XII. COMMUNICATIONS BIOPHYSICS*

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A. AURAL TRACKING OF MUSICAL NOTES: THE PROBLEM OF THE MISSING FUNDAMENTAL

1. Introduction: Musical Notes and Sounds

In Western music, an internationally agreed upon note scale has been developed which characterizes musical sounds solely by their fundamental frequencies. A simple musical message consisting in a sequence of notes (monophonic music) can be played with instruments that have very different frequency transfer (formant) characteristics,

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and yet the same melody is perceived. We shall report some results of a series of psychophysical experiments in which we are attempting to learn how the auditory system encodes the information of the fundamental frequency in the perception of musical sounds. In these experiments, musical behavior was simulated by having subjects identify simple monophonic musical messages (melodies). A set of musical sounds was employed for which there already exists a large body of relevant psychophysical and physiological data.

2. Basic Experiments

a. Demonstration of Musical Behavior

Four synthetic musical sounds at 50 dB SPL were presented monaurally in regular time sequence, each sound being a two-tone complex with frequencies at successive harmonics of some (missing) fundamental frequency. The lower harmonic number was chosen randomly between 3 and 5 for each sound. Four different sequences of fundamentals between 200-400 Hz were used to generate four classes of stimuli, each class having 81 elements. The stimuli were generated electrically by programmable oscillators (G. R. 1161-A, K. H. 4031R) and presented via TDH-39 headphones to subjects who were seated in a sound-insulated chamber (I. A. C. Model 1200). A DEC PDP-4 computer was used to control the experiment. In the first part of the experiment, subjects could control the class of the stimulus and were instructed to listen for a (a priori unknown) melody characterizing each class, and to write it down using a relative note scale. In the second part, elements of all four classes were presented at random, and subjects were asked to identify the class of each element. All subjects were familiar with musical dictation. Eight out of nine subjects characterized each class by the (missing) fundamentals in the first part, and scored perfectly in the second part. These results demonstrate the musical phenomenon of fundamental-tracking, namely that, under certain conditions, a musical message comprising a series of fundamental periods can be retrieved aurally from a sequence of periodic sounds.

b. Identification of Intervals

Experiments were performed to study the conditions under which the phenomenon demonstrated above is present. The task of the subject was to identify on a given trial which one out of 8 known two-note melodies (i. e., intervals) was presented. These simple melodies had identical envelope time structure, and began with the same note. The sounds representing the notes had only two successive harmonics, where the lower harmonic number was randomly chosen for each note over a range of 3 successive integers. The middle of the range of the lower harmonic number, n, and the fundamental frequency of the first note, f_o, were chosen as independent parameters in measuring identification performance (% correct). The basic experimental paradigm is illustrated in Fig. XII-1. Before the test was performed, a control experiment was performed using square-wave sounds to test the subject's ability to identify musical

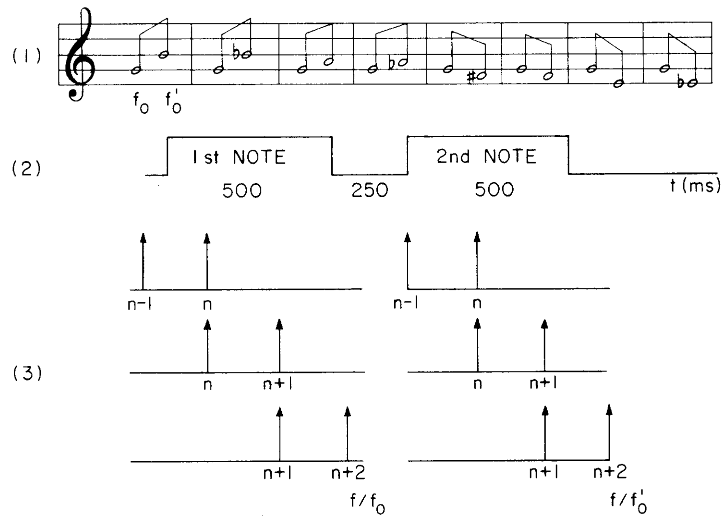

Fig. XII-1. Stimulus paradigm for experiment 2b. Musical intervals to be identified (1), timing of the stimulus (2), and the three possible two-tone stimuli for each of the two notes (3). For each note, a random choice was made among the three possible stimuli.

intervals when more "normal" musical sounds are used. An essentially perfect score was required before proceeding with the test experiments. The results of the interval identification experiment with two-tone sounds, performed with monotic presentation (one ear) at a sensation level of 20 dB, are shown in Fig. XII-2. Data on only one subject (A. H.) are reported here and in the next figures. Similar results have been obtained from 3 other subjects, but are still incomplete. It is evident from Fig. XII-2 that the best performance is achieved with the lowest harmonics. This, together with what is known about the physiology of the cochlea and the psychophysics of resolution of partials in complex tones, suggests that both harmonics of the sounds employed in this experiment must be processed through separate channels of the cochlear output to obtain successful identication.

To investigate this possibility further, all experiments mentioned above were repeated, with the exception that the two harmonics of each sound were presented dichoticly, one harmonic in each ear. In the dichotic version of experiment 2a, the performance of 5 out of 9 subjects was the same as in the monaural version; that is, they perceived melodies corresponding to the missing fundamentals, and scored perfectly in the identification part. Three subjects had some difficulties in both parts,

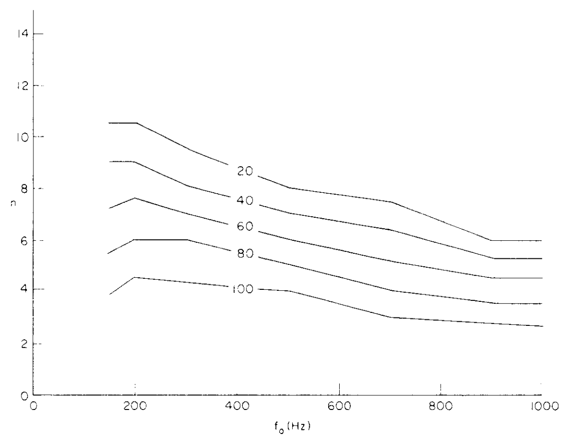

Fig. XII-2.

Equal-performance contours (per cent correct) for identification of 8 musical intervals (shown in Fig. XII-1) as a function of harmonic number n, and fundamental frequency f_o. Stimulus presented monoticly at 20 dB SL.

