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Quasi-real time translation of morse-coded signals using digital delay processing.

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Monterey, California. Naval Postgraduate School

QUASI-REAL TIME TRANSLATION OF MORSE-CODED SIGNALS USING DIGITAL DELAY PROCESSING

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NAVAL POSTGRADUATE SCHOOL
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THESIS

Quasi-Real Time Translation
of Morse-Coded Signals
Using Digital Delay Processing

by

William Alexander Hickey, III

June, 1976

Thesis Advisor: S. Jauregui, Jr.

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of Morse-Coded Signals
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by

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Lieutenant, United States Navy
B. Chem., University of Tulsa, 1969

Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

Following the development of Morse-coded electromagnetic waves, major powers throughout the world were quick to utilize this new method for military and naval signalling. The advantages gained were long-distance communication, speed of transmission, and reliability of reception under extremely adverse conditions. In the years since, civilization has made significant advances in communications technology and there has been increasing pressure to eliminate the use of Morse code in the crowded radio frequency spectrum.

Morse-coded continuous wave transmissions are still the most reliable in the presence of high noise or heavy interference. Additionally, they offer the advantage of being the simplest (generally implying the least expensive) mode of communication from an equipment standpoint. Yet "civilized" countries are spurning the use of Morse code. Besides being "archaic" and slow, it is too labor intensive a task to train and maintain communications operators in the use of Morse code. Certainly, Morse is a rather old method, but many nations still use it as a primary means of communications because of its reliability and simplicity, not because of its age or "speed" in transmission.

Assuming that the use of Morse code will continue at approximately the same level in the foreseeable future, and given the continuing need for a general monitoring capability that includes Morse-trained operators, it is logical to assume that the requirements for Morse monitoring activity should remain essentially the same.

Unfortunately, budgetary restraints and resulting manpower cuts have dictated some significant changes in monitor philosophy. It has become necessary to consider at least three alternatives in maintaining adequate coverage of existing Morse circuits: (1) continue present coverage with a reduced staff of trained operators, (2) replace all of the operators with automatic translation devices, or (3) utilize automatic Morse translation devices to "assist" those operators remaining on the job.

Alternative (1) is unsatisfactory simply because it dictates further overloading operators who are already taxed to their physical and mental capacity, resulting in a marked decrease of operator efficiency. Alternative (2) is not the panacea it might seem to manpower managers, for no device or algorithm currently available is capable of reliably replacing the human operator in all the complex aspects of transcribing Morse code. Alternative (3) appears to be the best approach, since it offers the advantage of human operator intervention in those situations where automatic translation does not work or is marginal in its output; moreover, it allows the machine to perform the more tedious and routine transcriptions that human operators might otherwise abandon out of boredom or fatigue.

This thesis addresses alternative (3) specifically, and presents a logical modification applicable to commercially available Morse decoders.

II. PROBLEM DESCRIPTION

A. GENERAL INFORMATION

Morse code is not a language in itself, but merely a way of representing virtually any language. It is comprised of five basic elements: (1) the dot, (2) the dash, (3) the intra-character space, (4) the letter space, and (5) the word space. Elements from groups (1) and (2) are MARK elements and are detected by the presence of a signal. Elements from groups (3), (4), and (5) are SPACE elements and are detected by the absence of a signal. Appendix A contains a listing of the MARK/SPACE sequences used in the International Morse code.

A "dot" (also known as "di" or "dit") is the basic unit of the Morse code and will be assigned a relative time duration of one (1.0). All other ideal elements may be expressed in terms of their relative dot lengths as shown in Table 1.

There are two very broad categories of Morse-coded signals: (1) machine-sent (automatic) Morse, and (2) hand-sent (manual) Morse. At this point, it is necessary to divide the discussion of Morse code properties into these categories.

TABLE I

STANDARD MORSE ELEMENT LENGTHS

MARK ELEMENT		SPACE ELEMENT	
dot	= 1.0	intra-character	= 1.0
dash	= 3.0	letter	= 3.0
		word	= 7.0

B. PROPERTIES OF MACHINE-SENT MORSE CODE

Machine-sent Morse code is the easiest to describe because, without predesigned variations, it is the standard to which all other Morse is compared. Automatic-Morse code can be generated by a number of devices, either electrical or mechanical. Keyboard-type devices are by far the most common and require operators to send coded signals by touch typewriting techniques. Without memory or buffer devices, the operator may not type faster than the code is being generated. If the speed of the code being generated is much greater than the average speed of the characters being typed by the operator, the result will be a great variation in LETTER SPACE and WORD SPACE lengths. The magnitude of these variations will be a function of the operator's typing rhythm.

Figure 1 is a histogram of the MARK/SPACE elements generated by a keyboard encoder during the sample message. As expected, the DOT, DASH, and INTRA-CHARACTER SPACE elements are well-defined. Note, however, the disparate LETTER SPACE and WORD SPACE definition. This is attributable to operator rhythm and will not generally be of serious consequence in the decoded output. Figure 2 is a further breakdown of the histogram information by plotting the relative length of a MARK element versus the relative length of its subsequent SPACE element.[1] The previous information may also be noted using this graph, and the plot's significance will not become apparent until Manual-Morse code generation is discussed in greater detail.

C. PROPERTIES OF HAND-SENT MORSE CODE

Manual-Morse code is generated by either the simple hand key or a semi-automatic ("bug") key. The hand key amounts to a single-pole-single-throw switch being opened and closed in the proper sequence to generate the desired code character. A semi-automatic key makes "dots" automatically by vibrating a weighted spring against a contact. "Dashes" are made manually one at a time by the operator. The keying paddle is moved horizontally as opposed to the vertical motion used in the hand key. A well-adjusted "dot" contact on a semi-automatic key should make 18 to 20 evenly spaced "dots" of nearly identical length. The sending speed is adjusted by sliding a weight in or out on the dot vibrator arm.

