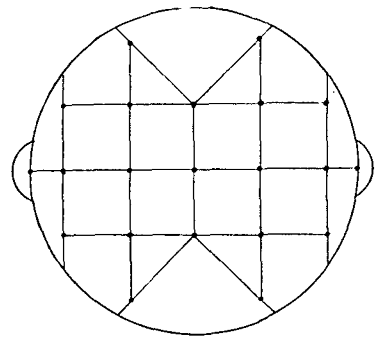
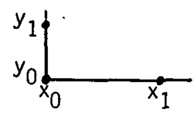


Fig. 2a : repartition of the projection of Fig. 1 in segments for three- and four-point interpolation.



$$x_1 - x_0 = h \qquad y_1 - y_0 = k \qquad 0 \leqslant p;q \leqslant 1$$

$$\text{(I)}\quad f(x_0 + ph, y_0 + qk) = (1-p-q)\, f_{00} + p\, f_{10} + q\, f_{01} + 0\,(h^2)$$

Fig. 2b : three-point interpolation formula (4).

$$x_1 - x_0 = h \qquad y_1 - y_0 = k \qquad 0 \leqslant p;q \leqslant 1$$

$$\begin{aligned} f(x_0 + ph, y_0 + qk) &= (1-p)\,(1-q)\, f_{00} + p(1-q)\, f_{10} + q(1-p) f_{01} + pq\, f_{11} + 0(h^2) \\ &= (1-p-q)\, f_{00} + p\, f_{10} + q\, f_{10} + q\, f_{01} + pq(f_{00} - F_{10} - f_{01} + f_{11}) + 0(h^2). \end{aligned}$$

Fig. 2c : four-point interpolation formula (4).

The different reasons for this choice are :

1) other research (6) has demonstrated that the EEG-potentials in a point on the scalp are mainly influenced by the cerebellum regions just below the immediate neighbourhood of that point. Thus it seems to be useless to take account of the far situated electrodes, as did Ueno and Matsuoka (7). The main advantage of their method is to produce a smooth result.

2) the rapidity of the calculation is essential, because the display must be done in real time; complicated algorithms must therefore be discarded in favour of fast ones.(It should be noted that the formulas of Fig. 2b and 2c are not used in this form; it is in fact possible to eliminate all multiplications in the interpolation algorithms (5)).

3) there are not yet sufficient physiological data available to conclude which interpolation method would be better, thus a relatively simple method has been chosen.

4. DISPLAY METHOD

Using the methods described above, iso-energy maps for six frequency bands of the EEG-spectrum are calculated, and these have to be displayed in colour. Since graphical terminals in colour are unavailable, it is obvious a TV monitor must be used. This means a hardware memory of sufficient size must be present to contain all the video information. In order to minimize the size of this memory, a character oriented display method, as described by Ward (8), has been chosen. This has the following advantages :

- when using second-order maps, 25 different characters (including the blank character) are required for plotting the curves, which means that five bits of memory are needed to store one character. On the other hand, each character contains 144 dots (12 x 12 matrix) which when individually addressed would require 144 bits of memory. Thus a large saving of memory is obtained, at the price of limiting the possibilities of the type of characters which are displayed.

- the character-oriented method makes it much more convenient and fast to calculate the shape of the curve from the given interpolated function values. Since the time factor is crucial in the design, this is a decisive consideration.

We use second-order maps since this involves no extra multiplications, but considerably smoothens the resulting curve, as compared to first order maps. Furthermore, only 25 characters are needed to plot these maps, as compared to the 55, needed for third-order maps.

Eight iso-lines are displayed with a light intensity proportional to the displayed level. Defining each character by its shape and intensity, 24 x 8 characters are needed to make a complete map (excluding the blank character). Thus, an 8 bit code is needed for the character addresses in a character generator (Fig. 3). The remaining 64 codes are used for alphanumerical characters, some greek and mathematical symbols, and punctuation marks.

A7	A6	A5	A4	A3	A2	A1	A0

A7–A3: 24 possible display characters
A2–A0: 8 possible intensities

exception : 010XXXXX, 111XXXXX } used for 64 alphanumerical, greek, mathematical and punctuation characters.