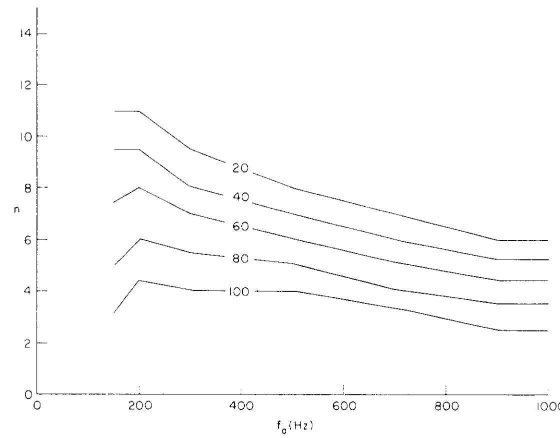

Fig. XII-3.

Stimulus presented dichoticly at 20 dB SL. Otherwise the same as in Fig. XII-2.

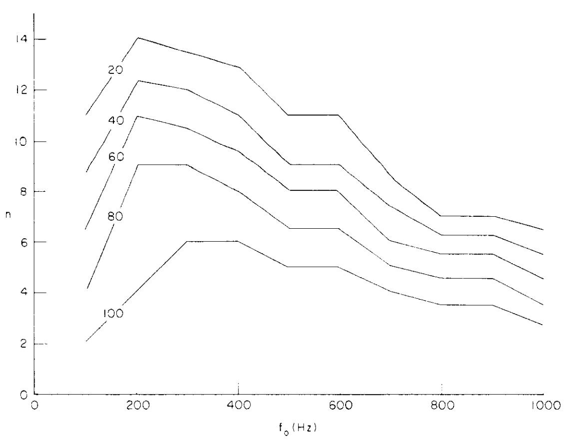

Fig. XII-4.

Stimulus presented monoticly at 50 dB SPL. Otherwise the same as in Fig. XII-2.

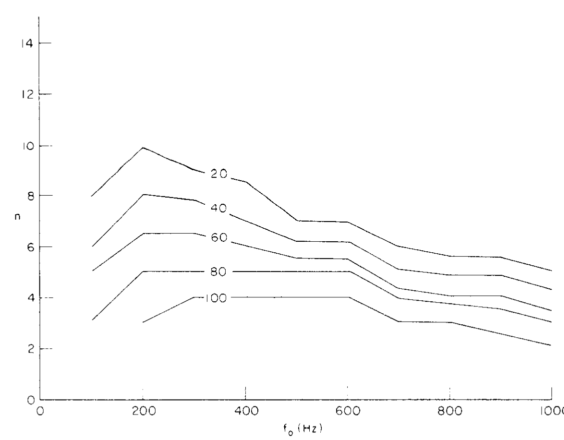

Fig. XII-5.

Stimulus presented dichoticly at 50 dB SPL. Otherwise the same as in Fig. XII-2.

probably reflecting a lack of training. One subject was completely unable to perform the task (the same subject had difficulty with the monaural experiment).

The results of the dichotic version of the interval identification experiment are shown in Fig. XII-3. The performance in this dichotic test is essentially identical to that of the monotic test described in Fig. XII-2. This suggests that a central mechanism integrates and processes information from both cochleas and that the inputs to this mechanism are similar for the dichotic and monotic stimuli used.

To investigate the dependence of performance on intensity, the interval identification experiments were repeated, both monotic and dichotic, at a higher intensity level, 50 dB SPL. The results are shown in Figs. XII-4 and XII-5. Noteworthy are the similarity of Figs. XII-5, XII-2 and XII-3, and the upward shift of the equal performance contours by approximately 2 or 3 harmonic numbers in Fig. XII-4. This upward shift might be expected because of the presence of aural combination tones generated in the peripheral ear with these monotic stimuli (Goldstein,[1] Goldstein and Kiang[2]). These combination tones provide the ear with 2 or 3 useful harmonics below those contained in the stimulus, so that the effective harmonic number is 2 or 3 lower than the value of n in Fig. XII-4. In the dichotic experiments, combination tones are not present, and in the monaural experiment at 20 dB SL, they are near or below threshold.

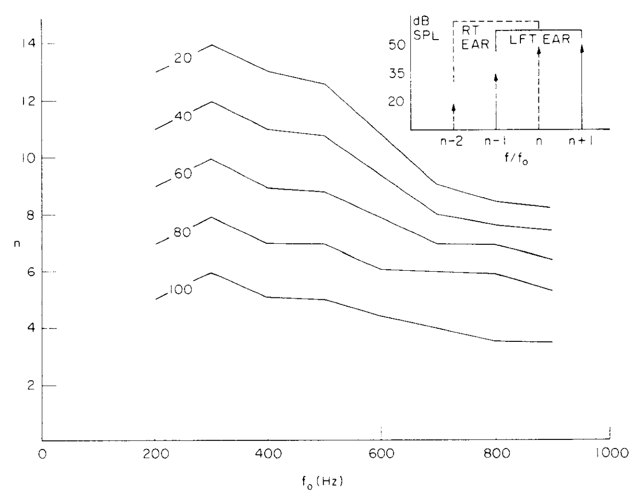

Fig. XII-6. Stimulus the same as in Fig. XII-5, with the addition of two tones, at intensities and frequencies shown, to simulate combination tones.

The combination-tone hypothesis was tested with an interval identification experiment using dichotic stimuli containing tones that simulate the aural combination tones of the monotic stimuli. The stimulus paradigm and the experimental results are shown in Fig. XII-6. The similarity of Figs. XII-4 and XII-6 supports the combination-tone hypothesis.

3. Control Experiments

The foregoing experiments demonstrate the ability of observers to respond as though they are tracking the fundamental of various monotic and dichotic periodic sounds. We next inquired whether this behavior is directly determined by the ability of observers to track individual partials in periodic sounds. If observers can infer the frequency of individual partials, perhaps from the characteristic quality of each partial, then the fundamental could be deduced from the spacing between harmonics. Moreover, either of the two simple tones of each sound can in principle be used to infer the fundamental frequency from a known class because the stimuli used to represent different notes contain almost no coincident frequencies. Simple control experiments were performed to test these possibilities. Experiments similar to those of section 2 were conducted in which the two harmonics used for each note were presented in time sequence rather than simultaneously as before. No subject could report the notes in experiments 2a or identify known intervals significantly better than chance in experiments 2b.

4. Relation to Earlier Work on Fundamental Extraction

a. Experiment

For well over a century, the phenomenon of fundamental-tracking in the perception of periodic musical sounds has been actively studied and reported in terms of pitch perception evoked by single sounds with fixed harmonics (Schouten, Ritsma and Cardozo,[3] Plomp,[4] Helmholtz,[5] Seebeck[6]). We have chosen to perform experiments using sequences of sounds with random harmonic number: (i) because we found that successive notes evoked in subjects a sense of musical interval and provided a context for the feature of each sound that was being contrasted; (ii) to minimize the opportunities for behavioral responses that are directly correlated with tracking of individual partials; and (iii) to demonstrate directly the role of this phenomenon in musical behavior. Despite our departures from earlier procedures, we believe that our investigations involve the same phenomenon as described by earlier work.