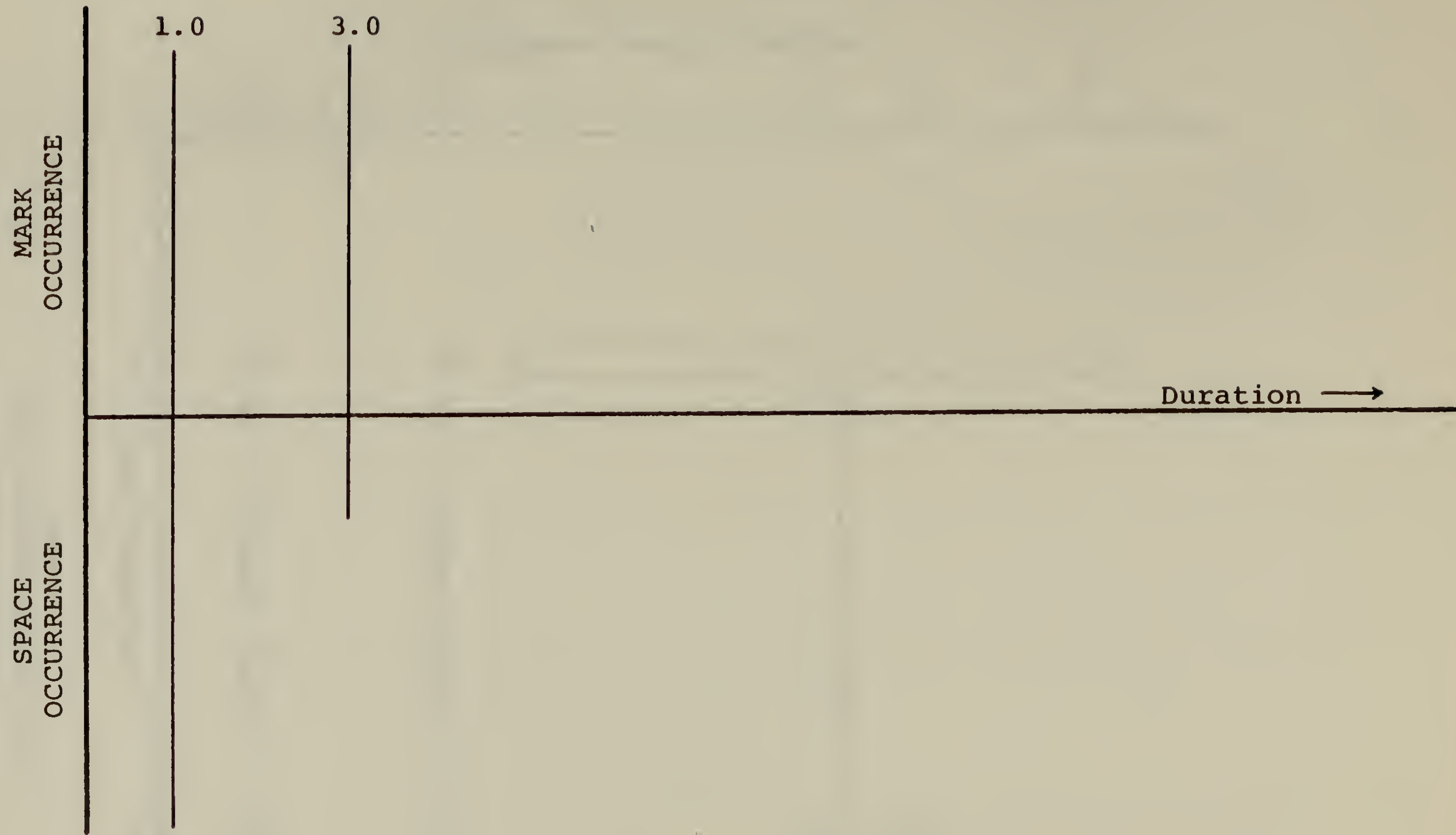

Figure 1.
Character Duration Histogram
(Machine-Morse)

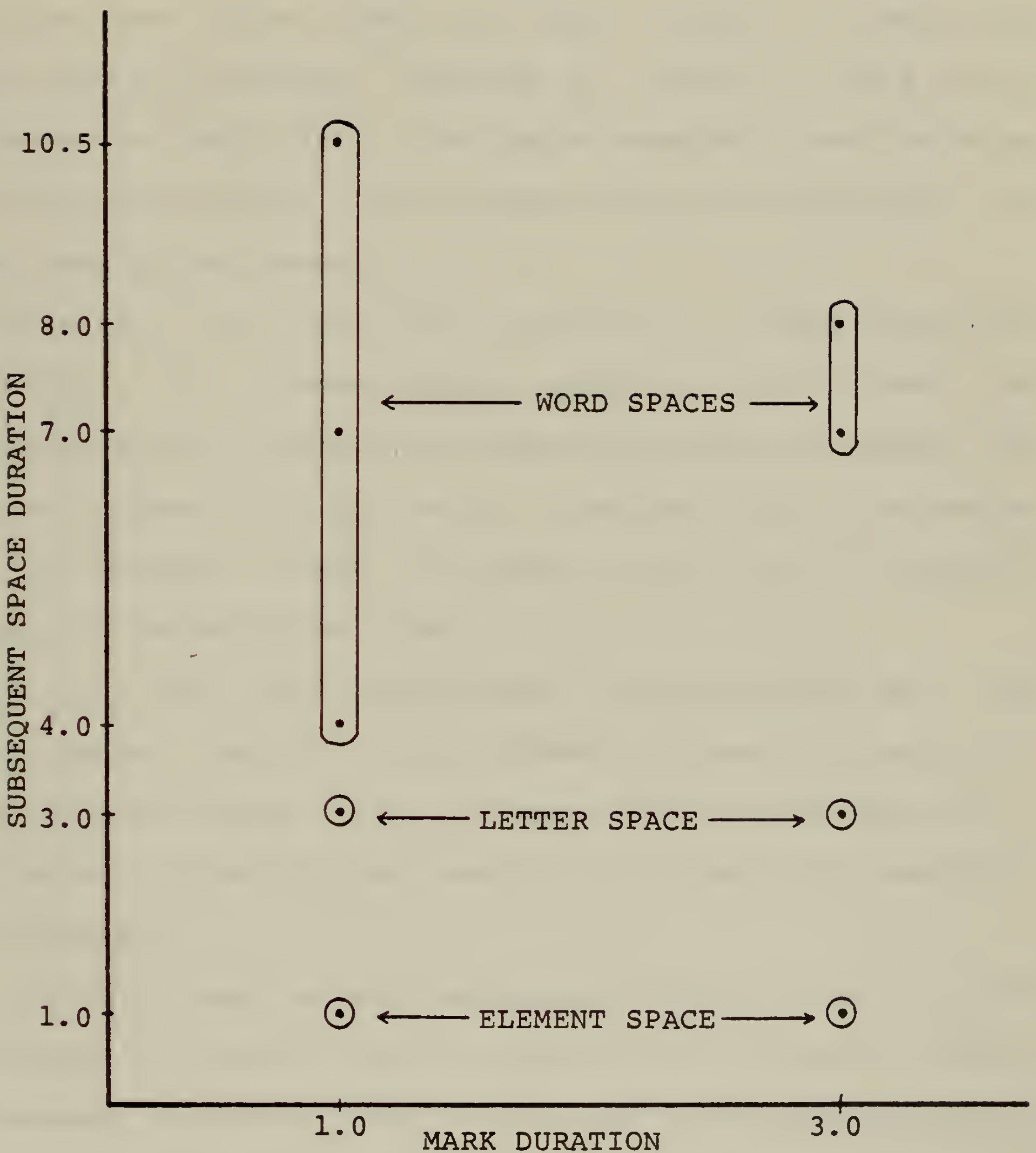

Figure 2.
Data Distribution Plot
(Machine-Morse)

It is generally conceded that code speeds in excess of 30 wpm (words-per-minute) are beyond the capabilities of operators using hand keys. At speeds greater than 20 wpm a "bug" is generally preferred by experienced operators. Although the current world's speed record for receiving Morse code (set by Ted R. McElroy in 1939) is 75.2 wpm, there are few operators in the world capable of sending over 45 or 50 wpm manually. See Appendix B for a discussion of Morse code speed standards.

Because of the "infinite" variety of characteristics describing the Manual-Morse signal, any attempt at "comprehensively" discussing those properties is doomed to failure before it is initiated. Therefore, this discussion will be limited in scope to some of the more "typical" aspects of Manual-Morse code.

One of the most significant complications of the Manual-Morse signal is the tendency of human operators to send erroneous code. This is sometimes attributed to a semi-automatic device, but usually it is just plain operator carelessness.

For the test message using a hand-key, figures 3 and 4 correspond to figures 1 and 2 respectively. Figures 5 and 6 correspond similarly and are for the test message using a semi-automatic key. Figure 7 illustrates the differences in relative spacing for the three keying methods. Since the individual methods of keying used different speeds, the lengths of the elements shown in figure 7 have been normalized to give a basis for comparison.

