Title	Korean character display by variable combination method
Sub Title	
Author	Lee, Joo-Keun
Publisher	慶応義塾大学工学部
Publication year	1973
Jtitle	Keio engineering reports Vol.26, No.10 (1973.) ,p.107- 129
JaLC DOI	
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Notes	
Genre	Departmental Bulletin Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO50001004-00260010-0107

KEIO ENGINEERING REPORTS
VOL. 26 NO. 10

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By

JOO-KEUN LEE

FACULTY OF ENGINEERING
KEIO UNIVERSITY
YOKOHAMA 1973

KEIO ENGINEERING REPORTS
VOL. 26, NO. 10, pp. 107-129, 1973

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JOO-KEUN LEE*

(*Received Nov. 15, 1973*)

ABSTRACT

The author has developed a new system of character generator which is able to display more than 14,364 different Korean characters by the inputs of the 24 fundamental elements. In this system, all of the Korean characters are formalized into 30 kinds of character forms (each having 70–980 characters), from which the seven form features are detected to control and combine the input fundamental elements at their proper sizes and positions in a character frame.

The device is very simple and economical and all of the Korean characters can be displayed on CRT by the operation of only 24 input keys in good character quality.

1. Introduction

Character display has been rapidly progressed from the simple number indicator to the monitoring and checking of information in accordance with the development of information society. In addition to CRT as its output device, plasma display, liquid crystal, and light emitting diode have been employed according to the exploitation of new materials [POOLE (1966), HOBBS (1966), WILLSON (1968), BITZER (1968), RUSS (1968)].

The problem of character generation is utmost important in the character display, which is true particularly in the case of Korean and Chinese characters where the kinds of characters are numerous and hence very complicated devices are required [SHAITO (1968)]. In contrast with the conventional methods of character display where, in general, one output is generated corresponding to one input, in the pro-

* Dr. Lee is Professor of Electronic Engineering at Nin-ha University, Seoul, Korea, He had been a visiting professor at Keio University from Dec. 1972 to March 1973.

posed method, the inputs of fundamental elements constituting a character are changed in their sizes and positions and combined to form that characters at the output. So, the 14,364 different Korean characters can be generated from only 24 keys of 5 bits and good quality of combined characters can be obtained with a simple and economical device. From the experiment with this device, it was confirmed that over one million characters, including those which can express the pronounciation of archaic words, dialects, and words of foreign origin, can be generated from the 24 fundamental elements. In section 2, the general description of Korean character is presented. The principal ideas and methods of this study are introduced in section 3. That is, the discriminations of character forms are performed by giving the characteristic codes to the fundamental elements. In section 4, the practical circuits of this system are constructed. Conclusions and discussions are presented in section 5.

2. Korean character

The Korean character, Hangeul, was invented by Sejong the Great in September, 1446. It is one of the most perfect phonogram that has ever been established by man in human history. The scientific fabrication and its logical process of character synthesis will be explained here.

A. Fundamental elements

It should first be noted that, in Korean character, there are 28 fundamental elements and all of the characters are synthesized by the combination of this 28 fundamental elements in rectangular frame.

The 28 fundamental elements are composed of 17 consonants and 11 vowels which are combined to represent all of the possible sounds of Korean language. These consonants and vowels are presented in Table 1.

As shown in Table 1, the 17 consonants are partitioned into 5 groups in accordance with their phonetic characteristics and each of these 5 groups has their basic consonants such as " ㄱ, ㄴ, ㅁ, ㅅ, ㅇ ". It is very interesting to note the fact that each of the symbols of the basic consonants resembles the figure of the vocal organs when they are pronounced. All of the other consonants had been deriven successively by adding one stroke to their basic consonant. For instance, the consonant " ㅌ " can be derived from the consonant " ㄷ " which is also able to be deriven from the basic consonant " ㄴ ". It is very important to note the fact that every element in the same row in Table 1 belongs to the same pronounciation series. That is to say, in the 5th row of consonant in Table 1, the element " ㅊ " is the voiced sound of the element " ㅈ " and also this pronounciation is

Table 1. Fandamental elements (17 consonants and 11 vowels)

Classification of sound	Consonants (a)		
Velar sound	ㄱ (g) →	ㅋ (k')	ㆁ (ŋ)
Lingual sound	ㄴ (n) →	ㄷ (d') →	ㅌ (t')
Labial sound	ㅁ (m) →	ㅂ (b') →	ㅍ (p')
Dental sound	ㅅ (s) →	ㅈ (dʒ') →	ㅊ (tʃ')
Guttaral sound	ㅇ →	ㆆ* →	ㅎ (h)
Semi-lingual-S Semi-dental-S	ㄹ (r.l)	ㅿ*	

Vowels (b)	(c)
ㅡ (ɯ) →	ㅣ (i)
ㅏ (a) →	ㅑ (ja)
ㅓ (ə) →	ㅕ (jə)
ㅗ (o) →	ㅛ (jo)
ㅜ (u) →	ㅠ (ju)
ㆍ*	

deriven from the pronounciation of the element " ㅅ ". This is only because the elements had been partitioned by their phonetic characteristics.

The vowels, presented in Table 1, are able to be deriven by the same method used in the derivation of the consonants. The vowels which are on the same row in Table 1, also belong to the same pronounciation series.

The elements " ㅿ, ㆁ, ㆍ ", and " ㄹ " do not conform to this way of derivation. They were particulary established to represent the peculiar vocals of Korean language at first. However, the pronounciations of the elements " ㅿ, ㆍ ", and " ㆆ " had vanished from the modern Korean language and are not being used nowadays. Also, the elements " ㆁ " and " ㅇ " are being used recently without distinction. Therefore, it is regarded that there are 24 fundamental elements in Korean character nowadays. In addition to these fundamental elements, a few of single consonants such as " ㄱ, ㄷ, ㅅ, ㅂ, ㅈ " can be used as double consonants like " ㄲ, ㄸ, ㅆ, ㅃ, ㅉ ". The pronounciations of the double consonants which have stronger accents than the corresponding single consonants are not differentiated in western languages.

B. Combining process

In combining the fundamental elements to synthesize characters, the concept of the initial sound, medial (vowel), and the final sound should be understood. This concept applies to the partition of a syllable. Namely, the initial sound means any consonant which is pronounced first in a character and the final sound means any consonant which is pronounced last in a character. The medial (vowel) is the leading sound of a character. Note is to be made that the Korean character is a monosyllabic one. This classification of sounds in a character merely represents the order of sounds when they are combined into a character, not the difference between the pronounciations of their sound.