Schouten et al.[3] reported pitch matches in which inharmonic complex tones with uniform frequency spacing were aurally matched to periodic complex tones with a fundamental that differed systematically from the spectral spacing of the inharmonic sound. We essentially replicated these results with a matching experiment in which a two-note melody A-B was matched to another melody A-X. A and B were periodic two-tone complexes with fixed harmonic numbers of 4 and 5. X had 2 simple tones with a fixed

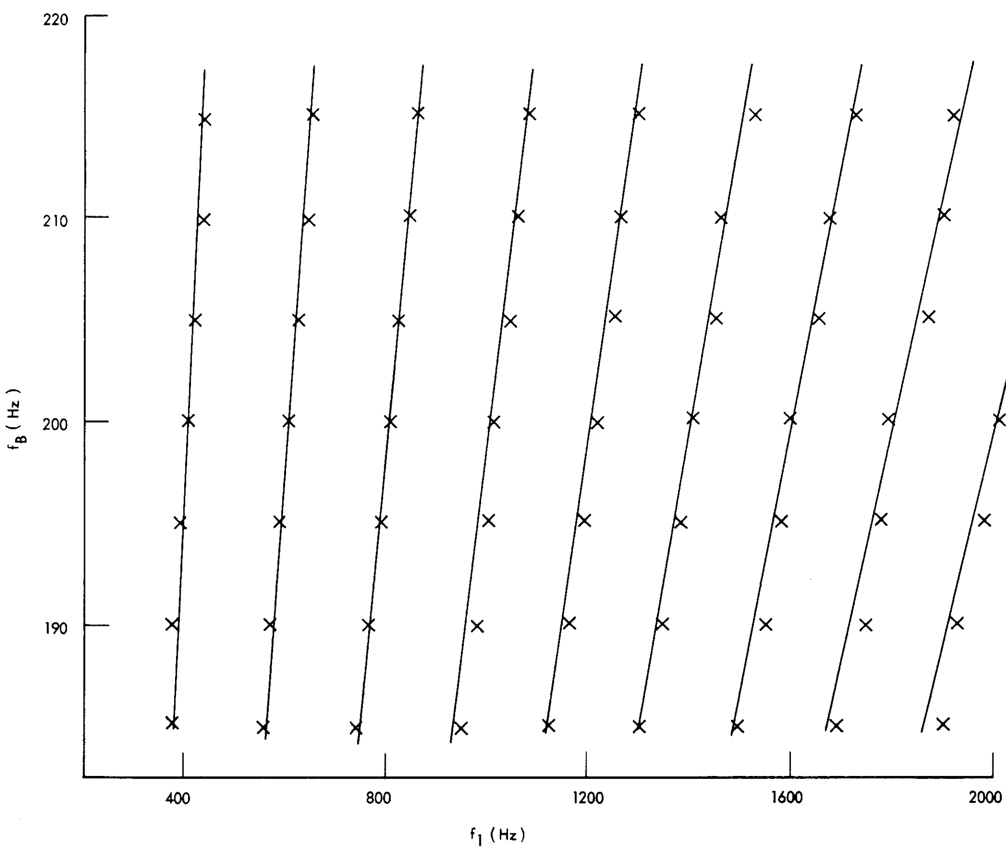

Fig. XII-7. Frequencies, f_1 and $f_2 = f_1 + 200$ Hz, of the two-tone stimulus X that were measured for each stimulus with fundamental f_B in aurally matching the interval A-B to A-X. The data are roughly described by straight lines drawn through the harmonic frequencies $f_1 = 200n$ Hz, and $f_B = 200$ Hz, with a slope of $1/n$.

spectral spacing of 200 Hz. The fundamental of B was set equal to one of the seven frequencies at 5-Hz steps in the range 185-215 Hz, and the fundamental of A was always a full tone below that of B (i.e., a ratio of 8/9). The subject aurally matched the intervals of A-X and A-B by adjusting the frequencies of X and produced the results shown in Fig. XII-7. Consistently with earlier reports, these data suggest that the fundamental-tracking mechanism does not simply operate on the difference frequency between successive tones.

Finally, an experiment was conducted to relate the findings of pitch-matching experiments more directly to our experiments on interval identification. Interval identification was tested with monotic stimuli that were the same as those which yielded perfect performance (see Fig. XII-5), except that for each note the two frequencies of the note were uniformly shifted up or down in frequency by some random increment less than the fundamental. The resulting inharmonic two-tone sounds preserved the relevant message in their difference frequencies. Nevertheless, the random performance in interval identification that was actually obtained agrees with the behavior expected from the pitch-match data for inharmonic stimuli.

b. Theory

The two currently popular theories of musical pitch perception are the frequency-detection theory (Helmholtz[5]) and the periodicity-detection theory (Schouten[7]). According to the former theory, the cochlear spectrum analyzer maps the energy of the fundamental tonotopically, and pitch is associated with spatial position of the fundamental. According to the latter theory, some mechanism is presumed to measure the temporal periodicities at the output of the cochlear spectrum analyzer and then associate pitch with temporal interval.

The dichotic experiments that we have reported prove directly that neither fundamental energy nor fundamental periods in the cochlear output are necessary for fundamental tracking. This definitive contradiction of the periodicity-detection theory is a new finding. The inadequacy of the frequency-detection theory has already been established by earlier reports that fundamental-tracking with periodic stimuli (below ~60 dB SL) containing no fundamental energy cannot be attributed to distortion tones generated in the peripheral ear (Schouten et al.,[3] Plomp,[4] Goldstein[1]).

If we consider these theories from a converse viewpoint we observe that a sufficient basis for fundamental-tracking can be provided by energy at the fundamental frequency, but probably not by fundamental periods in the cochlear output. The interval identification data suggest that fundamental periods in the cochlear output are irrelevant for the following reasons: (i) Interval identification data with monotic and dichotic stimuli are very similar except for differences at the higher stimulus intensities which are well accounted for by combination tones. Hence the fundamental periods in the cochlear output, which can arise only for the monotic stimuli, are of little or no value in tracking the fundamental. (ii) The possibilities with monotic stimuli for fundamental periods in the cochlear output are enhanced as the harmonic number, n, is increased. Yet interval identification deteriorates to random with increasing harmonic number. (iii) All monotic stimuli for which identification performance was better than random either consisted of behaviorally resolvable tones or generated such tones as combination tones. A behaviorally resolvable tone is a partial of a complex tone stimulus that can be aurally matched to a simple tone of similar frequency as the partial. Partials of a two-tone stimulus, as well as combination tones generated by this stimulus that are spaced in frequency by less than approximately 10%, cannot be behaviorally resolved (Plomp,[8] Goldstein[1]). This close correlation between the limits on fundamental-tracking and behavioral frequency resolution suggests that for complex tone stimuli the tracking mechanism necessarily operates on those stimulus tones or combination tones that are resolved in the cochlea.