For the hand-keyed Morse sample, it is seen that there are two distinct distributions for MARK. These may readily be defined as "dot" (1 unit) and "dash" (3.6 units). Note that this is slightly higher than the "ideal" three-to-one dot/dash ratio specified in Table I. Further, definition in the MARK distribution is much clearer than in the SPACE distribution. While it appears that the possibility of boundary decision error for differentiation between INTRA-CHARACTER SPACE and LETTER SPACE is small, it could become a significant factor in a larger sample. For this sample, the INTRA-CHARACTER SPACE seems to be approximately 1.1 units. At this point, the reader is cautioned not to make hard decisions regarding the distribution of LETTER SPACE (apparently 3.8 units) and WORD SPACE (apparently 5.6 units) since it is quite possible that LETTER SPACES and WORD SPACES are thoroughly inter-mixed in Manual-Morse samples. Figure 4 illustrates this effect and is appropriately annotated. The distinction here is largely academic; since the generation of additional spaces or the deletion of intended spaces will rarely damage the context of the message.

Similar conclusions may be made from the semi-automatically keyed samples shown in figures 5 and 6. Here, the apparent regularity of "dot" formation is attributed to the automatic nature of the keying device. Using the "dot" reference, "dash" appears around 3.9 units, LETTER SPACE around 4.0(?), and WORD SPACE around 6.0(?). Note that there will be four types of SPACE elements representing the INTRA-CHARACTER SPACE: (1) the space between two "dots" automatically generated by the key, (2) the space between an automatic "dot" and a subsequent "dash" manually keyed, (3) the space between a manual "dash" and a subsequent "dot" automatically keyed, and (4) the space between two "dashes" manually keyed. SPACE elements of type (1) would be expected to be quite regular, but all other types may be so irregular as to overlap into the LETTER SPACE "boundary" or possibly the WORD SPACE boundary.

It is of interest to note that figures 4 and 6 illustrate the premise that SPACES preceded by dots tend to be longer than those preceded by dashes.[2]

D. MORSE TRANSLATION OBJECTIVES

Automatic decoding of Morse-coded signals is a classical problem in statistical detection theory. Although automatic decoders have been highly successful in monitoring Automatic-Morse code of suitable signal-to-noise ratio, no practical system has been developed for reliably decoding all variations of hand-sent Morse code. This has been due to the inability to deal with all of the non-stationarities of the Manual-Morse signal. (Reflected only partially by the MARK/SPACE statistics of different operators or by the

Figure 3.
Character Duration Histogram
(Hand-sent Morse)

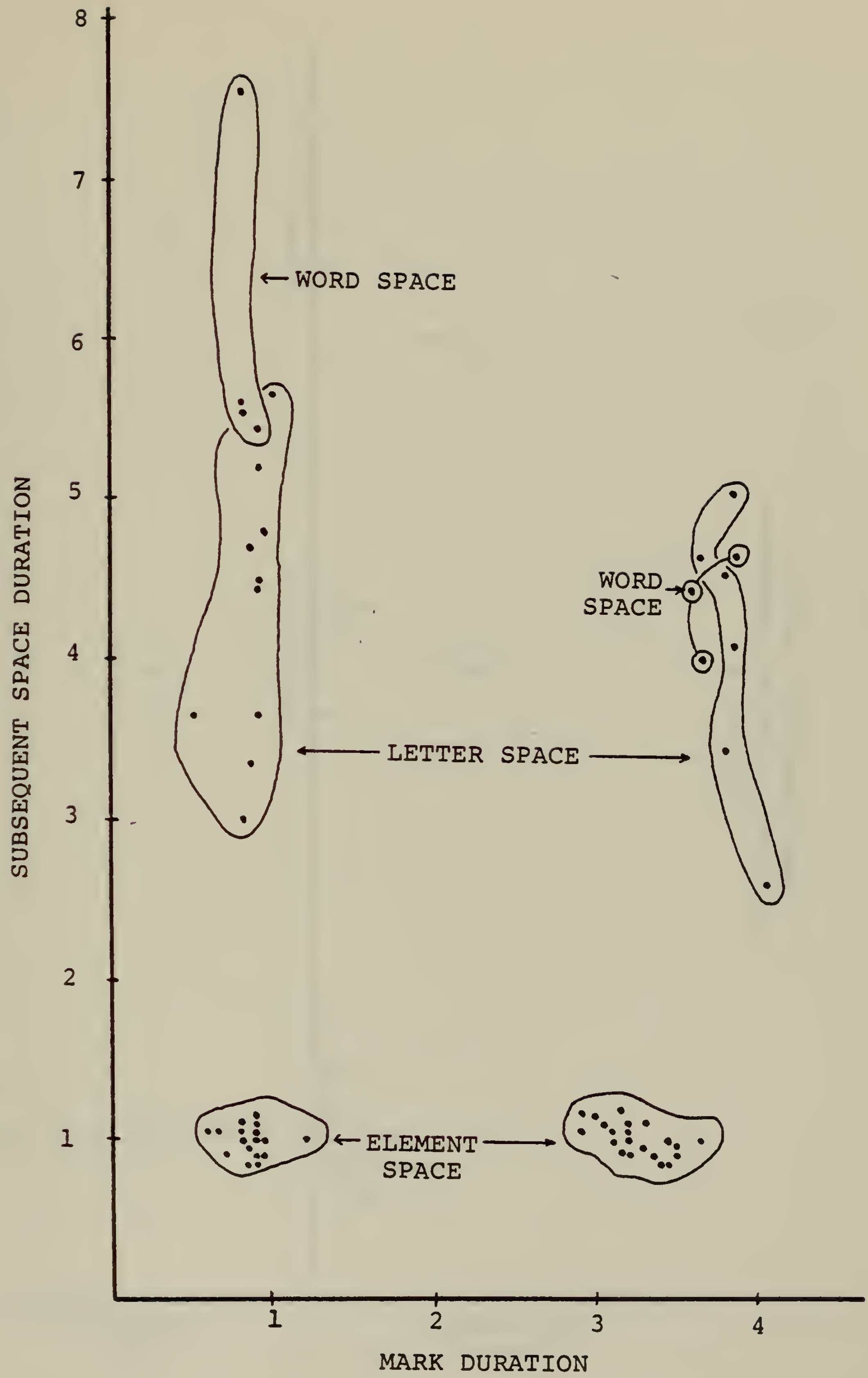

Figure 4.
Data Distribution Plot
(Hand-sent Morse)