For instance, the character " 다 (da) " is composed of the initial sound " ㄷ (d) " and a medial sound " ㅏ (a) ". The character " 달 (dal) " can be obtained by adding the final sound " ㄹ (l) " to the character " 다 (da) ". Also, the charcter " 닭 (dalg')," which makes use of a compound consonant " ㄺ (lg')", can be obtained by adding the consonant " ㄱ (g) " to the character " 달 (dal)". Another example shows that, when the consonant " ㄷ (d) " is combined with the vowel " ㅗ (o) ", it makes the character " 도 (do)" and also makes the character " 돌 (dol)" and " 돍 (dolg') " with the addition of another single or compound consonant. This logical process of character synthesis are shown in Table 2.

As shown in the example above, all of the Korean characters are synthesized in the logical process of combining the consonants and vowels in succession. This is the special characteristics of the Korean character structure. Note the fact that, in Korean character, some of the vowels (such as ㅏ, ㅑ, ㅓ, ㅕ, ㅣ) are combined with the consonants horizontally and the others (such as ㅗ, ㅛ, ㅜ, ㅠ, ㅡ) are combined with the consonants vertically. Also these vowels can be combined with the consonants in both directions simultaneously. In Table 3, the four examples of character synthesis are shown.

Table 2. Process of character synthesis.

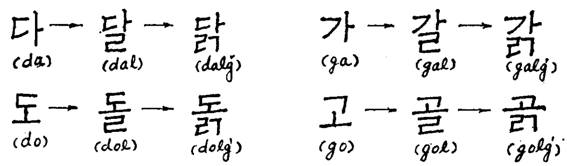


Table 3. Examples of Korean character

	ㅏ	ㅑ	ㅓ	ㅕ	ㅗ	ㅛ	ㅜ	ㅠ	ㅡ	ㅣ
ㄱ	가	갸	거	겨	고	교	구	규	그	기
ㄴ	나	냐	너	녀	노	뇨	누	뉴	느	니
ㄷ	다	댜	더	뎌	도	됴	두	듀	드	디
ㄹ	라	랴	러	려	로	료	루	류	르	리
ㅁ	마	먀	머	며	모	묘	무	뮤	므	미
ㅂ	바	뱌	버	벼	보	뵤	부	뷰	브	비
ㅅ	사	샤	서	셔	소	쇼	수	슈	스	시
ㅇ	아	야	어	여	오	요	우	유	으	이
ㅈ	자	쟈	저	져	조	죠	주	쥬	즈	지
ㅊ	차	챠	처	쳐	초	쵸	추	츄	츠	치
ㅋ	카	캬	커	켜	코	쿄	쿠	큐	크	키
ㅌ	타	탸	터	텨	토	툐	투	튜	트	티
ㅍ	파	퍄	퍼	펴	포	표	푸	퓨	프	피
ㅎ	하	햐	허	혀	호	효	후	휴	흐	히

(a)

ㅣ
⇓

	ㅐ	ㅒ	ㅔ	ㅖ	ㅚ	ᆈ	ㅟ	ᆔ	ㅢ
ㄱ	개	걔	게	계	괴	ᄀᆈ	귀	ᄀᆔ	긔
ㄴ	내	냬	네	녜	뇌	ᄂᆈ	뉘	ᄂᆔ	늬
ㄷ	대	댸	데	뎨	되	ᄃᆈ	뒤	ᄃᆔ	듸
ㄹ	래	럐	레	례	뢰	ᄅᆈ	뤼	ᄅᆔ	릐
ㅁ	매	먜	메	몌	뫼	ᄆᆈ	뮈	ᄆᆔ	믜
ㅂ	배	뱨	베	볘	뵈	ᄇᆈ	뷔	ᄇᆔ	븨
ㅅ	새	섀	세	셰	쇠	ᄉᆈ	쉬	ᄉᆔ	싀
ㅇ	애	얘	에	예	외	ᄋᆈ	위	ᄋᆔ	의
ㅈ	재	쟤	제	졔	죄	ᄌᆈ	쥐	ᄌᆔ	즤
ㅊ	채	챼	체	쳬	최	ᄎᆈ	취	ᄎᆔ	츼
ㅋ	캐	컈	케	켸	쾨	ᄏᆈ	퀴	ᄏᆔ	킈
ㅌ	태	턔	테	톄	퇴	ᄐᆈ	튀	ᄐᆔ	틔
ㅍ	패	퍠	페	폐	푀	ᄑᆈ	퓌	ᄑᆔ	픠
ㅎ	해	햬	헤	혜	회	ᄒᆈ	휘	ᄒᆔ	희

(b)

	가	갸	거	겨	고	교	구	규	그	기
ㄱ	각	갹	걱	격	곡	굑	국	귝	극	긱
ㄴ	간	갼	건	견	곤	굔	군	균	근	긴
ㄹ	갈	걀	걸	결	골	굘	굴	귤	글	길
ㅁ	감	걈	검	겸	곰	굠	굼	귬	금	김
ㅂ	갑	걉	겁	겹	곱	굡	굽	귭	급	깁
ㅅ	갓	걋	것	겻	곳	굣	굿	귯	긋	깃
ㅇ	강	걍	겅	경	공	굥	궁	귱	긍	깅
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
ㅎ	.	.	.	.	.	.	.	.	.	.

(c)

까	꺄	꺼	껴	꼬	꾜	꾸	뀨	끄	끼
따	땨	떠	뗘	또	뚀	뚜	뜌	뜨	띠
빠	뺘	뻐	뼈	뽀	뾰	뿌	쀼	쁘	삐
싸	쌰	써	쎠	쏘	쑈	쑤	쓔	쓰	씨
짜	쨔	쩌	쪄	쪼	쬬	쭈	쮸	쯔	찌

(d)

As shown in Table 3(b), 140 characters of Table 3(a) can be changed to another 126 characters all at once by adding a vowel " ㅣ (i) ". This means the abundance of sounds in Korean character. In this way, total of 14,364 characters can be synthesized from the combination of the 24 fundamental elements. However, the average number of Korean characters which is good enough in every day life amounts to 3000-4000 characters approximately.

3. Basic considerations for optimum design

A. Several problems in combining the fundamental elements

In displaying the large number of characters (more than 10 thousand), the character generator is one of the most troublesome part to construct on account of the large number of input lines and the massiveness of its apparatus. The one feature which raises hopes of a workable Korean character generator is the fixed number of its fundamental elements and the logical methods of character synthesis. However, the singularity and complexity of its character structure raises a lot of problems.

For example,

1) the number of elements that are combined in a character are not constant.
2) in order to be combined in a rectangular frame, the same fundamental elements should be varied in their sizes and positions in a character,
3) the directions of combining the fundamental elements are not fixed because these fundamental elements in a character are to be combined in horizontal, vertical or both horizontal and vertical directions with the number of two to seven of the fundamental elements.

To solve these problems stated above, a new method of character generator is proposed in the following section.

B. The formalization of Korean characters and its features.

In this paper, the formalization of Korean characters and its features are approached by three stage processes.