Further research on fundamental tracking is in progress.

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B. ARTERIAL PULSE WAVE VELOCITY AS AN INDICANT OF DIASTOLIC PRESSURE

There is a need in clinical medicine for an instrument to conveniently monitor blood pressure in ambulatory patients during a day's normal activities. Such a device would contribute to the diagnosis, therapy, and epidemiology of hypertension and its related complications. Previous data gathered by others (Bramwell and Hill,[1] Steele[2]) have suggested that a linear relationship exists between diastolic pressure and pulse wave velocity. If substantiated, this relationship might form the basis for a system to continuously monitor diastolic pressure.

To a first approximation, the elastic arteries such as the aorta may be regarded as elastic tubes filled with incompressible fluid. The heart provides a pulsatile input to the system. Pulses propagate in a wavelike manner with a characteristic velocity that is a function of the modulus of elasticity for lateral expansion of the artery (E), the arterial wall thickness (a), the density of blood (ρ), and the arterial radius (R) (Moens[3]).

$$V = \sqrt{\frac{Ea}{\rho R}}.$$

It is clear from this equation that as E increases the wave velocity increases.

Furthermore, it is known that for arteries E increases rapidly with increasing R; and R in turn increases with diastolic pressure. Thus, it should be expected that pulse wave velocity increases with increasing diastolic pressure. In fact, it has been experimentally demonstrated by Steele[2] that for a given individual the pulse velocity increases linearly with diastolic pressure.

The present series of experiments was performed on dogs to determine whether the linear relationship reported by Steele could be verified, and whether it would hold in the presence of such physiologic manipulations as vasoconstriction, vasodilation, sympathetic stimulation, changes in cardiac output and contractility, and changes in blood volume. Pressures were measured in the carotid and femoral arteries, and in the arch of the aorta. In one experiment, the mechanical pulsations of the carotid and femoral arteries were measured by means of transducers made of phonograph cartridges. In that experiment, aortic pressure was also measured. EKG's were recorded for all subjects. Typical experimental data are shown in Fig. XII-8, illustrating both mechanical and

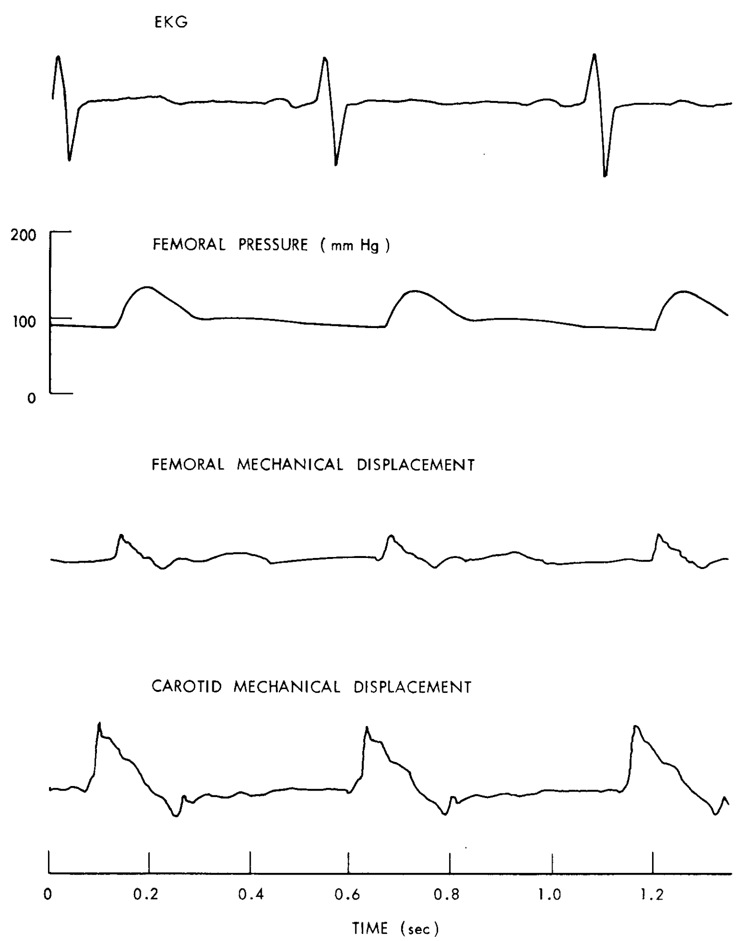

Fig. XII-8. Waveforms from Experiment 1.

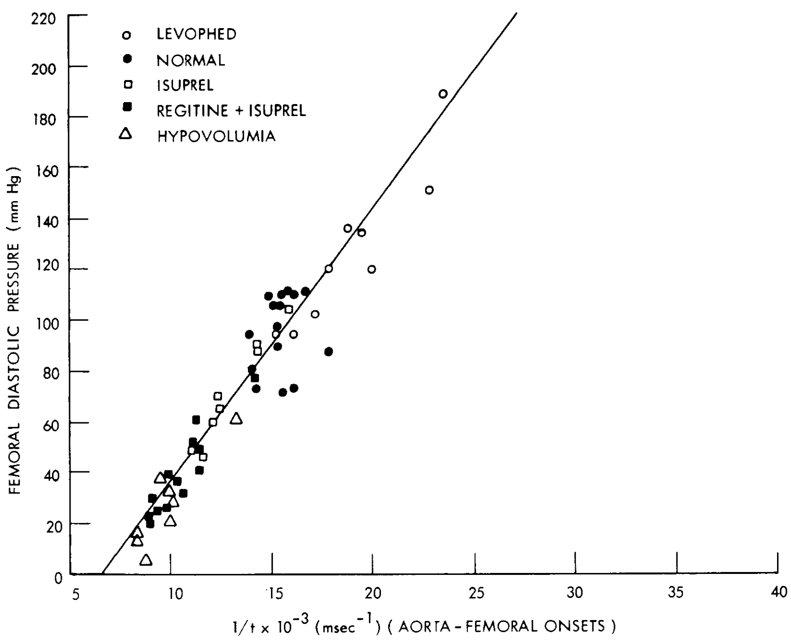

Fig. XII-9. Femoral diastolic pressure vs aortic-femoral velocity (1/t) calculated from pressure waveforms from Experiment 3.