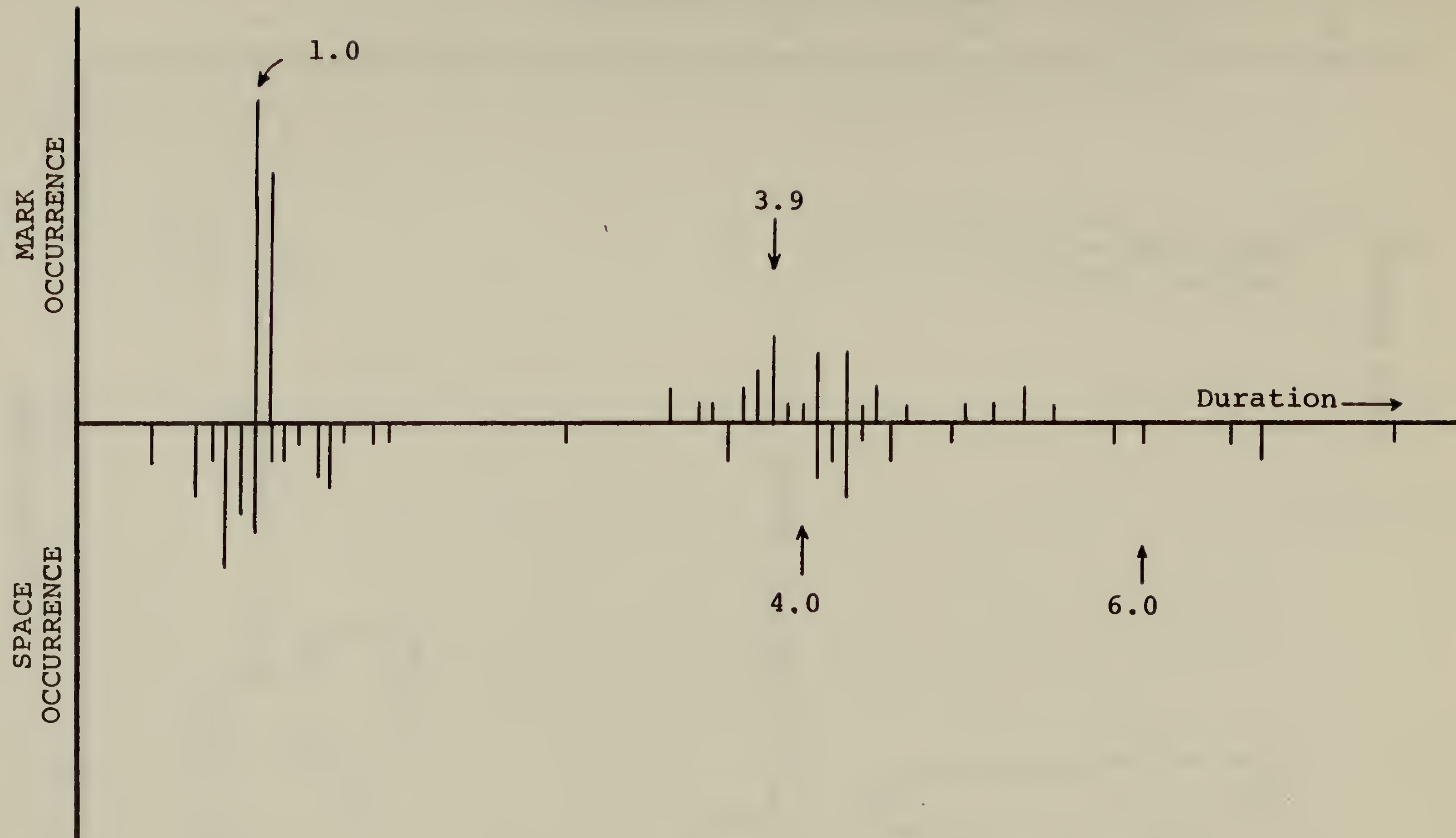

Figure 5.
Character Duration Histogram
(Semi-Automatic Morse)

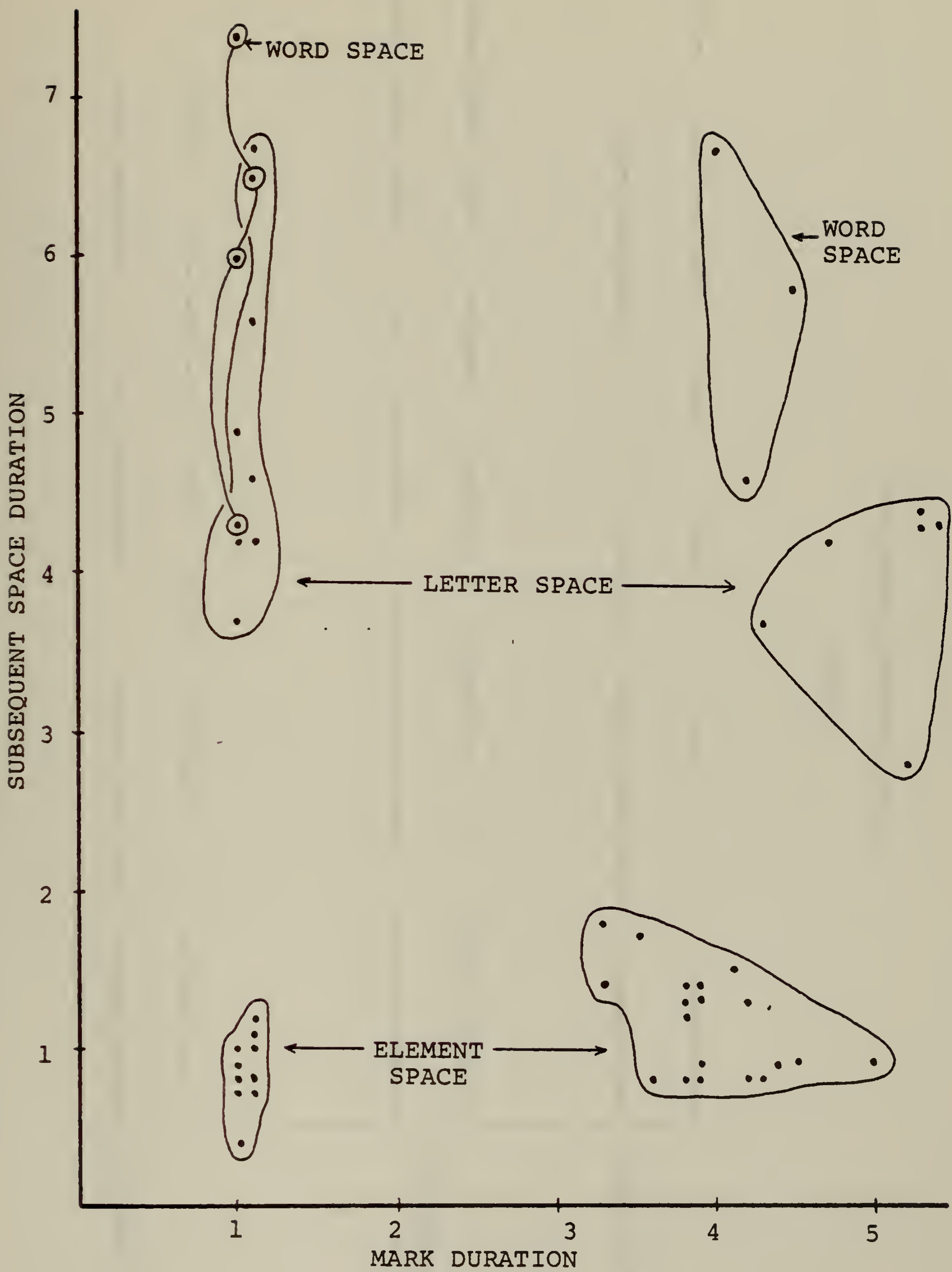

Figure 6.
Data Distribution Plot
(Semi-Automatic Morse)