1) In the first stage, the 24 fundamental elements are partitioned into consonants and vowels, represented respectively by the symbol C and V.

Table 4. Symbols of Fundamental elements

C: (ㄱ ㄴ ㄷ ㄹ ㅁ ㅂ ㅅ ㅇ ㅈ ㅊ ㅋ ㅌ ㅍ ㅎ)$_{14}$
V: (ㅏ ㅑ ㅓ ㅕ ㅣ ㅗ ㅛ ㅜ ㅠ ㅡ)$_{10}$

These C and V are defined as the form elements by which all of the Korean character forms are constructed.

2) In the second stage, all of the possible forms of Korean characters are for-

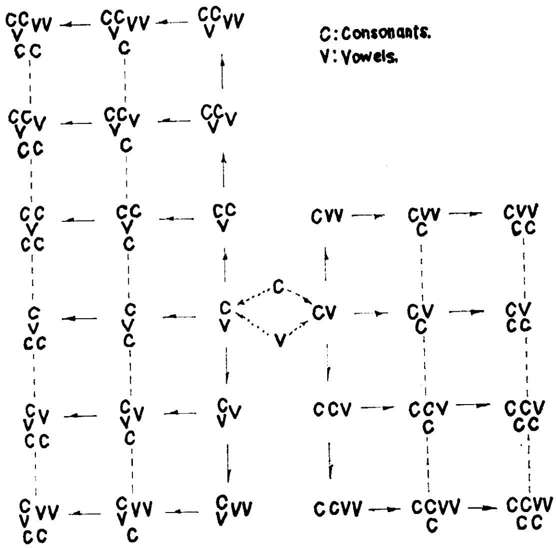


Fig. 1. Character forms

malized into 30 kinds of forms by the combination of this C and V. All of these forms are presented in Fig. 1.

One of the most scientific and logical characteristics in the synthesis of Korean character is that, as shown in Fig. 1, there are two basic character forms (CV and $\begin{matrix}C\\V\end{matrix}$) and all of the other 28 character forms are obtained from these two basic forms by adding one of form element C or V sequentially. All of the Korean characters belong to one of these 30 kinds of character forms.

3) In the third stage, seven form features of character forms are deriven from the 30 kinds of character forms so as to discriminate the individual character forms. These seven features are defined as follows.

a. $Y_1(C_kC_k)$; in the case when the final sound is composed of two consonants, i.e. the final sound is a digraph (double consonants or compound consonants).
b. $Y_2(C_k)$; in the case when there is one consonant as the final sound.
c. $Y_3(C_i)$; in the case when there is one consonant as the initial sound.
d. $Y_4(C_iC_i)$; in the case when there are two consonants as the initial sound (double consonants).
e. $Y_5(V)$; in the case when the vowels are combined under the initial sound.
f. $Y_6(V_i)$; in the case when the vowel follows immediately at the right side of the initial sound.
g. $Y_7(V')$; in the case when a vowel follows immediately after the vowel which is combined with the initial sound element horizontally.

These seven form features defined above, which take into account the position, sequence, and the existence or non-existence of the form elements, represent the

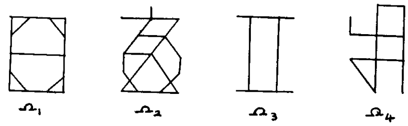


Fig. 2. Pattern parameters of the fundamental elements.

local features of the character forms. The subscript (i) represents a consonant preceding a vowel (initial sound), and (k) represents a consonant following a vowel (final sound). The successive usage of C such as C_iC_i or C_kC_k represents the digraph of the initial sound or the final sound.

This concept of defining the seven features is fundamentally different from the concept of defining the character forms which has generally been used. In this method of using the seven features of character forms, all of the characters are not defined individually but defined collectively. That is to say, all of the Korean characters belong to one of the 30 kinds of character forms and this 30 kinds of character forms are automatically discriminated by the sequence and the existence or non-existence of the seven form features.

C. *Pattern parameters*

In general, the Roman alphabets or the Arabic numbers can be discriminated on CRT even though the pattern parameters are varied more or less. In Korean character, however, it is very defficult to discriminate the characters on CRT if a single pattern parameter is given because one element may be used several times in a character. Therefore, the four pattern parameters for the fundamental elements are established in this paper to improve the quality of the displayed characters. These four parameters are shown in Fig. 2.

Though these four pattern parameters cause to increase the pattern selection gates, it is very effective to improve the quality of the displayed characters. The vowels of (table 1b) and (table 1c) can be obtained in pattern parameter by exchanging their X and Y axises of timing pulses.

D. *Characteristic codes*

In order to discriminate the character forms from their fundamental elements, the characteristic codes are established in Table 5.

These characteristic codes of $ABCDE$ are taken into account the position and sequence of the fundamental elements in a character.

The explanation of this coding is followed here by several stages

1) The discrimination between consonants and vowels are performed by the code position $A(1,0)$.

2) The consonants are partitioned into two groups in code position $B(1,0)$ in order to make the selection of the pattern parameter Ω_1, and (Ω_2, Ω_3).

Table 5. Characteristic codes

code / consonants	A	B	C	D	E
ㄱ	1	1	0	0	0
ㄴ	1	1	0	0	1
ㄷ	1	1	0	1	0
ㄹ	1	1	0	1	1
ㅁ	1	1	1	0	0
ㅂ	1	1	1	0	1
ㅅ	1	1	1	1	0
ㅇ	1	1	1	1	1
ㅈ	1	0	1	0	1
ㅊ	1	0	1	1	0
ㅋ	1	0	1	1	1
ㅌ	1	0	0	0	1
ㅍ	1	0	0	1	0
ㅎ	1	0	0	1	1

code / vowels	A	B	C	D	E
ㅏ	0	1	1	1	1
ㅑ	0	1	1	1	0
ㅓ	0	1	0	0	1
ㅕ	0	1	0	1	0
ㅣ	0	1	1	0	1
ㅗ	0	0	0	0	1
ㅛ	0	0	0	1	0
ㅜ	0	0	1	1	1
ㅠ	0	0	1	1	0
ㅡ	0	0	1	0	1
SPACE	0	0	1	0	0

4) The vowels are partitioned into two groups in code position $B(1, 0)$ according to their way of combination (horizontal and vertical).

5) The vowels are again partitioned into 5 pairs as (ㅏ, ㅜ), (ㅑ, ㅠ), (ㅓ, ㅗ), (ㅕ, ㅛ), and (ㅣ, ㅡ) In each pair, the two vowels have the same codes in *C*, *D*, and *E* positions. By this coding, one vowel of each pair can be obtained from the other vowel by exchanging their *X* and *Y* axes of the timing pulse and so, the next stage of the circuit can be simplified.

By partitioning the 5 bit codes into *AB* and *CDE*, many of the common codes are obtained to simplify the design of the circuits. This partitioning is also useful in selecting the several conditions that will be discussed later. Note is to given to the code positions *A* and *B*. These two code positions have some special meanings.