11111111 blank character

Fig. 3a : address code format for the character generator.

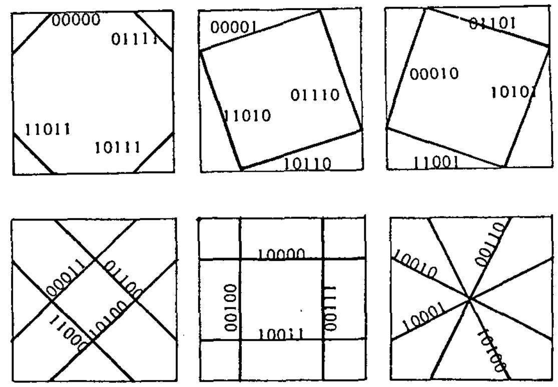


Fig. 3b : the 24 special display characters with their address codes (A7-A3). Only six logical operations and one interpolation calculation are needed to determine an address code.

It should be noted that the ambiguous situation which occurs when a curve passes through all four sides of a character is of a very exceptional nature. The characters described by Ward (8) to cover this case are not implemented, but are replaced with blanks.

Finally, the colour in which the map has to be displayed, is determined by the display software.

The display image is composed of 67 by 50 characters, each contained in a matrix of 12 x 12 dots. The image is interlineated, and has a display frequency of 50 rasters per second.

5. DISPLAY HARDWARE

The hardware used is microprocessor-based. A 6800 microprocessor and a 6845 CRT controller organise the display of data on the TV-Monitor. They allow also data to be brought in by a keyboard.

5.1. Video display principle

The information necessary for the display of the different energy maps (or energy spectra of different channels, etc.) is stored in four different 4K x 8 RAM's called video RAM's, in the way as discussed in 5.2. Thus, each video RAM contains the 67 x 50 matrix of character codes, representing a complete video image.

Three of these images are user-selected energy maps; the fourth is the background of the image, i.e. the image of the projection of the 10-20 system on the head (see Fig. 1). (In case of display of energy spectra, the background contains the coordinate axes with appropriate scaling indications).

We note here that the character codes stored in the video RAM's, contain only information about the kind and the luminous intensity of a character, not of the display colour. This colour is fixed for any given frequency band. The colours used are red (R), green (G), blue (B), R + G, G + B, B + R for the energy maps, and R + G + B for the background. This means that any (except the fourth video RAM can happen to have to be displayed in any colour (except R + G + B), while the fourth video RAM is always displayed in R + G + B.