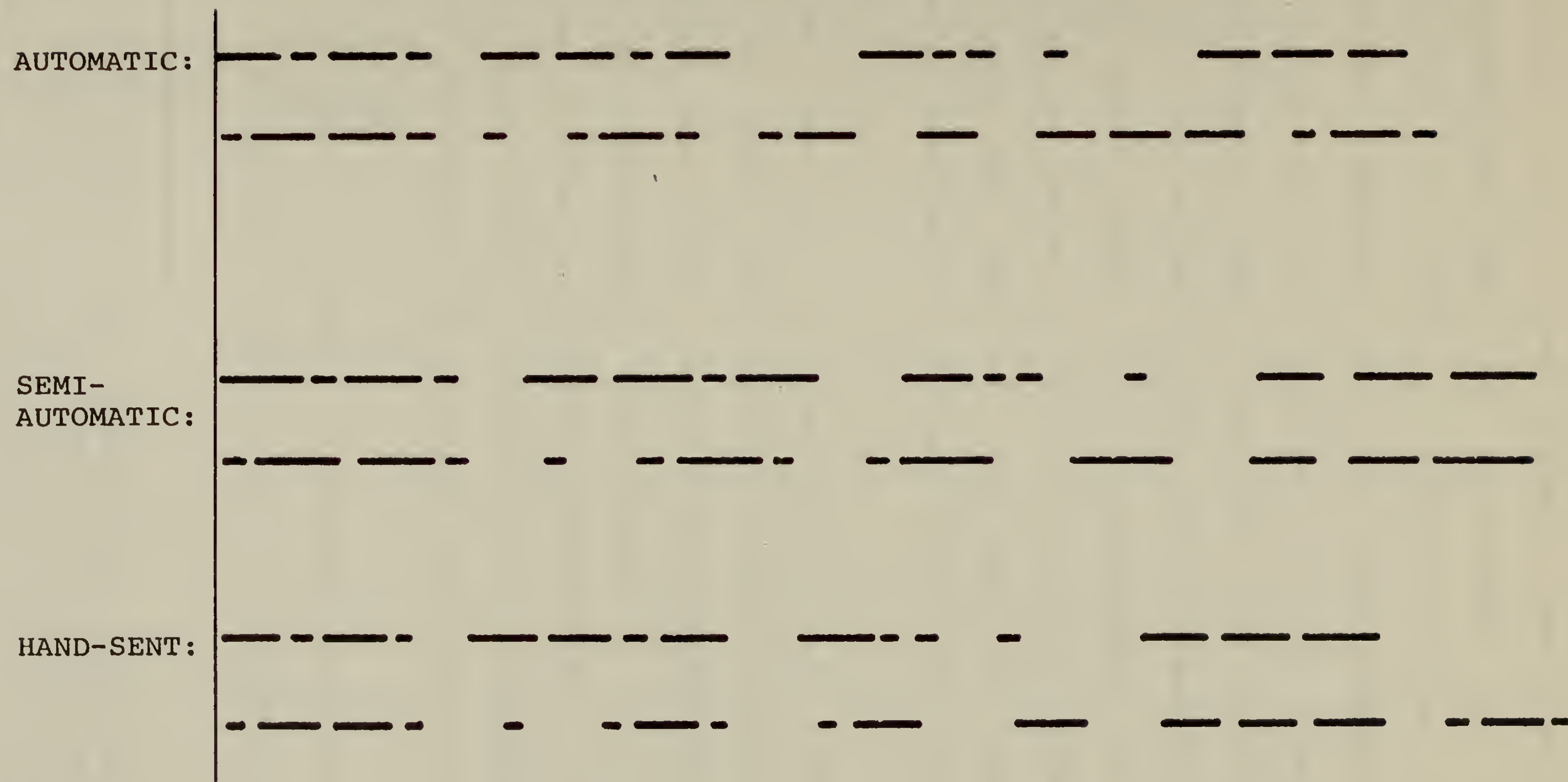

Figure 7.

Test Message Comparison

statistics of the same operator over a period of time.) Characteristics that have contributed to the overall difficulty in automatic decoding include: (1) gradual transmitter frequency drift, (2) rapid transmitter frequency drift ("chirp"), (3) receiver drift, (4) sloppiness during certain types of traffic (e.g. call-sign traffic), (5) the use of "cut" number[1] traffic, (6) propagation effects, (7) noise from any source, and (8) the presence of many other Morse and non-Morse signals in the receiver passband.

To get some idea of what must be expected of an automatic decoder, a discussion of human attributes is in order.

The human ear is a remarkable device. Coupled with the brain, it forms a very powerful audio processing system. Although the system is basically broad-banded (covering a range of approximately ten octaves), it can be made extremely narrow-banded instantaneously and without physical effort.[3,4] Figure 8 shows that, for frequencies between 200 Hz and 900 Hz, the critical bandwidth of the single ear is 50 Hz.[5]

The ear is capable of hearing signals below the noise level. It has been reported that: (1) Morse code signals at

---

[1] "Cut" numbers are numbers that have been shortened by repetitive dashes. (e.g. The numberal 9 is normally sent as [- - - - .] but as a "cut" number would be sent as the letter "N" [- .].) See Appendix A for a listing of "cut" number representations.