With these 5 bit codes shown in Table 5, it is possible to represent all of the Korean characters (more than 10 thousand characters).

E. Optimum design conditions

The conditions which are needed to design the Korean character generator are established as follows.

(a) The conditions for discriminating the character forms.

(b) The conditions for varing the magnitude of *X* and *Y* components of the form elements.

(c) The conditions for shifting the element positions in a character in proportion to the variation ratio of the form elements.

The standard size of a fundamental element in this condition is the same as the size of the character frame and the position shifting is taken up from the point where the stroke has been initiated. The size and position of fundamental element depend upon the number of elements in a character.

The detailed explanation about these conditions are followed here.

1) The conditions for discriminating the character forms

The decision of a character form is performed by the form features which are detected from the successive input elements. However, the number of input elements combined into one character are not constant that it is necessary to separate the consonants which are located between the vowels. (Note that the Korean character is a monosyllabic character)

To seperate the consonants into syllables, spaces can be inserted between every characters. But the speed of displaying the input characters is lowered on account of the spaces between every characters. The automatic seperation of the input characters can be achieved by using the seven form features defined above.

2) The conditions of varing the form elements

The sizes of form elements should be varied in inverse proportion to the number of elements in a character because several elements are to be combined into a rectangular frame. Also, the position of the form elements should be shifted in proportion to the variation ratio of the form elements. These several conditions of variations and shifting are stated below in detail.

i) The reduction ratio of X component

(a) When the input character form is C_iC_i, C_kC_k, C_iV, or $\genfrac{}{}{0pt}{}{C_i}{V_i}V$ the X component of each input element should be reduced to a half of their standard size. The coefficient of this ratio is symbolized as $F(x_{1/2})$.

(b) When the character form is C_iC_iV, or C_iC_iV', or C_iVV', the X component of each element should be equally reduced to one-third of their standard size. The coefficient of this ratio is symbolized as $F(x_{1/3})$.

(c) When the character from is $\genfrac{}{}{0pt}{}{C_i}{V_i}$ or $\begin{matrix}C_i\\V_i\\C_k\end{matrix}$ the X component of each element should be equally reduced to two- thir of theird standard size. The coefficient of this ratio is symbolized as $F(x_{2/3})$.

(d) When the character form is $\genfrac{}{}{0pt}{}{C_iC_i}{V_i}V$ the X component of the element V_i should be reduced to two-third of its standard size. The coefficient of this ratio is symbolized as $F(x_{2/3})$. All of the other element in this character form should have the reduction ratio of $F(x_{1/3})$ which is the case of (b).

(e) When the character form is C_iC_iVV', the X component of each element should be reduced to a quarter of their standard size. The coefficient of this ratio is symbolized as $F(x_{1/4})$.

ii) The shifting ratio of X component

The elements that has been reduced in their sizes should be shifted in their positions in accordance with their reduction ratio of their sizes.

(a) When the consonant digram C_iC_i, or C_kC_k is appeared in a character form, the X component of each element should be reduced to a half of their standard size and the second consonant C_l, and C_k should be shifted one interval toward the right side. The meaning of one interval in each case of shiftings equal to the size of each consonant or vowel.

The coefficient of this shifting ratio is symbolized as $S(x_{1/2})$.

(b) When the character form is $C_iC_l V$, the X component of each element should be reduced to one-third of their standard size and the vowel V is to be shifted two interval toward the right side. The coefficient of this ratio is symbolized as $S(x_{1/3})$.

(c) When the consonant C_i and C_k is being used alone as their initial and final sound, the X component of this single consonant is to be reduced to one-third of their standard size and should also be shifted one interval toward the right side. The coefficient of this ratio is symbolized as $S(x_{1/3})$.

(d) When the character form is $C_iC_l VV'$, the X component of each element should be reduced to a quarter of their standard size and the vowel V' is to be shifted three interval toward the right side. The coefficient of this ratio is symbolized as $S(x_{3/4})$.

iii) The reduction ratio of Y component

(a) When there is vowel V_l in a character form, the Y component of each element should be reduced to a half of their standard size. The coefficient of this ratio is symbolized as $F(y_{1/2})$.

(b) When there are vowel V_l and consonant C_k in a character form, the Y component of each form element should be reduced to one-third of their standard size. The coefficient of this ratio is symbolized as $F(y_{1/3})$.

(c) When there are vowel V and consonant C_k in a character form, the Y component of each form element should be reduced to a half of their standard size. The coefficient of this ratio is symbolized as $F(y_{1/2})$.

iv) The shifting ratio of Y component

(a) When there is vowel V_l in a character form, the Y component of each form element should be reduced to a half of their standard size and the vowel V_l should be shifted down one interval. The coefficient of this ratio is symbolized as $S(y_{1/2})$.

(b) When the consonant C_k and the vowel V appear in a character form, the Y component of this C_k and V is to be reduced to a half of their standard size and the consonant C should be shifted down one interval. The coefficient of this ratio is symbolized as $S(y_{1/2})$.

(c) When there are vowel V_l and consonant C_k in a character form, the Y component of each form element should be reduced to one-third of their standard size and the consonant C_k is to be shifted down two intervals. The coefficient of this ratio is symbolized as $S(y_{2/3})$.

At first glance, all of these conditions stated above seem very complicated. However, with the logical composition of the seven form features, it is possible to accomplish both of these variation and shifting conditions simultaneously. Therefore, the circuit of accomplishing these conditions can be minimized.

4. Pattern wave synthesis

To combine the fundamental elements into a rectangular frame, a new system

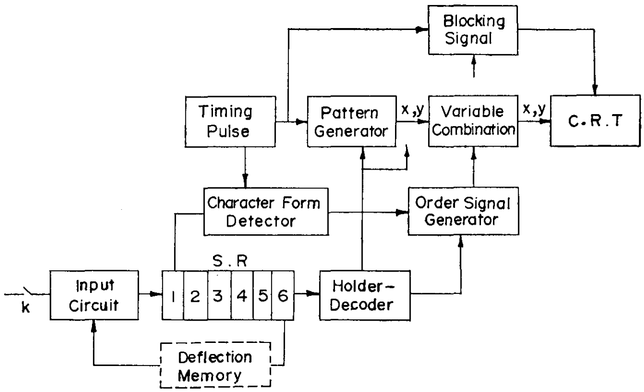


Fig. 3. Block diagram of the character generator.

of character generator is composed which performs the several conditions stated in the previous sections. The major part of this new system of character generator is composed of the charactor form detector, order signal generator, pattern generator, and variable combination system. The complete block diagram is shown in Fig. 3.