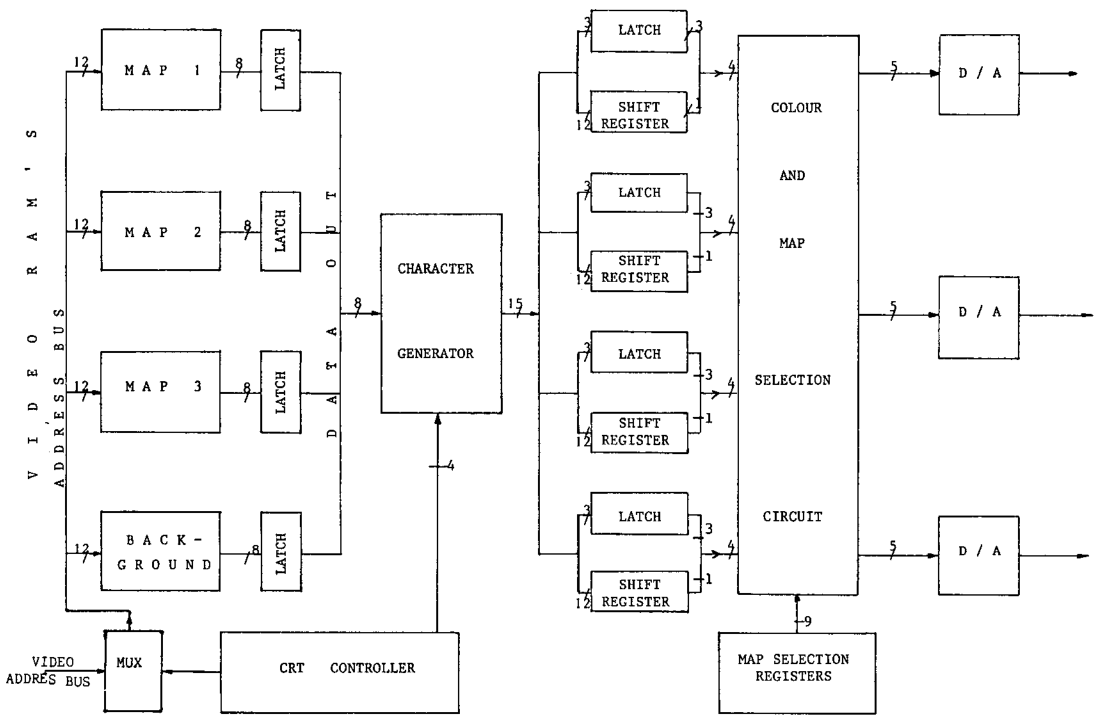


Fig. 4. From video RAM's to analog video output.

The four video RAMS's are continuously and simultaneously addressed by the CRT controller (Fig. 4). The 8 bit output of each RAM is latched, and clocked one after the other into the character-generator, which gives a 15 bit output : 12 bit representing the 12 dots of one line of a single character are loaded into a shift register, and 3 bit representing the luminous intensity are latched. A 12 bit shift register and a 3 bit latch are associated with each of the four video RAMS's.

The shift registers are used to give the dot output for each map, while the latches contain intensity information which is the same for all points of a given character. A colour and map selection circuit (Fig. 5) contains the logic necessary to feed the required analog information to each of the three video colour inputs. Provision has been made to ensure that composite colours (such as R + G) are not brighter than the three primary colours. The contents of the map selection registers determine the colour with which each video RAM will be displayed, while the background information is always white.

5.2. Microprocessor hardware of the video system (Fig. 6).

The 67 x 50 character matrices for each frequency band are calculated by the parallel microprocessor-system which also performs the FFT and related calculations. These matrices are transferred through an adequate interface to the video system.

A so-called video bus interconnects a 6800 microprocessor with private ROM and RAM, DMA and CRT controllers, the video RAM's, the map selection registers, the parallel system interface, keyboard, and cassette interface.

5.2.1. The parallel system interface

The data transfers through this interface are in fact DMA transfers between the video system and one particular processor of the parallel processorsystem. Two types of DMA transfers exist :

- from parallelsystem to video RAM's; this happens each time a new set of video maps must be transferred to the video RAM's;
- from the parallelsystem to 6800 processor memories and vice versa; this allows communication of data and commands between 6800 and parallel system (such as : limits of frequency bands, display mode, alarms, etc.).

A description of this interface is given in ref. (1).

5.2.2. The 6800

The 6800 controls the proper working of CRTC, DMAC, keyboard and cassette, interfaces and map selection registers.