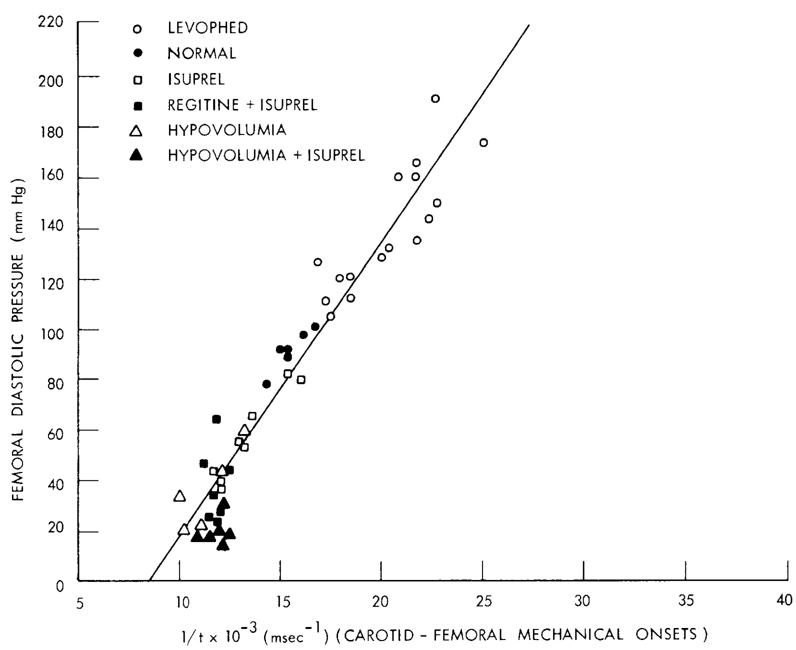

Fig. XII-10. Femoral diastolic pressure vs carotid-femoral velocity (1/t) calculated from mechanical transducer waveforms from Experiment 3.

pressure waveforms. Blood pressure was increased by administration of Levophed, and decreased by means of Isuprel, Isuprel and Regitine, or by blood volume depletion. For each pressure, the transmission time ΔT between the onset of pressure in the aorta and its onset in the femoral artery was measured. The results from one animal are shown in Fig. XII-9, where femoral diastolic pressure is plotted against the quantity $1/\Delta T$ which is velocity in arbitrary units. The line was obtained by the method of least squares. It is significant to note that there are no systematic departures from linearity because of the different types of physiological manipulations. The mechanical data are plotted in Fig. XII-10, which shows femoral diastolic pressure vs the pulse velocity calculated from the difference in pulse arrival times at carotid and femoral arteries. Again the relationship is remarkably linear.

The latency between the QRS complexes of the EKG and the onset of pressure in the aorta was also measured. It was discovered that the variability in this latency under the various experimental conditions was quite large (of the order of 50 ms). This variability is of the same order of magnitude as the transmission time of the pulse wave from aorta to femoral artery. Hence, the EKG may not be used as a time reference for measuring pulse wave transmission times.

Based on these encouraging results, work in this area continues, and will be concentrated in the following areas: (i) use of the second heart sound as a time reference, (ii) development of reliable transducers to detect pulse wave arrivals at peripheral arteries without discomfort to ambulatory patients, and (iii) design of related circuitry.

K. A. LaBresh, R. G. Mark

References

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C. USE OF A HARDWARE CHARACTER GENERATOR WITH SMALL COMPUTERS

A hardware character generator is a device that accepts a character code from a computer or other device and, upon receipt of a start command, draws a character on a display device. The hardware itself generates all necessary incremental horizontal and vertical deflection signals and plot (intensify) signals, thereby leaving the originating device (computer) free to go on to other operations.

Until recently, hardware character generators were not to be found in inexpensive computer display systems. While the basic elements in hardware character generators are fairly simple and the control logic not much more complex than that in the usual peripheral device such as a teletype, the character generator requires several thousand bits of memory. Until very recently, such memory capacity was fairly expensive, costing approximately a thousand dollars for a single unit. Now large-scale-integrated circuit (LSI) memories are available which reduce this cost by approximately an order of magnitude and also consume less space and power. Thus a hardware character generator has become economically comparable to a teletype interface, and hence seems quite feasible for inclusion in a small computer system.

This device has considerable advantage over software generation of alphanumeric displays, which uses a point-plotting program running in the central processor and stored tables for the character set. These advantages may be compared in terms of both memory requirement and display speed (or refresh rate).

1. Memory Requirement: A typical algorithm used for generation of an alphanumeric character might involve 40 instructions plus the character table itself which would occupy another 150 locations. (There are techniques that considerably reduce this number at the cost of reduced display rates.) The preliminary instruction sequences needed to position the character, determine format, unpack data, and so forth might require an additional 40 locations in memory. This additional requirement, however, is an "overhead" which is necessary whether hardware or software is used for the actual generation of the character. So the actual memory requirement is reduced from approximately 230 locations to approximately 40 locations (a factor of six). Of course, the cost of 230 locations is often low enough to make this saving alone an insufficient reason to invest in a hardware character generator.

2. Display Speed: The time needed to produce a character display can be broken down into two parts: (a) the time needed to determine which character to display and where it would be positioned; and (b) the time needed to actually display the character. When using a software character generation routine, these operations must be executed sequentially. A hardware generator allows these operations to overlap, thereby offering a potential speed-up of the character display. A software character display algorithm might involve a tight program loop of approximately 6 instructions that must be executed 35 times; once for each possible point in the display. Although clever programming can overlap the execution of this loop with the intensification of the previous point to minimize wasted time, the fundamental limitation of the refresh-rate of a high-speed oscilloscope display is usually determined by the total number of instructions executed rather than by the display device itself. When using a hardware character generator approximately 50 instructions must be executed for each character displayed. (This time includes overhead.) Most hardware can display a