The fundamental elements coded at the input circuit is circulated on the loop circuit which is composed of input circuit, shift register (SR), and deflection memory. The shift register shifts the input signals to the right and delay it until the seven form features are discriminated completely in letter form detector. This delay operation is to become necessary because a character form is determined completely after the maximum six fundamental input elements come into the shift register in this paper is composed of 6 stages because 7 element characters are seldom used in everyday Korean nowadays.

The character form detector detects the seven character form features from the characteristics of the input codes and stores it until the latest element code comes into the shift register. The element codes which have passed the shift register are detected in holder decorder to generate the order signals. This order signal is applied to the variable combination circuit to control the X and Y component of the pattern wave in accordance with the character forms to be combined.

The pattern wave of X and Y components is generated by the combination of the pattern parameter which has been selected from the characteristics of the fundamental input element detected in holder decorder and the timing pulse from the timing pulse generator. The non-necessary part of the pattern wave is cancelled by the blocking signals applied on the Z axis of the CRT.

In short, the coded input elements are combined automatically into a rectangular character frame in various sizes and positions according to their character form.

This automatic variation of input elements in a character frame resembles the psychological concept which is applied when we write a character. The detailed descriptions of the major parts are given below.

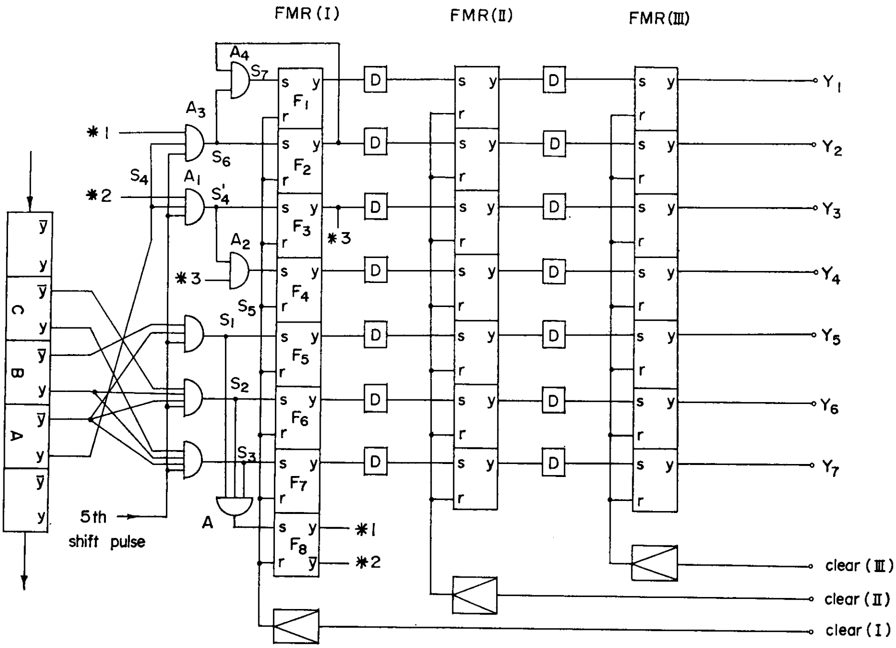


Fig. 4. Character form detector

A. *Character form detector*

The character form detector is composed of a few and gates and a parallel three stage registers each of which has seven flip-flops as shown in Fig. 4. The four character form features are discriminated in this character form detector by the combination of the output of the three flip-flops (A, B, C) among the five flip-flops of the first stage of shift register. Each of the four combinations of this three output states (such as y_4, $\bar{y}_4 \cdot \bar{y}_3$, $\bar{y}_4 \cdot y_3 \cdot \bar{y}_2$, $\bar{y}_4 \cdot y_3 \cdot y_2$) corresponds to the four characteristics of the fundamental element codes (such as A, $\bar{A}\bar{B}$, $\bar{A}B\bar{C}$, $\bar{A}BC$). The relationships between the four output states and the characteristics of the fundamental elements which correspond to the four form elements are tabulated in Table 6.

From these four states (such as C, V_i, V, V'), the seven form features can be discriminated by the sequence of its appearance. That is, the form element $C(A)$ (consonant) is tranformed into four of the form features such as $Y_1(C_kC_k)$, $Y_2(C_k)$, $Y_3(C_i)$, $Y_4(C_iC_i)$, by the operation sequence of the flip-flops such as A_1, A_2, A_3, A_4, respectively. Therefore, seven form features (such as $y_1(C_kC_k)$, $y_2(C_k)$, $y_3(C_i)$, $y_4(C_iC_i)$, $y_5(V_i)$, $y_6(V)$, $y_7(V')$) can be detected at the output terminals of the character form detector. So, all of the character forms are discriminated by the sequence of the appearance of these seven form features. However, it is necessary to store these detected form features for a while on account of the fact that the seven form features do not appear at a time. If all of the charcters are composed of 6 elements,

Table 6. Characteristics of the fundamental elements and its form features

	Out put states of flip-flop	Code features	Form features
1	y_4	A	C
2	$\bar{y}_4 \cdot \bar{y}_3$	$\bar{A}\bar{B}$	V_i
3	$\bar{y}_4 \cdot y_3 \cdot \bar{y}_2$	$\bar{A}B\bar{C}$	V
4	$\bar{y}_4 \cdot y_3 \cdot y_2$	$\bar{A}BC$	V'

it may be good enough to equip the form detector with one stage register which has seven flip-flops. But when the two element characters come into the shift register, three characters can exist in the shift register. Therefore, it is necessary to equip the three stage parallel registers (Fig. 4).

B. Order signal generator

In this circuit, the seven form features $y_i(i=1, 2, \cdots, 7)$ and the characteristics of the fundamental element codes (A, $\bar{A}$, AB, $\bar{A}\bar{B}$, $\bar{C}\bar{D}\bar{E}$, $\bar{C}D\bar{E}$, $\bar{C}DE$, $C\bar{D}E$, $C\bar{D}E$, $\bar{C}\bar{D}E$, $A\bar{B}$, $CD\bar{E}$, CDE, C), which had been detected in holder-decorder are combined to generate the order signals of character forms which control the sizes and positions of a pattern wave. This circuit is symmetrical in X and Y axises.

1) The order signal of X component

To derive the logical expressions about the relationships between the conditions of $F(x_i)$, $S(x_i)$, the character form features, and the characteristics of the fundamental element codes, a few symbols are defined as follows.

a. When there is a consonant C_i in a character, this statement is defined as y_f.
b. When there is a consonant C_k in a character, this statement is defined as y_l.
c. When there is a vowel V in a character, such a state is defined as $\bar{A}B$.
d. When there is a vowel V_i in a character, such a statement is defined as $\bar{A}\bar{B}$.