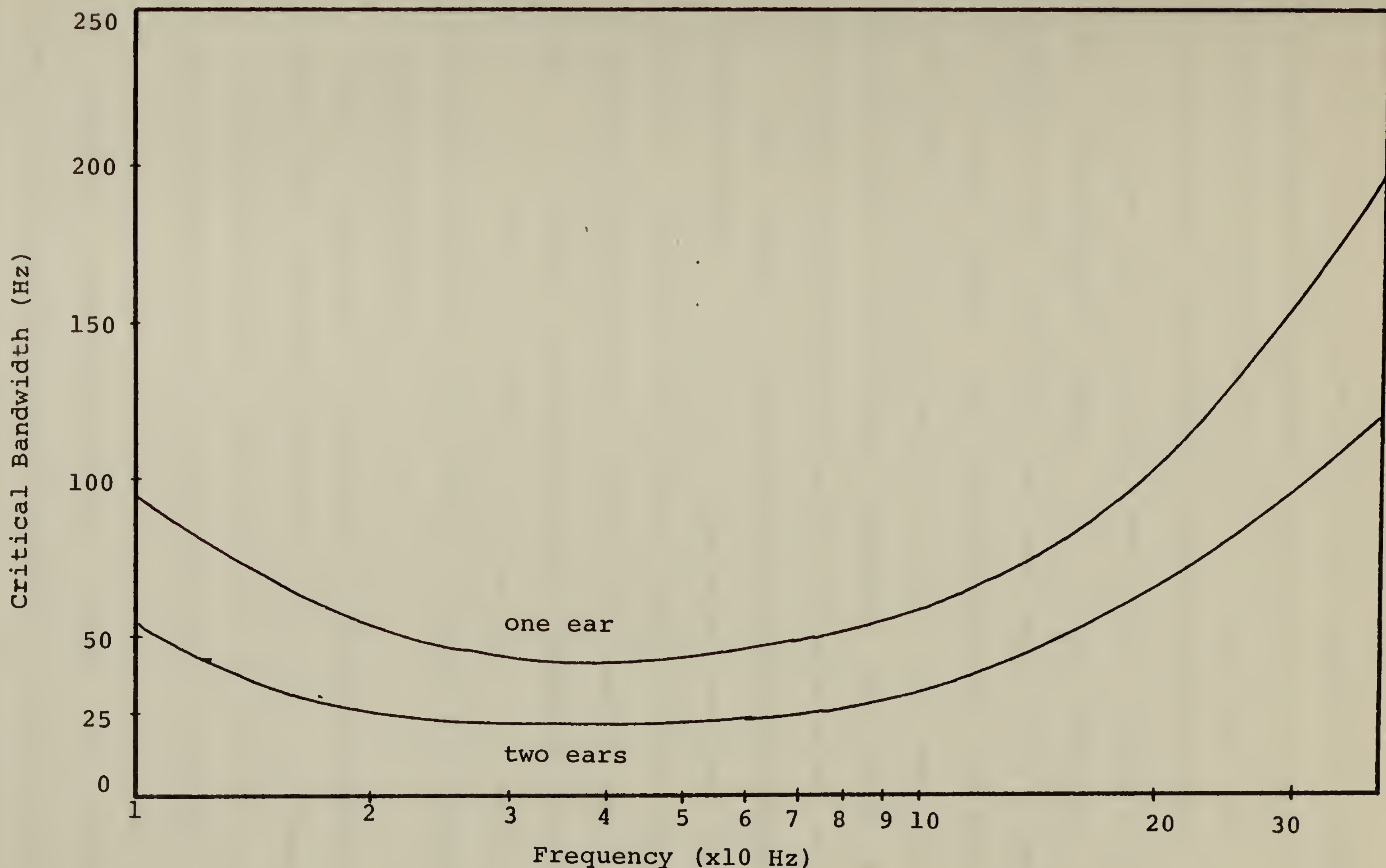

Figure 8. Critical Bandwidth of the Human Ear

0 dB SNR (signal-to-noise ratio) were completely readable, (2) call signs were accurately identified at -9 dB to -12 dB SNR, and (3) the "presence" of signals at -20 dB SNR could be detected but those signals were not readable.[4,6]

The human brain is a very complex but flexible processor that automatically adapts to a wide range of signal characteristics. Further, since knowledge of the code and the language being used is already present, the brain can make contextual analysis on the signal and even allow a certain amount of anticipatory response. When there is some doubt about a particular character, an experienced operator will "lag" behind a few characters and piece together the intended message. Since the experienced monitor operator frequently knows what the sender intends to say, tremendous allowances can be made in translating poorly sent Morse code. For example, an operator might recognize the signals [- .-. -- .-] contextually as the letters CQ; a mechanical translator would usually indicate the letters T R M A (as it was sent).

For a mechanical translator to REPLACE an experienced operator, the following characteristics would be required: (1) narrow-band audio response, (2) the ability to track gradual frequency drift yet ignore "chirp" on a signal, (3) the ability to detect signals at or below the noise level, (4) the ability to segregate Morse signals from non-Morse signals in the passband, (5) the ability to select a desired Morse signal from many Morse signals in the passband, (6) the ability to track speed variations with little or no effect on decoding, (7) the ability to identify the sending operator and make allowances for idiosyncrasies in sending, and (8) the ability to perform contextual analysis on the message as a whole.

By current standards, a device approaching these standards would have to be a special-purpose computer with a rather large memory. Such an installation would not be practical in mobile environments, and would probably be too costly to maintain for fixed installations. Further, there is no machine available that can successfully replace the human monitor operator in daily operations.

Because it is generally conceded that sophisticated decoding algorithms alone are unable to satisfactorily solve the whole problem, certain compromises must be made. If an operator is allowed to make critical decisions regarding suitability for machine translation, an automatic translation system becomes feasible. For an automatic translator to ASSIST an experienced operator, the following characteristics are recommended: (1) relatively narrow-banded audio response (used in conjunction with a tracking receiver if possible), (2) detection of a signal at reasonably low SNR, (3) track speed changes with little detriment to the decoded output, and (4) sufficient tolerance of poorly sent Morse code enabling translation correct enough for contextual analysis by an operator.

It is obvious that automatic translators can be used with great success at higher code speeds because those high speeds are probably being generated by a machine. This would free an operator, normally transcribing a tape at a slower speed, to monitor a less adaptable signal.

For this thesis, a Pickering model 230D automatic Morse code translator was chosen. Although there were many considerations made in this choice, the primary reasons for the final decision were: (1) ease of modification to existing circuitry, (2) ability to accept reasonable variations in code signals, (3) cost, and (4) output device flexibility. Reference [7] supports this decision and contains an evaluation of the 230D's performance.

III. ALGORITHM DESIGN AND IMPLEMENTATION

A. ORIGINAL ALGORITHM

Figure 9 is a functional block diagram of the Pickering 230-D International Morse Decoder. Audio output from a receiver is applied to the PVP (Period Variance Processor). The PVP serves as a narrow-banded audio filter with a passband from 780 Hz to 960 Hz and converts this analog audio input into a digital output signal that can be analyzed by the decoder.

The 230-D decoder algorithm is similar to that presented by Guenther[1], and is based on the DOT-PERIOD AVERAGE[2] (internally designated "A") of the code being received. The digital tracker within the decoder measures the time interval between two adjacent marks on EVERY OTHER transition between marks. This interval is designated "An" and is subject to a fixed boundary decision which allows the value of "An" to be averaged into "A" only if it is less than (3A/2). This permits the tracker to discard any value which would probably be a dash. If the value of "An" is suitable, the formula for averaging is: A=(3A/4)+(An/4).

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2 For a discussion of the DOT-PERIOD AVERAGE and other algorithms, see Appendix D.