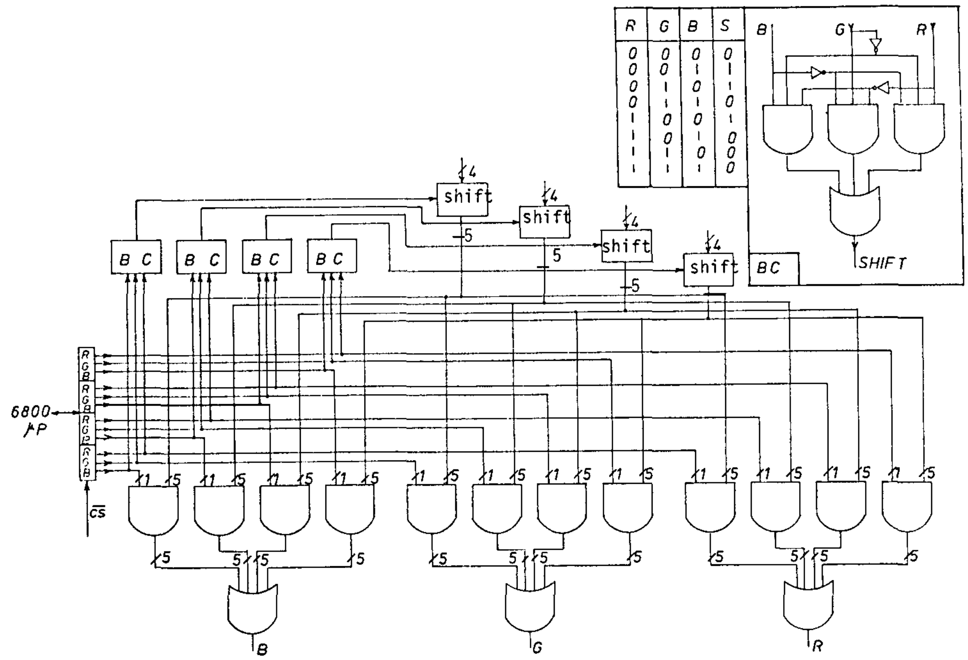


Fig. 5 : The colour and map selection circuit

The 6800 can load data under control of the DMAC into each of the four video RAM's (e.g. user commands and data from keyboard), and to the parallel system. The MPU also controls and updates the map selection registers. The selection of the different resources of the 6800 is obtained by means of the 4 most significant data lines, fed into a 4-to-16 decoder.

5.2.3. The CRT controller

This unit generates the refresh addresses for the four video RAM's simultaneously, a line address for the character generator, and the synchronisation signal for the monitor.

The video memory receives its addresses either from the CRT controller or from the video bus, as decided by a multiplexer. This means the refresh addresses cannot interfere with the working of the processor. The character data can be connected for testing purposes to the video bus through a tri-state buffer.

5.2.4. The DMA controller

Three different DMA transfers are used :

- from parallel system to the video RAM's; (new contour maps are loaded into the video RAM's). This DMA is executed during one single raster scan; the CRTC is disconnected from the address bus, so that one half image (25msec) is lost.
- from parallel system to 6800 memory and vice versa;
- from 6800 memory to video RAM's.

These two last DMA transfers are performed during the vertical return periods of the CRTC, so that no images are lost.

5.2.5. The video RAM's

These are dynamic memories which are continuously refreshed through the CRTC addressing. The addresses can originate from the CRTC (normal display mode), the DMAC (loading of the map), and the MPU (testing the memories).

5.2.6. The map selection registers

The map selection registers are latches which are addressed by the MPU. They are updated each time that the user changes the map display selection. If the user selects a fourth map for display, the corresponding code will be written in the register which contained the code of the first map, so that this map will be lost.

6. RESULTS

Fig. 7 shows hard copies of several EEG maps, obtained according the method described in this paper. One should note that the graphic copy does not show colours nor different line intensities. As already mentioned earlier, the representation of the head with the electrode configuration is displayed with low intensity white lines, while the energy maps are displayed in different colours with changing luminous intensity for the different contour lines.

7. CONCLUSIONS

The system described here has many possible applications outside the one for which it was primarily designed. It is suited to cases where complex information must be represented in real-time, which means a display method is needed which is clear,