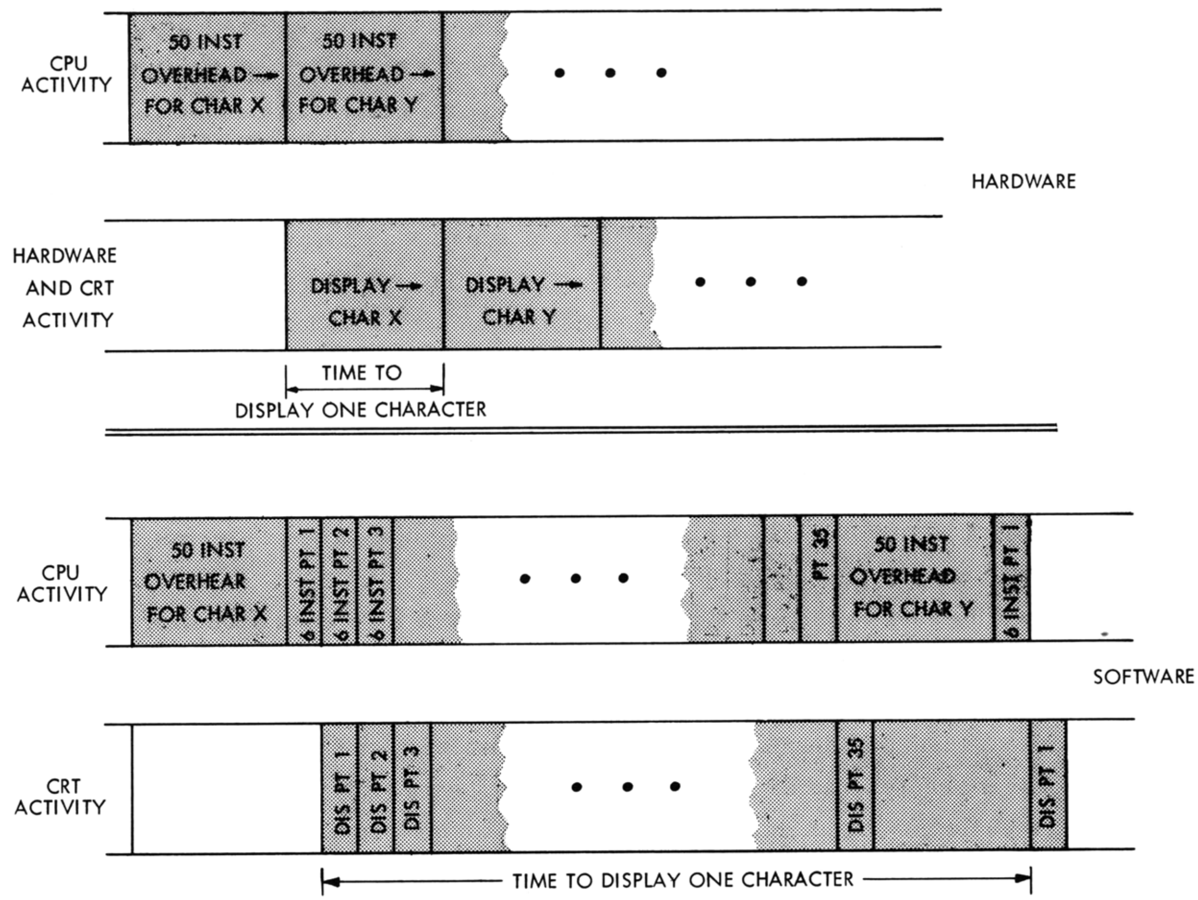

Fig. XII-11. Comparison of hardware and software character generation. Activity of the central processing unit (CPU) and of the hardware and CRT display are indicated on the two timing diagrams provided for each of the two methods. The time scales are equal. It is assumed that both methods produce displays of adequate brightness and that longer intensification time is not desirable.

character in a comparable amount of time. This must be compared with the time required to execute approximately 300 instructions associated with a software character generation algorithm. If the operation of the hardware completely overlaps execution of the 50 "overhead" instructions, then the over-all refresh-rate has been improved by a factor of six. These operations are illustrated in Fig. XII-11,

Thus the advantages of a hardware character generator include savings of approximately 200 memory locations and a factor of six in speed. The total parts cost of the device described is around $200, which suggests that it is an attractive addition to a small computer facility.

1. Operation

Multiple ASCII symbols are formed by displaying points arranged in a 5 × 7 dot matrix. (This matrix, with all 35 points intensified, appears in Fig. XII-14a and the display of the ASCII code for the numeral "2" appears in Fig. XII-14c.) This display is achieved by sequentially positioning the oscilloscope beam (or pen, in the case of a plotter) at points corresponding to a 5 × 7 raster and examining the memory to see if the point should be plotted. If it should, a plot-command (ZOUT) is given and the point is plotted. After a plot-complete signal (PTCMPL*) is received from the display device, indicating that the point has been plotted, these operations repeat for the next point. In case the point should not be plotted, the plot signal is omitted and a sequence of operations equivalent in effect to the plot-complete signal causes the character generator to advance. The display is initiated by a signal from the computer (RESET*), and begins in the lower left corner and advances from left-to-right until a row is complete. Rows are plotted from bottom-to-top, and the entire plot is complete after the upper right point has been examined and a completion pulse generated (CHARCMP).

The memory used for the character generator is organized into 5-bit words which correspond to the elements in a single row of a character. There are 7 such rows