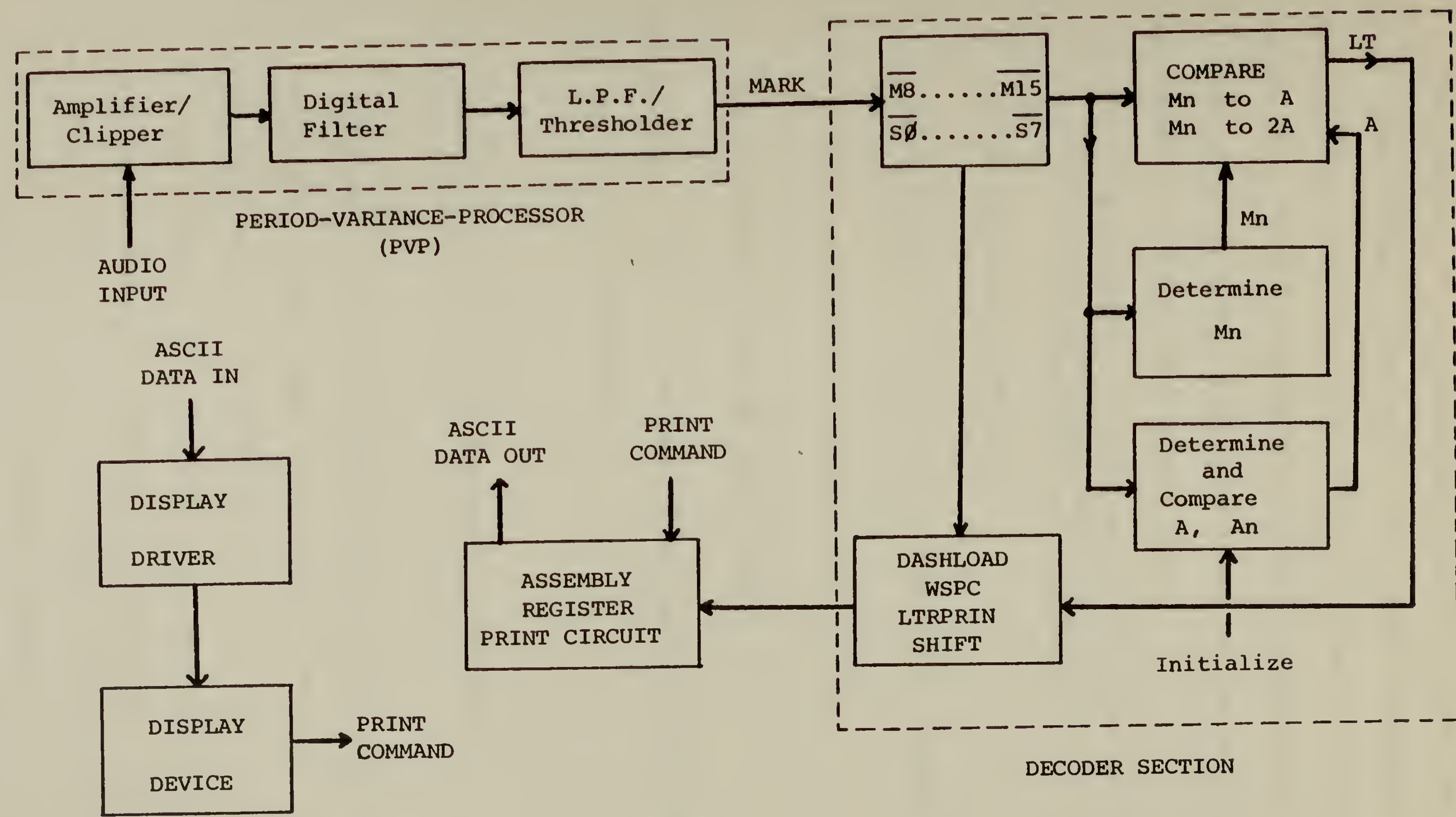


Figure 9.
Functional Block Diagram (Pickering 230-D)

Initially, "A" is internally set to the equivalent of 10.5 wpm Morse code and the tracker approaches the true speed of the received code in proportion to the accepted dot rate. Once "A" is reasonably close to the ACTUAL dot period of the received code, decoding takes place according to the following fixed boundary decisions:

(1) If the instantaneous interval (internally designated "Mn") of a mark was less than A, the mark was a dot.
$[\ Mn(MARK) < A \Rightarrow DOT\ ]$

(2) $Mn(MARK) \geq A \Rightarrow$ DASH

(3) $Mn(SPACE) < A \Rightarrow$ INTRA-CHARACTER (ELEMENT) SPACE

(4) $A \leq Mn(SPACE) < 2A \Rightarrow$ LETTER SPACE

(5) $Mn(SPACE) \geq 2A \Rightarrow$ WORD SPACE

Note that ALL of the above decoder decisions are based on the dot period average, A.

B. MODIFICATIONS TO THE ORIGINAL ALGORITHM

Because of the extensive circuit modifications required, no attempts were made to change the five basic boundary decisions used by the decoder.

With regard to the desired translation objectives for operator assistance: the area requiring most improvement was (3), the ability to track abrupt speed changes with little detriment to the decoded output.

An unmodified 230-D is capable of tracking slow or moderate speed variations with little difficulty. However, the decoder often loses the first four or more characters when initially establishing the dot period average and will also decode incorrectly for a time following an abrupt speed increase. If there is a sudden speed decrease (to a value less than two-thirds of the previous value in the tracker), the digital tracking circuit will "hang" and decode improperly for an indefinite period. Since downward speed tracking is limited by the fixed boundary acceptance of (3A/2), no effort to change this can be made without detriment to the overall 230-D algorithm.

Any improvement to upward speed tracking must cause the digital speed tracker to approach the actual sending speed at a faster pace. The first modification performed involved elimination of the sampling portion of the algorithm. (See figures 10 and 11.) Since "An" was sampled on every other transition, an inertial effect was observed in the digital speed tracker. The original sampling technique forced the decoder to make incorrect boundary decisions until the value of "A" was within the tolerance allowed by the 230-D algorithm. Incorrect decoding was observed for an indefinite period when appropriate (high dash or dash-only content) code characters were used; typical code sequences (random groups or plain text) produced incorrect decoded output for a number of characters, depending on content and speed. Specific results of this modification are documented