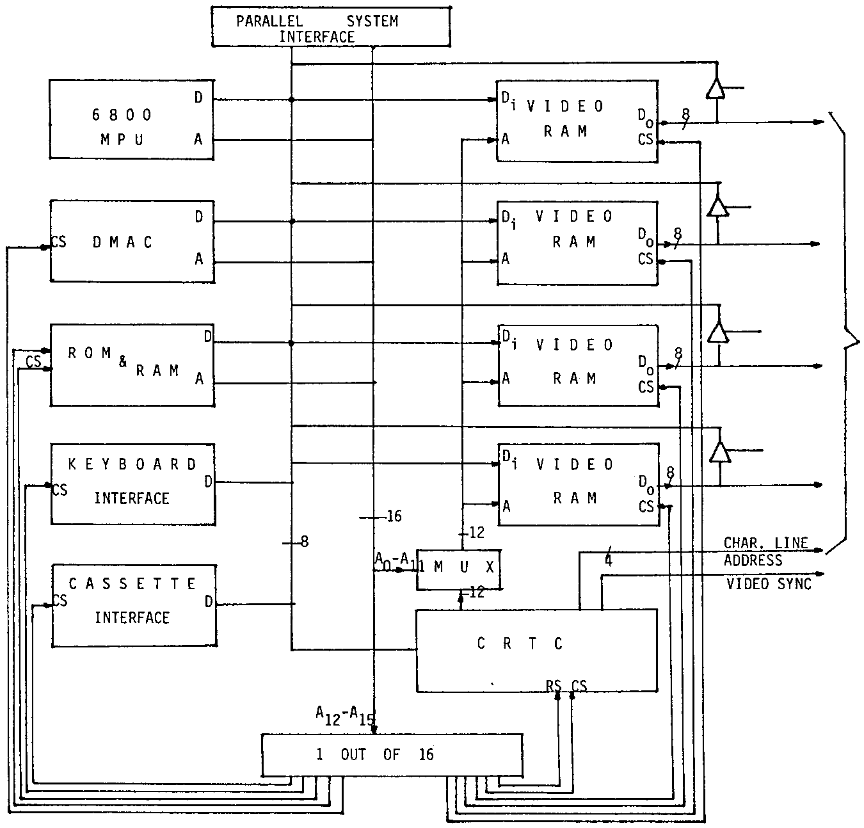


Fig. 6 : Microprocessor hardware of the video system

Fig. 7 : Graphic representation of energy contour maps of human EEG spectra. The subject is a healthy 46 year old man, who remained very restful during the recordings.

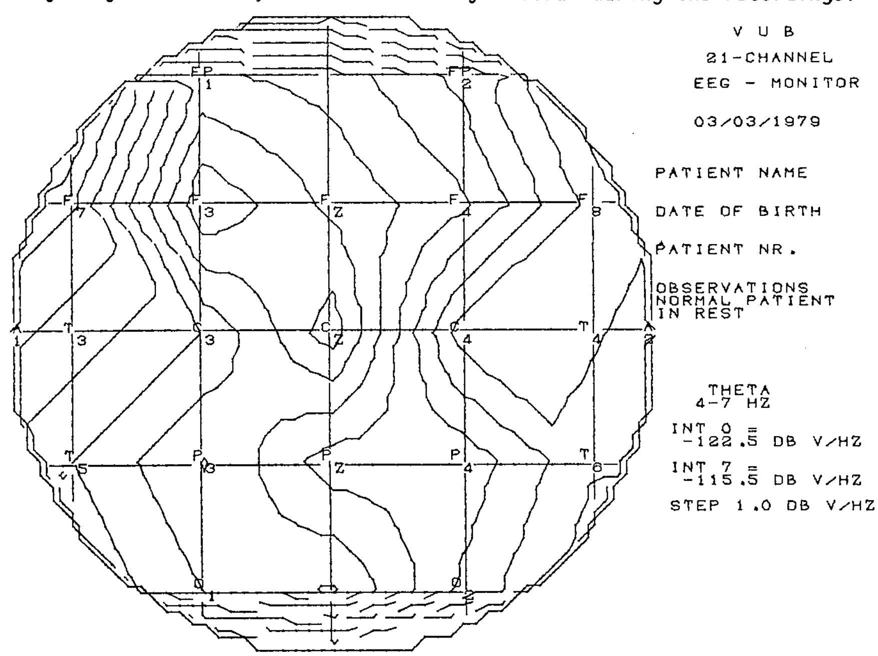


Fig. 7a : Prefrontal en frontal zones emit a θ activity which is slightly lower than the α activity on the same place (fig. 7b), indicating the rest state of the subject.