By these definitions stated above, it is possible to obtain the logical expressions about the X component of any input character forms. For example, if any character form has the form element $C_iC_i VV'$ as their X component, the reduction ratio of this character form is $F(x_{1/4})$. In this character form, the consonant C_iC_i means the form feature y_4 and the vowel V and V' mean the form feature y_6 and y_7. Also the consonant C_i has the characteristic of y_f and the vowel V, V' has the characteristics of $\bar{A}\bar{B}$. Therefore, the coefficient $F(x_{1/4})$ can be expressed logically as follows,

$$F(x_{1/4})=(y_f+\bar{A}B)\cdot y_4\cdot y_6\cdot y_7 \tag{1}$$

If any input character form has the form element $C_iC_i V$, $C_iC_i V'$, or $C_i VV'$ the reduction ratio of this X component is $F(x_{1/3})$ and the logical expression of this coefficient is obtained as follows,

$$F(x_{1/3})=(y_f+\bar{A}B)\cdot y_4(y_6+y_7)+y_6\cdot y_7+F(x_{1/4}) \qquad (2)$$

The coefficient $F(x_{1/4})$ in the expression (2) had been especially established to cut off the circuit operation of the expression (1).

In this way, the expressions about the coefficient $F(x_{2/3})$ and $F(x_{1/2})$ also can be obtained as follows,

$$F(x_{2/3})=(y_f+\bar{A}B)(y_6+y_7+y_4)+\bar{A}\bar{B}(y_6+y_7)+y_1y_l+F(x_{1/3}) \qquad (3)$$

$$F(x_{1/2})=A+F(x_{1/3}) \qquad (4)$$

The expressions about the coefficient of shifting ratios which is in proportion to the reduction ratios can be obtained as follows,

$$\begin{aligned} S(x_{3/4})&=F(x_{1/4})\cdot\bar{A}B\cdot C\bar{D}E \\ S(x_{2/3})&=F(x_{1/3})\bar{A}B\cdot C\bar{D}E+S(x_{3/4}) \\ S(x_{1/2})&=\bar{A}B+A_iA_j+S(x_{2/3}) \end{aligned} \qquad (5)$$

The symbol A_iA_j in the expression (5) represent the consonant digram C_iC_i.

2) The order signal of Y component

The Y component of character forms are composed of two or three steps such as $\frac{C_i}{V_i}$, $\frac{C_iC_i}{V_i}$, $\begin{matrix}C_i\\V_i\\C_k\end{matrix}$, and $\begin{matrix}C_i\\V_iV\\C_k\end{matrix}$. When there is V_i or C_k in any of input character form, the form feature of this character form y_5 or y_2 and the charcteristics of this fundamental element code is $\bar{A}\bar{B}$ or A. Therefore, the expressions for the reduction ratio $F(y_i)$ and the shifting ratio $S(y_i)$ can be obtained as follows,

$$\begin{aligned} F(y_{1/3})&=(A+\bar{A}\bar{B})\cdot y_2\cdot y_5 \\ F(y_{1/2})&=(A+\bar{A}\bar{B})\cdot y_5+y_2+F(y_{1/3}) \end{aligned} \qquad (6)$$

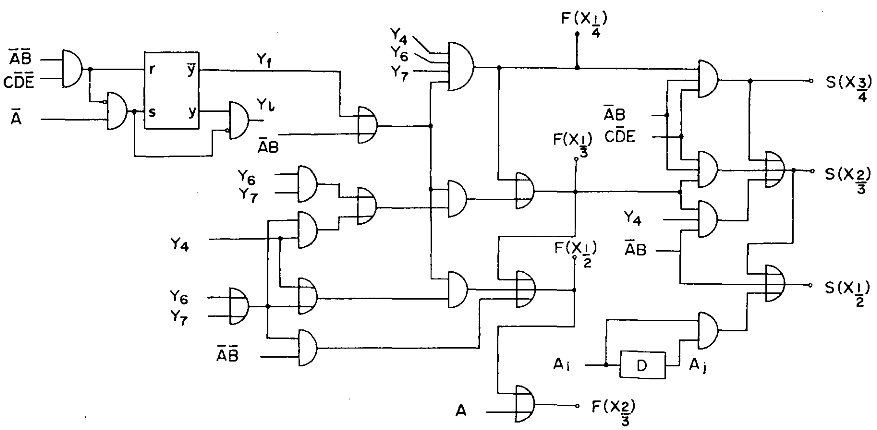
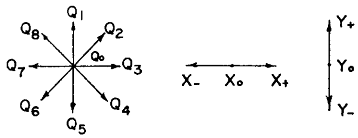


Fig. 5. Order signal generator



(a) (b)

Fig. 6. Vector pulse
(a) Given vector pulse
(b) X and Y component of the given vector pulses

$$\begin{aligned} S(y_{2/3}) &= y_l \cdot F(y_{1/3}) \\ S(y_{1/2}) &= (A \cdot y_l + \bar{A}\bar{B})F(y_{1/2}) + S(y_{2/3}) \end{aligned} \tag{7}$$

As a result, the logic circuits which have the $F(x_i)$, $S(x_i)$, and $F(y_i)$, $S(y_i)$ as their out put states can be constructed from these expressions of (1)-(7). These expressions of $F(x_i, y_i)$ and $S(x_i, y_i)$ generate the signals which control the size and position of the fundamental elements which are able to synthesize more than 14,364 Korean characters. The circuit of X and Y axises should be constructed symmetrically. The circuit of $F(x_i)$ and $S(x_i)$ are shown in Fig. 5.

C. *Pattern wave generator*

The generation of pattern wave is performed by the synthesis of the vector pulse Q_b which have been obtained by the combination of the pattern parameter Ω_i and the timing pulse y_j. The vector pulse Q_b and its X and Y components are shown in Fig. 6.

$$Q_b = \sum_{i=1.2,\cdots,4,\, j=1.2,\cdots,32} \Omega_i y_j \tag{8}$$

This vector pulse Q_b is analized into X and Y components each of which comprises the vector pulse components (x_-, x_0, x_+) and (y_-, y_0, y_+) as shown in Fig. 6. As a result, the expressions about the vector pulse components (x_-, x_0, x_+) and (y_-, y_0, y_+) can be obtained as follows.

$$x_- = \sum_{i=6}^{8} Q_i \qquad x_0 = \sum_{i=0,1,5} Q_i \qquad x_+ = \sum_{i=2}^{4} Q_i \tag{9}$$

$$y_+ = \sum_{i=1,2,8} Q_i \qquad y_- = \sum_{i=4}^{6} Q_i \qquad y_0 = \sum_{i=0,3,7} Q_i \tag{10}$$

The analysis of each vector pulse Q_b into (x_-, x_0, x_+) and (y_-, y_0, y_+) are tabulated in Table 7.