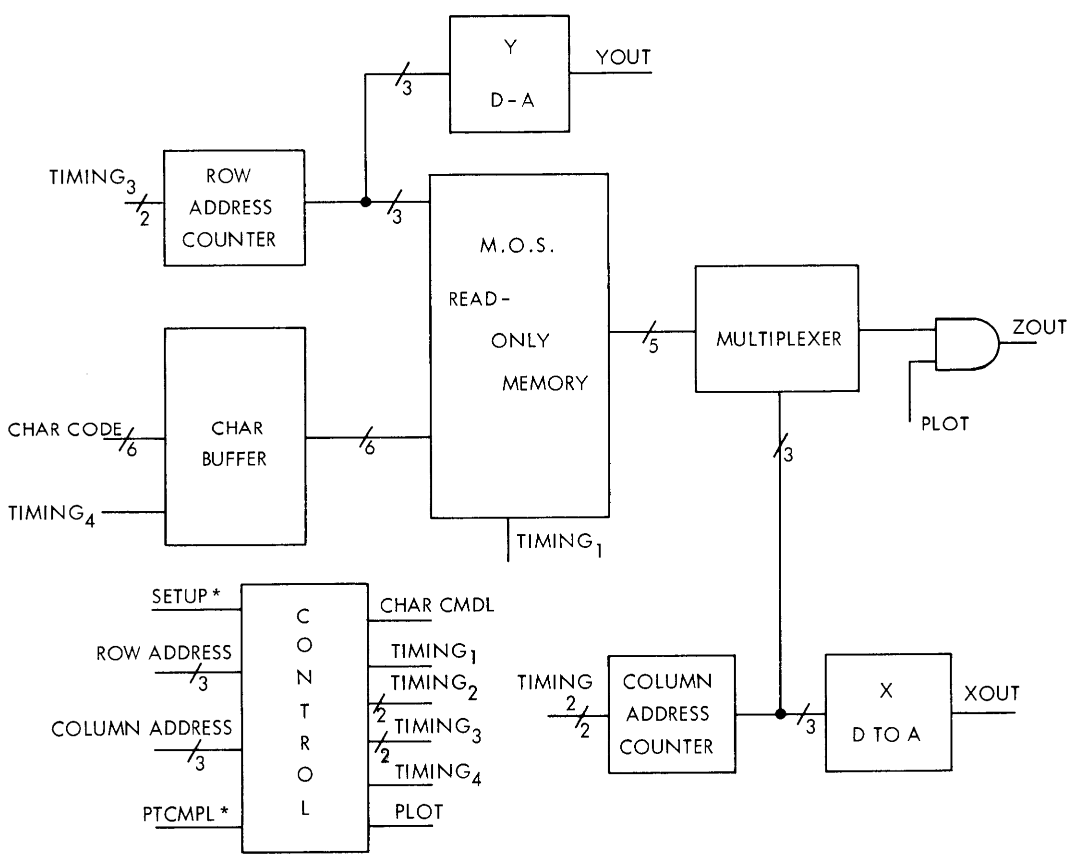

Fig. XII-12. Block diagram of character generator.

stacked vertically to form a complete character. Operation of the device involves 7 accesses to the memory and continues without demanding additional attention from the computer. The character generator is shown in the block diagram of Fig. XII-12.

Plotting a character is initiated by a start signal (RESET*) from the computer which strobes the ASCII code into the character buffer and resets the row and column address counters to zero. The trailing edge of this pulse causes row 0, containing the first 5 points of the specified character, to appear and remain at the memory output. When memory access is complete, the first point (Row 0, column 0) is examined, plotted if necessary, and then the column address counter is incremented. This causes the associated D-A converter to position the display to the point corresponding to column 1. The output of the memory corresponding to this point is then examined, plotted if necessary, and the process continues 3 more times until all 5 columns have been examined. At this time, the row address counter is incremented, and the second row is read from memory and the column address counter reset in that order. The second row of 5 dots is plotted in the same manner, and the process is repeated 5 more times until all 35 points in the 5×7 matrix have been examined and plotted if necessary. After the column counter advances, a character-complete pulse (CHARCMP) occurs which indicates that the character has been completely plotted. The display remains inactive until a new character plot is initiated.

2. Implementation

A schematic diagram of the complete character generation system is presented in Fig. XII-13. Components include 25 packages of Transistor Logic (TTL), a read-only memory (Electronic Arrays, Inc. Type EA3501), a MOS clock driver (Sylvania MS302) along with the associated resistors, capacitors, etc. These are mounted on three $4'' \times 5''$ circuit boards.

Most of the design is straightforward. There are, however, several unusual features. Notice that the D-A converters are implemented with 7404N hex inverters used as voltage switches to drive the binary weighted resistor network. Examination of several different units suggests that the offset and output impedance of the inverter permit accuracies of 1/2 of one bit in a 3-bit converter. Because of the possibility of noise on the +5 V logic line, use of a separate +5 V reference supply is recommended for this package. Another unusual feature is the use of TTL gates as the memory address drivers. Since external resistors return these outputs to the +10 V supply, it is necessary to select TTL which will withstand a minimum of 10 V on the output lead. (National Semiconductor Corporation claims that their DM8000 units will withstand this voltage.)

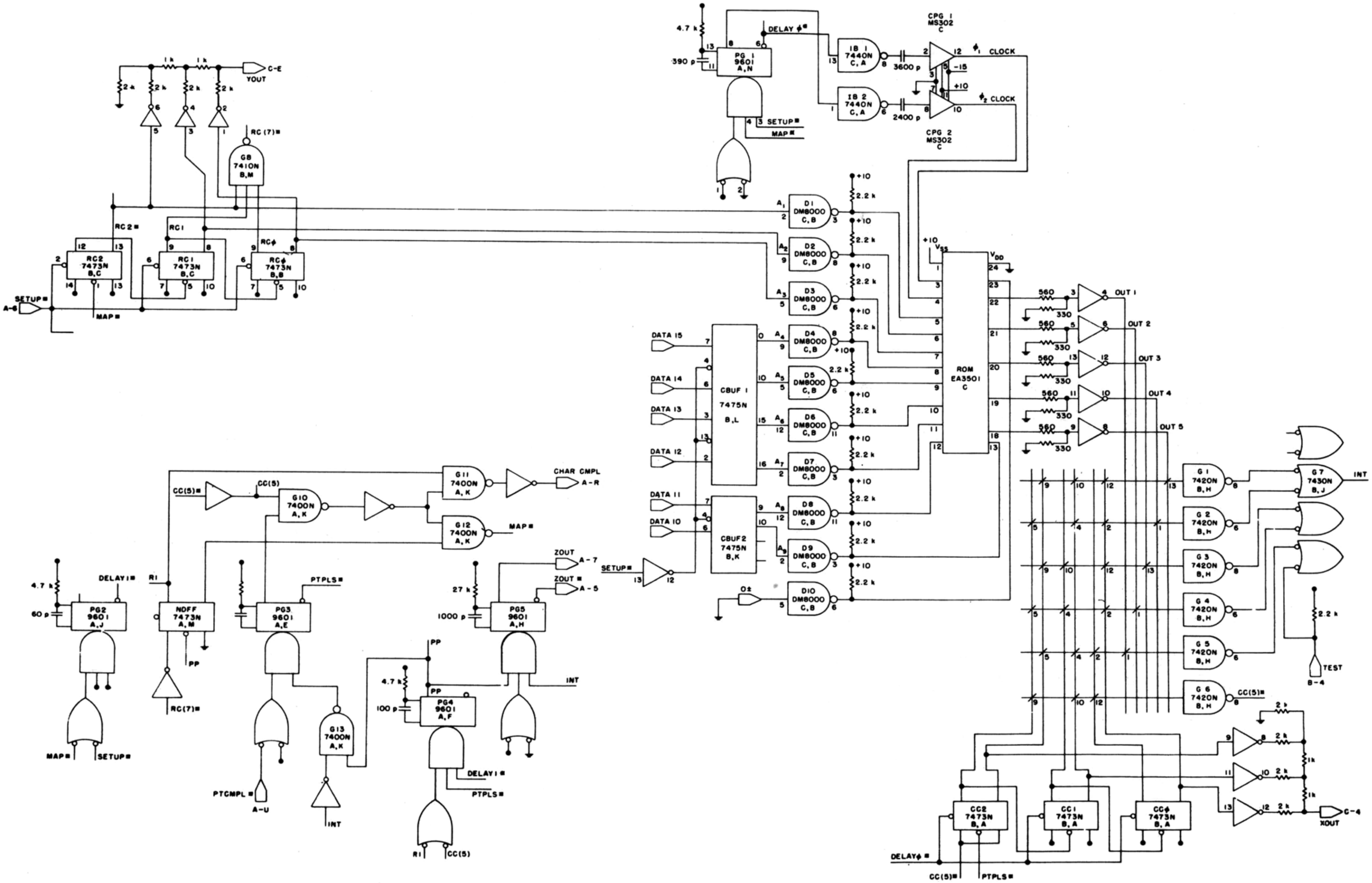

Fig. XII-13. Schematic diagram of character generator.