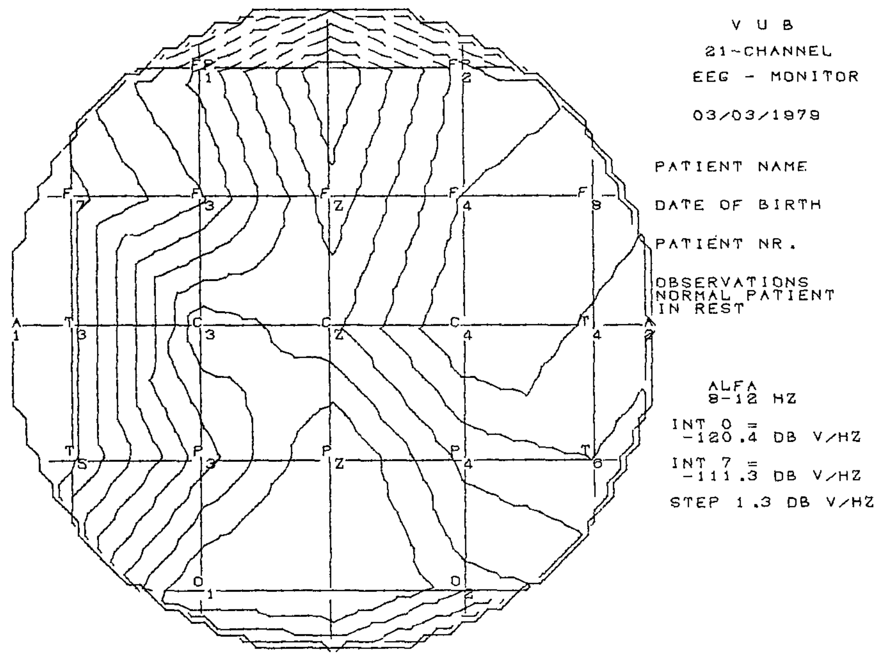


Fig. 7b : The prefrontal zone (between Fp_1, Fp_2 and F_z) generates a stable and symmetrical α rhythm (peak value about -111 dB V/Hz)

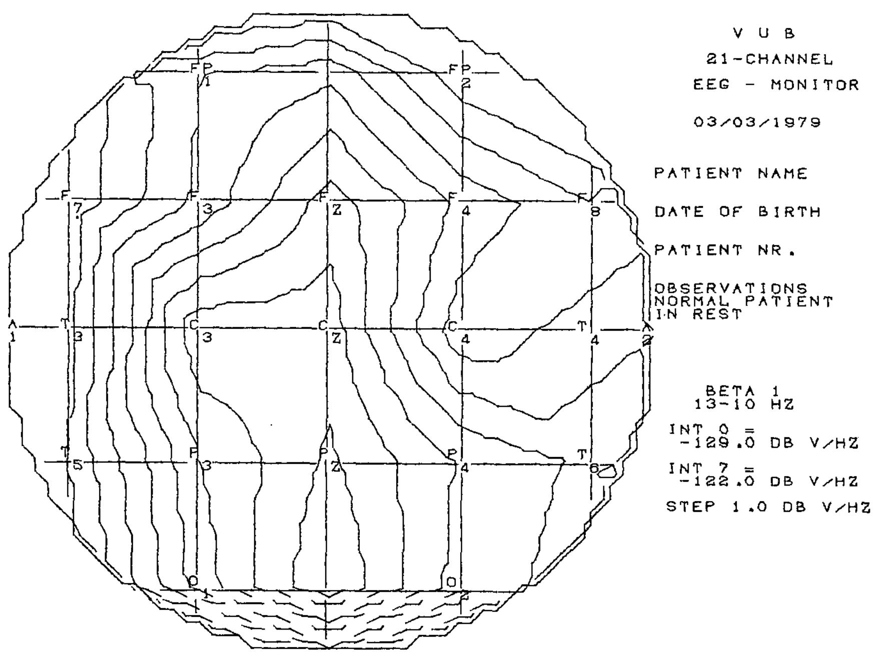


Fig. 7c : The right prefrontal zone (Fp_2) emits low frequent β waves.

but still simple enough to allow real-time calculation. The advantage obtained in this way is the introduction of the time axis in the display, since any changes of the phenomenon being studied can immediately reflected.

Drawings in perspective of complex surfaces are more attractive than the level lines we have used in our apparatus, but are of course impossible to be calculated and displayed in real time by an autonomous dedicated system. This type of graphical representation is suitable for the display of static results, such as the shape of an object, when calculation time is of no critical importance.

The display system we have realised is potentially useful in many areas, especially the treatment of signals of biomedical origin. In this last case, an extra advantage is that the result obtained can be used directly for clinical or diagnostic purposes.

8. ACKNOWLEDGMENTS.

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