Table 7. Vector pulse components

Vector Q_b	X component	Y component
0	X_o	Y_o
1	X_o	Y_+
2	X_+	Y_+
3	X_+	Y_o
4	X_+	Y_-
5	X_o	Y_-
6	X_-	Y_-
7	X_-	Y_o
8	X_-	Y_+

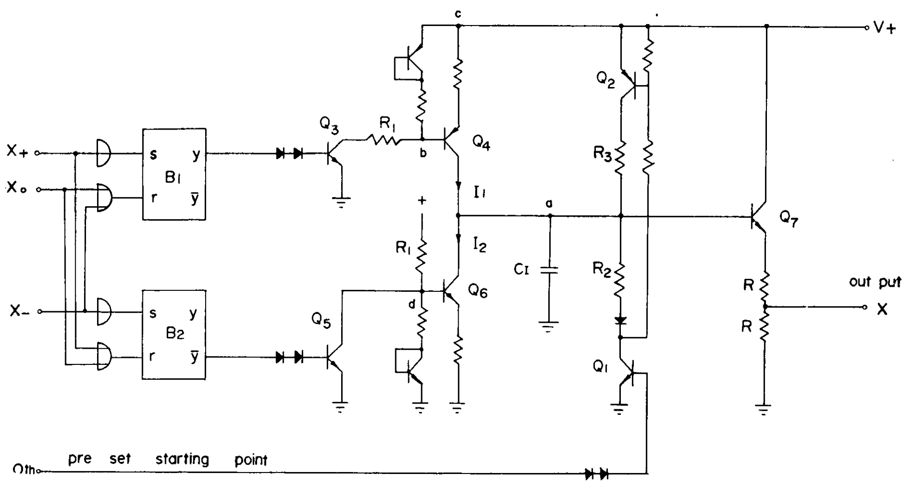


Fig. 7. Pattern wave generator

These vector pulse components described in the expressions of (8), (9), and (10) can be realized by the three stage logic circuit.

The circuit of pattern wave generator by the input of these vector pulse components is shown in Fig. 7.

As shown in Fig. 7, the vector pulse components (x_-, x_0, x_+) are selected by the two flip-flops B_1 and B_2 and these selected vector pulse components make the switching circuit charge or discharge the condenser C_1 alternately. The charging current $I_1 = -I_2$ which correspond to the pattern wave induce the ramp voltage of slope ± 115 mv/μs. The 0th pulse of the timing pulse y_j makes the Tr Q_1 and Q_2 to devide the voltage +V. This devided voltage V supply the initial condition of the condenser C_1, which is the standard level of the pattern wave. The circuit of pattern wave generator is symmetrical in X and Y axises.

D. Pattern wave synthesis

In this circuit, the size and position of a pattern wave are controlled by the form order signals which are in proportion to the various conditions stated in the previous sections.

1) The circuit of reducing the size of a pattern wave

To reduce the size of a pattern wave, the emitter follower is employed in reverse mode. In general, the collector current i_c of emitter follower is given as,

$$i_c = \frac{\beta}{1+\beta} \frac{[(1+\beta)R_e]}{R_e[(1+\beta)R_e + \gamma_{be}]} \cdot e_{in}$$

$$\doteqdot \frac{e_{in}}{R_e} \tag{11}$$

$$(1+\beta)R_e \gg \gamma_{be}, \qquad \frac{\beta}{1+\beta} \doteqdot 1$$

If we let the input voltage e_{in}=const′, and make the emitter resistance increase step by step, the collector current i_c which correspond to the size of a pattern wave will increase step by step in inverse proportion to the emitter resistance. So, as shown in Fig 8(b), the emitter resistance is derived into three steps and each of which is connected to the two stage switching circuits. According to the input states of the terminal T_1 and T_2, the emitter resistance R_e is to be connected to the ground step to control the collector current i_c which corresponds to the size of a input pattern For instance,

a. when the states of T_1 and T_2 are both in 0 states, the node (a) and (b) is to

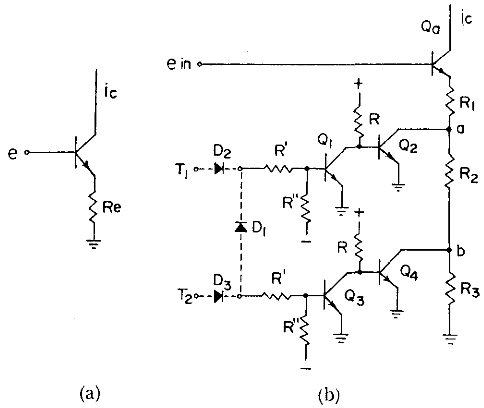


Fig. 8. Pattern wave control circuit

be connected to the ground and the emitter resistance of Tr Q_a is to become R_1. Then, the collector current is to become e_{in}/R_1 and this is the standard size of a pattern wave.

b. when the states are $T_1(1)$ and $T_2(0)$, the node (a) is to be opened from the ground and the node (b) is still in connection to the ground. In this case, the emitter resistance R_1 is to become $2R_1$ (if $R_1=R_2$) and the collector current becomes a half of the standard magnitude.

c. when the stages are $T_1(0)$ and $T_2(1)$, the node (a) and (b) are both opened from the ground and the emitter resistance R_e is to become $3R_1$ (if $R_1=R_2=R_3$). The collector current in this case becomes one-third of the standard magnitude. From this theoretic point of view, it is possible to construct the system of pattern wave synthesis as shown in Fig. 9.

The circuit of Tr Q_a and $N_{a_1}-N_{a_4}$ in Fig. 9 perform the reduction of the pattern wave. That is, by the input states of $N_{a_1}-N_{a_4}$, the collector current i_c which is in correspondence to the input pattern wave e_{in} is to be decreased 1/1, 1/2, 1/3, 1/4, and 2/3 in proportion to the reduction ratio of $F(x_i)$.

The magnitude 1/1 of collector current i_c means that the input pattern is displayed on CRT without reduction in their size. This magnitude of 1/1 is very useful in the case of when the single element characters such as Roman alphabet or Arabian numbers are used with the combinational characters such as Korean. The circuit of $N_{b_1}-N_{b_4}$ is to become necessary to compensate the shifting of starting point which is caused by the reduction of the fundamental patterns.

It is very important to note that the emitter resistance R_e should be carefully divided in order to perform the reduction ratios. The shifting of input pattern wave is performed by the circuit of $N_{c_1}-N_{c_3}$, $N_{d_1}-N_{d_3}$, Tr. Q_b, and the summing amplifier.