3. Timing

Type 9601 TTL monostable multivibrators are used for all timing except that which is based on the leading and trailing edges of the (SETUP*) pulse. (This pulse comes from the computer system and is assumed to be 500 ns.) Memory access is initiated by triggering PG1 either by the trailing edge of the SETUP* pulse or the trailing edge of the memory access pulse (MAP*). The leading edge of the 600-ns pulse from PG1, DELAY, generates a 500-ns ϕ_1 clock pulse for the MOS memory. The trailing edge of DELAY produces a 300-ns ϕ_2 clock pulse. Examination of the memory output is initiated by the trailing edge of a 1500-ns pulse from PG2, labeled DELAY1, which overlaps the memory access cycle. The duration of this pulse must be greater than or equal to the sum of the duration of the SETUP* pulse and the access time of the memory, since it is initiated by the leading edge of the SETUP* pulse. A 10-μs pulse, ZOUT, is generated by PG5 whenever a point is to be intensified (or plotted). Ten microseconds is probably adequate for most oscilloscopes, including the Tektronix storage displays. Another pulse generator, PG4, provides a 200-ns delay between the operations of incrementing the counters and initiating ZOUT to provide adequate time for the analog deflection signals to settle. The total times needed to display a character are split into two components: overhead, and intensification. Memory access requires 10.5 μs, since 7 accesses are required for each character and access time is 1500 ns. Examination of each of the 35 points in the matrix requires 400 ns, yielding another 14 μs of overhead for a total of 24.5 μs. For a CRT display, the intensification time is set for 10 μs, so the time needed to plot a character is given by 24.5 + 10N μs, where N is the number of points to be displayed. This overhead time (24.5 μs) could be cut down to approximately 10 μs by reducing the duration of the timing pulses. Since the total time required to display a character is approximately an order of magnitude larger, it hardly seems worth while.

4. Results

Some of the signals produced by the character generator are presented in Fig. XII-14. The dot matrix and the associated intensification and deflection signals appear in Fig. XII-14a and XII-14b. The time base is adjusted to display events concomitant with the display. Note that the X and Y signals increment sequentially, thereby positioning the beam from left to right and from bottom to top. The character "2" is displayed in Fig. XII-14c, and the associated deflection and intensification signals are shown in Fig. XII-14d. Notice that the beam does not remain at points that are not to be displayed nor is it intensified. Figure XII-14e is an expanded view of the second centimeter of the waveforms shown in Fig. XII-14d. In this interval the following events take place: the last two points on the bottom row are displayed; contents of the

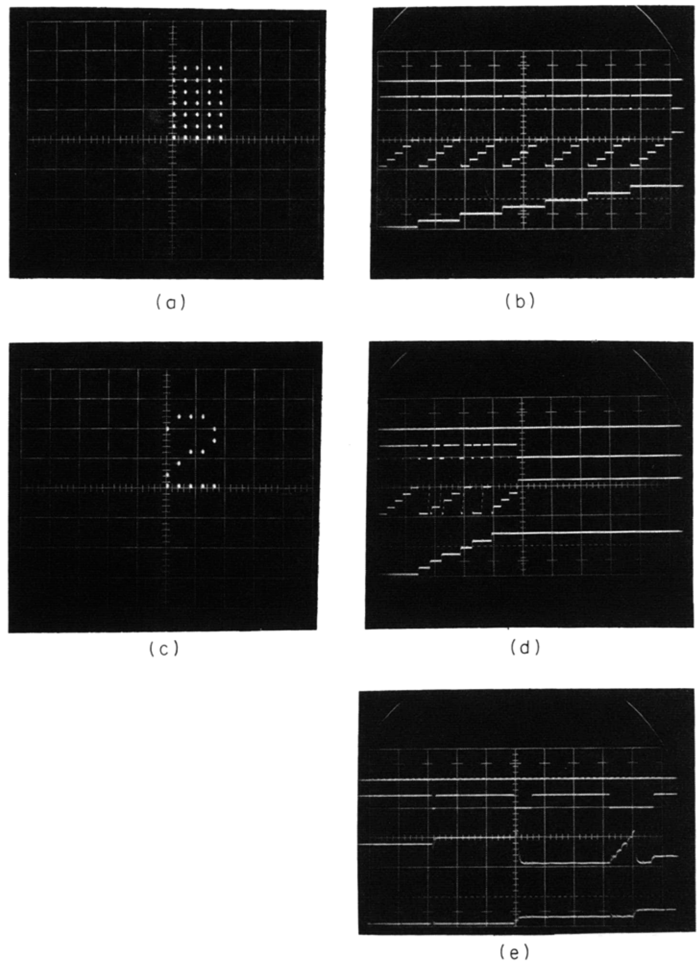

Fig. XII-14. (a) 35-point raster which is the basis of all sixty-four ASCII characters represented. Each point is intensified 10 μs. Horiz. and Vert. sensitivities are 1 V/cm.

(b) Waveforms associated with display of all 35 points shown in (a). Traces from top to bottom: 500 ns start pulse 10 V/cm; intensify signal ZOUT 10 V/cm; horizontal deflection XOUT 2 V/cm; vertical deflection 2 V/cm. The time base is adjusted to display events concomitant with the display of all 35 points.

(c) Raster used to display numeral "2".

(d) Waveforms associated with the display of "2" shown in (c). Same scales as in (b).

(e) Expanded view of the second centimeter of the waveforms shown in (d), corresponding to the display of the last two points in the bottom row, the first point in the second row, and the second point in the third row.

memory corresponding to the second row are read; the first point in the second row is intensified; the remaining 4 points in the second row are examined but not displayed; the third row is accessed, and the first point is examined and skipped; and finally the second point in the third row is intensified.

5. Summary

A character generator has been described which comprises readily available components costing less than $200, including the read-only memory. The system is interfaced for TTL logic and requires a 6-bit ASCII code specification of the character and a start-command coincident with the presence of the character code. The device displays a complete character in approximately 25 + NT μs, where N is the number of points in the character, and T is the time needed for plotting a single point. An average character is plotted on an oscilloscope in approximately 200 μs, allowing 10 μs for each intensification.

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