At first, the potential of V_a can be obtained as,

a. when there are no signals of $F(x_i)$ in the circuit of $N_{d_1}-N_{d_3}$, the potential

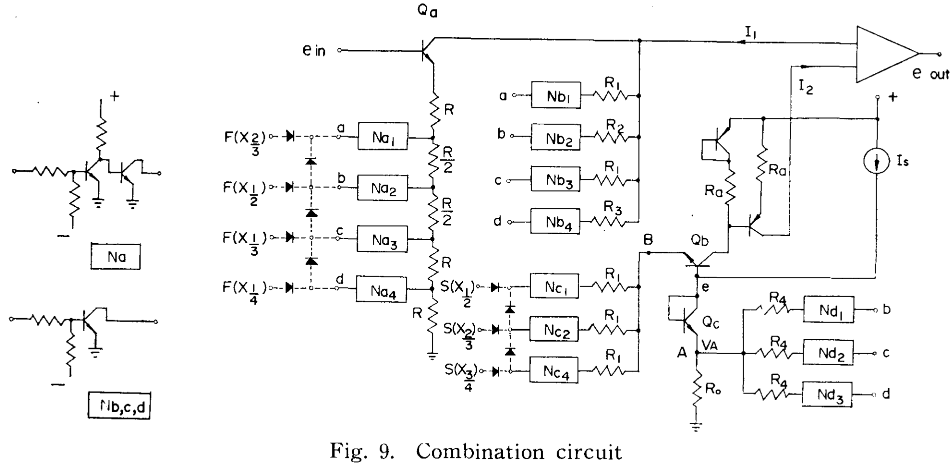


Fig. 9. Combination circuit

of node (a) becomes $V_a = I_s R_0$.

b. when there are signals of $F(x_i)$ in some of the $N_{d_1} - N_{d_3}$, the potential of node (a) becomes $V_a = I_s R'' F(x_i)$.

The insertion of Tr. Q_a makes the potential of node (a) and (b) the same ($V_a = V_b$). Therefore, the emitter current i_e of Tr Q_b can be obtained as follows

$$i_e = \frac{V_b}{R_0} \cdot S(x_i)$$

$$= K \cdot F(x_i) \cdot S(x_i)$$

$$K = I_s \frac{R''}{R_0}$$

As a result, the collector current $i_c = i_e$ makes the *d-c* current I_2 to be applied to the summing amplifier.

In short, in order to shift the position of the pattern wave, the level of current I_1 is controlled by the *d-c* current I_2 which is also controlled by the signal of $F(x_i)$ and $S(x_i)$.

5. Results of experiment and conclusions

To check out the capabilities of this device, a few representative Korean characters composed of 2 to 6 elements were displayed on CRT of this device as in Fig. 10.

(a) It was confirmed that, from the experiment with this device, more than 14,364 different Korean characters can be displayed in good character quality on CRT from only 24 fundamental input elements.

(b) The fundamental elements can be combined with perfect freedom into a character in vertical or perpendicular arrangement according to the form required by the character. At the same time, even the same elements can be displayed on CRT in automatically varied sizes and forms according to its positions required in a charcter.

(c) It was also confirmed that the maximum number of characters possible to be combined with this device amounts to about a milion, which includes all the obsolete charcters no longer in use.

(d) This device is simpler and more economical than any conventional device developed until recently.

(e) The form features obtained in this paper can be applicable to improve the character quality of Korean teletypewriter.

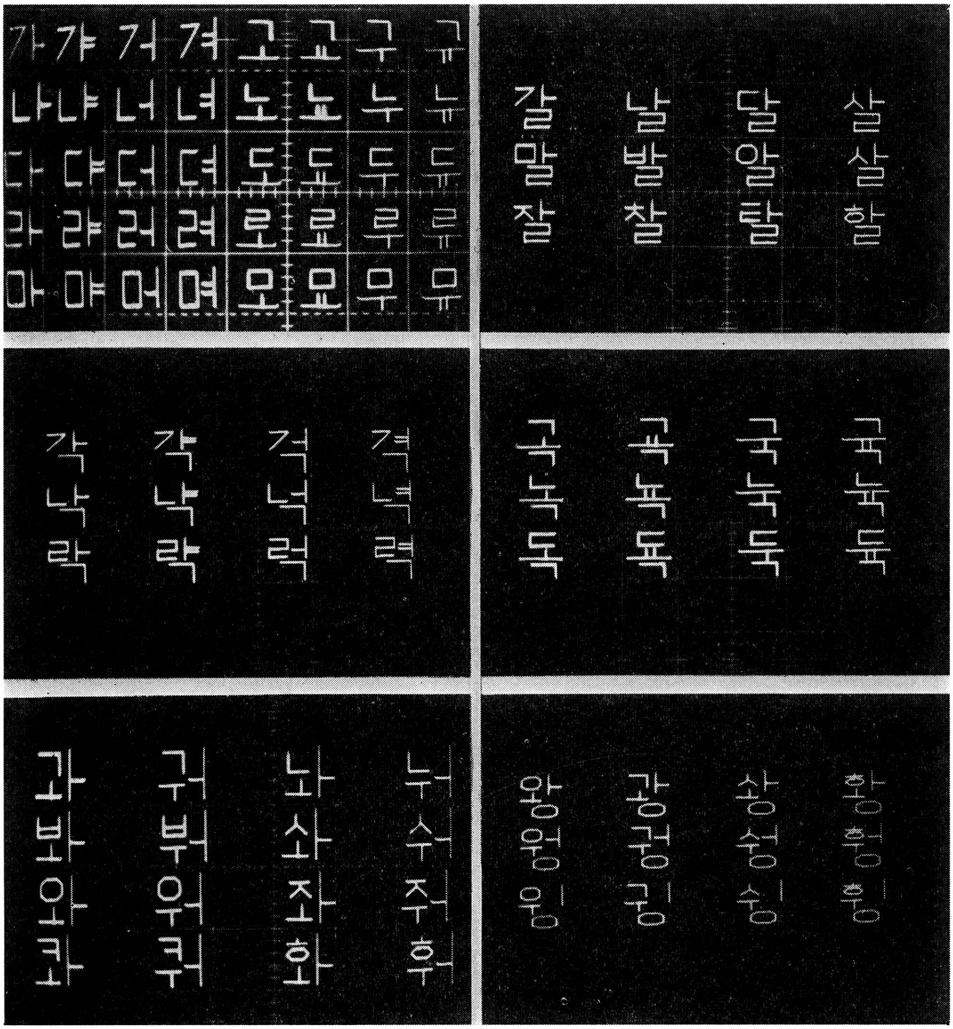

가 갸 거 겨 고 교 구 규
나 냐 너 녀 노 뇨 누 뉴
다 댜 더 뎌 도 됴 두 듀
라 랴 러 려 로 료 루 류
마 먀 머 며 모 묘 무 뮤
갈 날 달 살
말 발 알 샬
잘 찰 탈 할
각 갹 걱 격
낙 냑 넉 녁
락 략 럭 력
곡 굑 국 귝
녹 뇩 눅 뉵
독 됵 둑 듁
과 궈 놔 눠
봐 붜 솨 숴
와 워 좌 줘
콰 쿼 화 훠
왕 광 솽 황
웡 궝 숽 훵
윙 귕 슁 휭

Fig. 10. A

(B)
Fig. 10. Results of Experiment

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