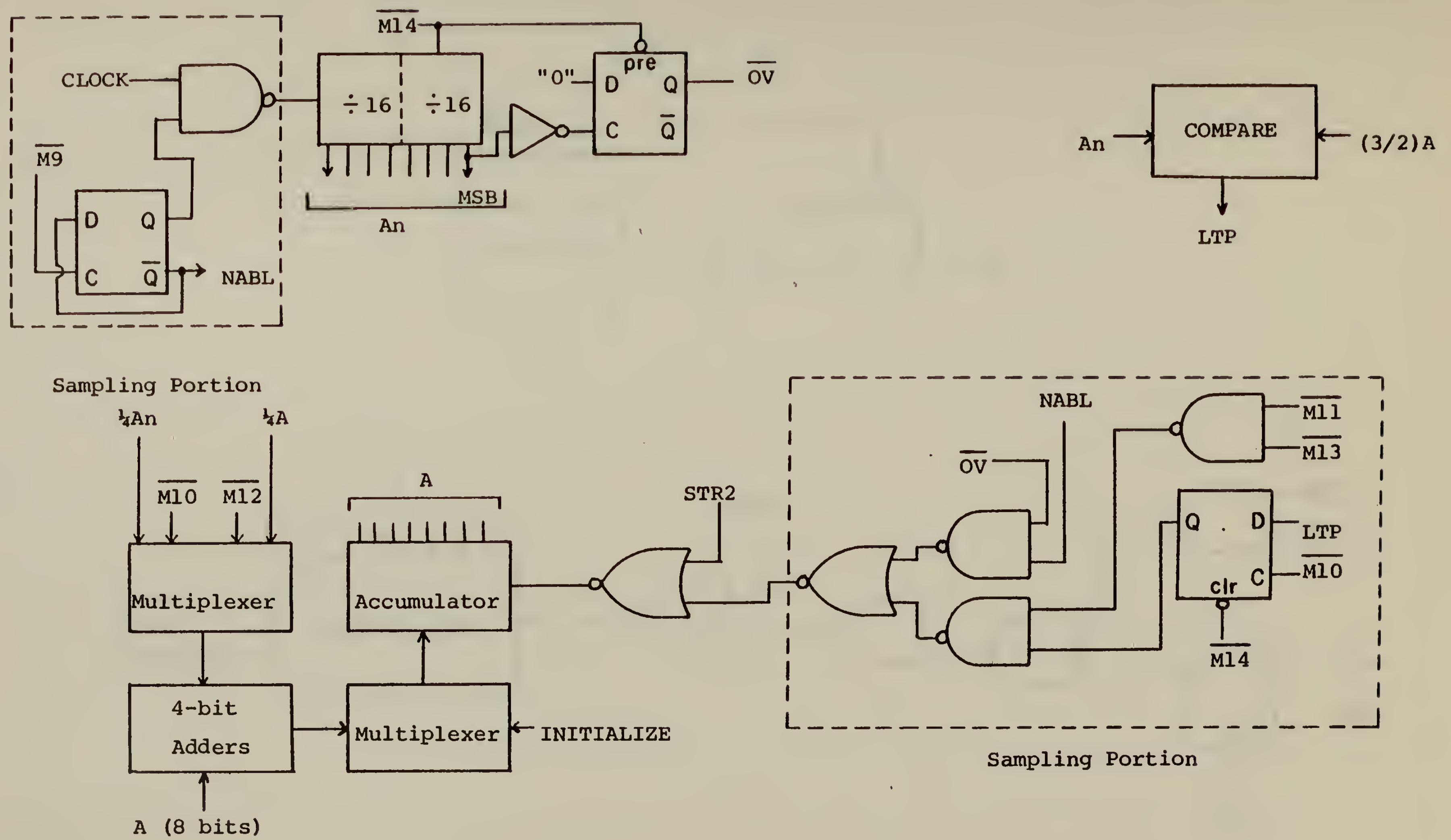
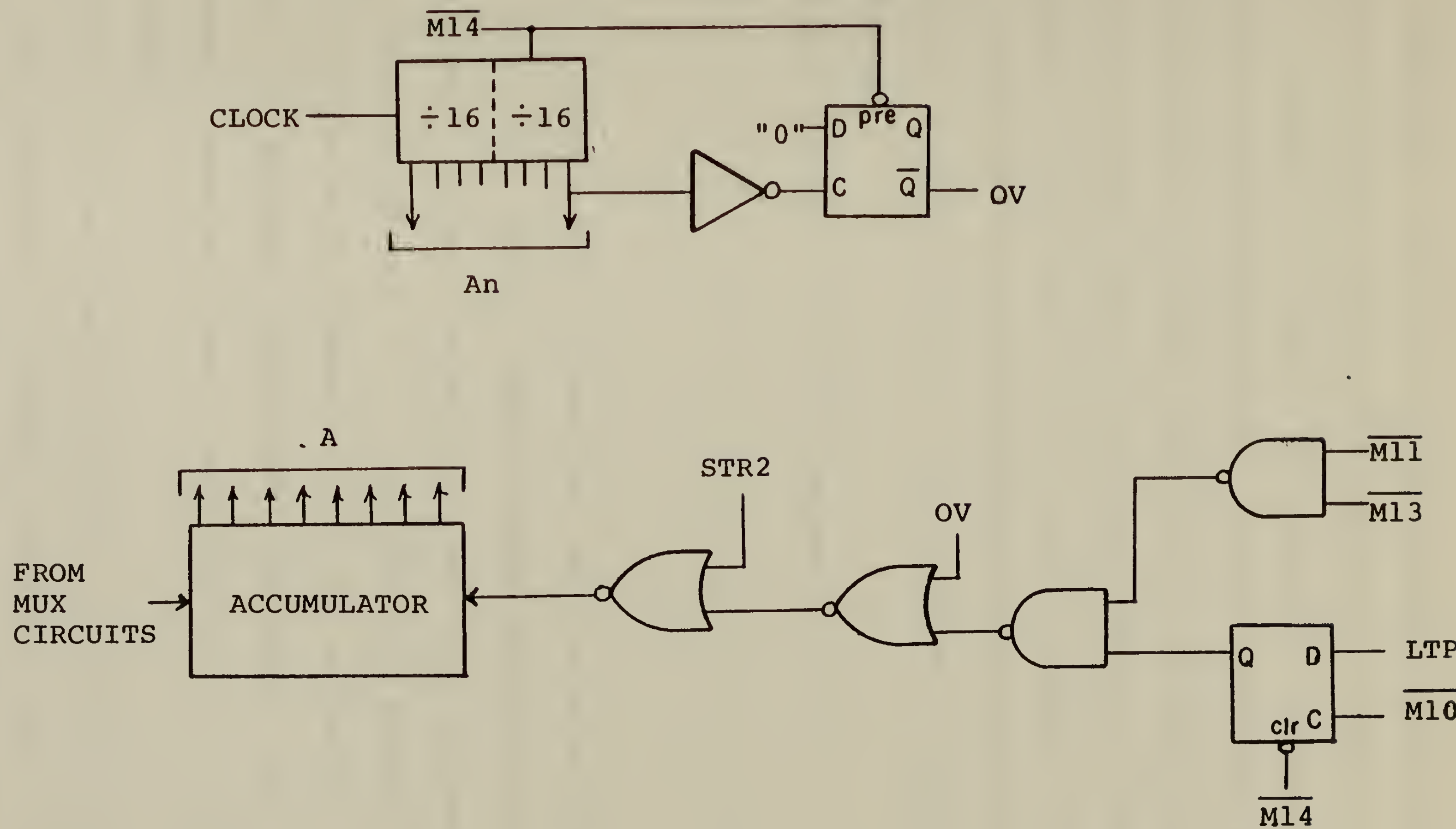


Figure 10.
Original 230-D Sampling Section Diagram



230-D (Mark Sampling Removed)

in Chapter IV, Section A.

A subsequent modification was proposed that used digital integrated circuit static shift registers to delay the MARK signal internally. Where the original algorithm based decisions on an average derived solely from the PREVIOUS code characters, the Delay Algorithm effectively allowed the character involved and a variable number of "previous" characters to contribute to the overall average. This would allow the decoder to base MARK/SPACE decisions on an average of past, present, and to some extent, "future" code characters.

Assume that the following sequence is sent:

[-.-. --.- -.. . --- .--. . .-. .- - --- .-. .----]

C Q D E O P E R A T O R 1

If the original algorithm sampled and declared the first dot, and the digital speed tracker required four sampled dots to begin correct decoding, then the decoder output would be: OPERATOR 1 (a loss of four characters). In practice, some early dashes might be averaged into the tracker if boundary conditions are met. For this and subsequent examples, dash contribution is considered negligible.

If the alternate sample provision is removed and if four dots are required to decode correctly, then the decoder output would be: E OPERATOR 1 (a loss of three characters). Although the removal of the alternate sampling appears to reduce character loss, there is still room for improvement.

If the Digital Delay modification is implemented and the digital speed tracker is allowed to determine the speed of received code BEFORE translation occurs, a definite improvement should result. If the delay holds an equivalent of four "average" Morse characters, the digital speed tracker should be able to begin decoding immediately with the output: CQ DE OPERATOR 1 (no loss of characters).

This modification is based on the knowledge that human operators often carry a few letters (or words) mentally before transcription. This trait in humans has two common ramifications: (1) it allows the operator to piece together portions of a message contextually when there is doubt about the character(s) sent, and (2) it tends to smooth out the rate at which code characters must be transcribed; this does away with the feeling of "panic" that results from trying to write down each character before the next one is heard.

Because the 230-D does not have a contextual analysis capability and machines are not generally known to panic, the actual effect of the delay is to allow the tracker to "anticipate" speed changes before the coded signals are applied to the decoder.

Since the number of bits of delay will contribute significantly to the overall effectiveness of the modification, the following assumptions were made: (1) 40 wpm will be considered the "optimum" working speed, (2) at 40 wpm, the delay should average about four characters, and

(3) a clocking frequency of 448us (available from the 230-D) will be used.

at 40 wpm: 1 dot = 30 msec
average Morse character = 12.3 dots
four characters = 49.2 dots

With a 448us clock frequency, the delay will require:

(49.2 dots)(30ms/dot)(1 bit/448us) = 3295 "bits"

Since the 2533 integrated circuit SSR (Static Shift Register) contains 1024 bits, the circuit will require a total of four chips (4096 bits). This will correspond to a delay of approximately 1.8 seconds.

12 wpm: (4096)(448us)(1/100ms) = 18.4 dots = 1.50 characters

20 wpm: (4096)(448us)(1/60ms) = 30.6 dots = 2.49 characters

40 wpm: (4096)(448us)(1/30ms) = 61.2 dots = 4.97 characters

60 wpm: (4096)(448us)(1/20ms) = 91.8 dots = 7.46 characters

It is interesting to note that the delay carries more characters as the speed increases - just as a human operator would tend to do!

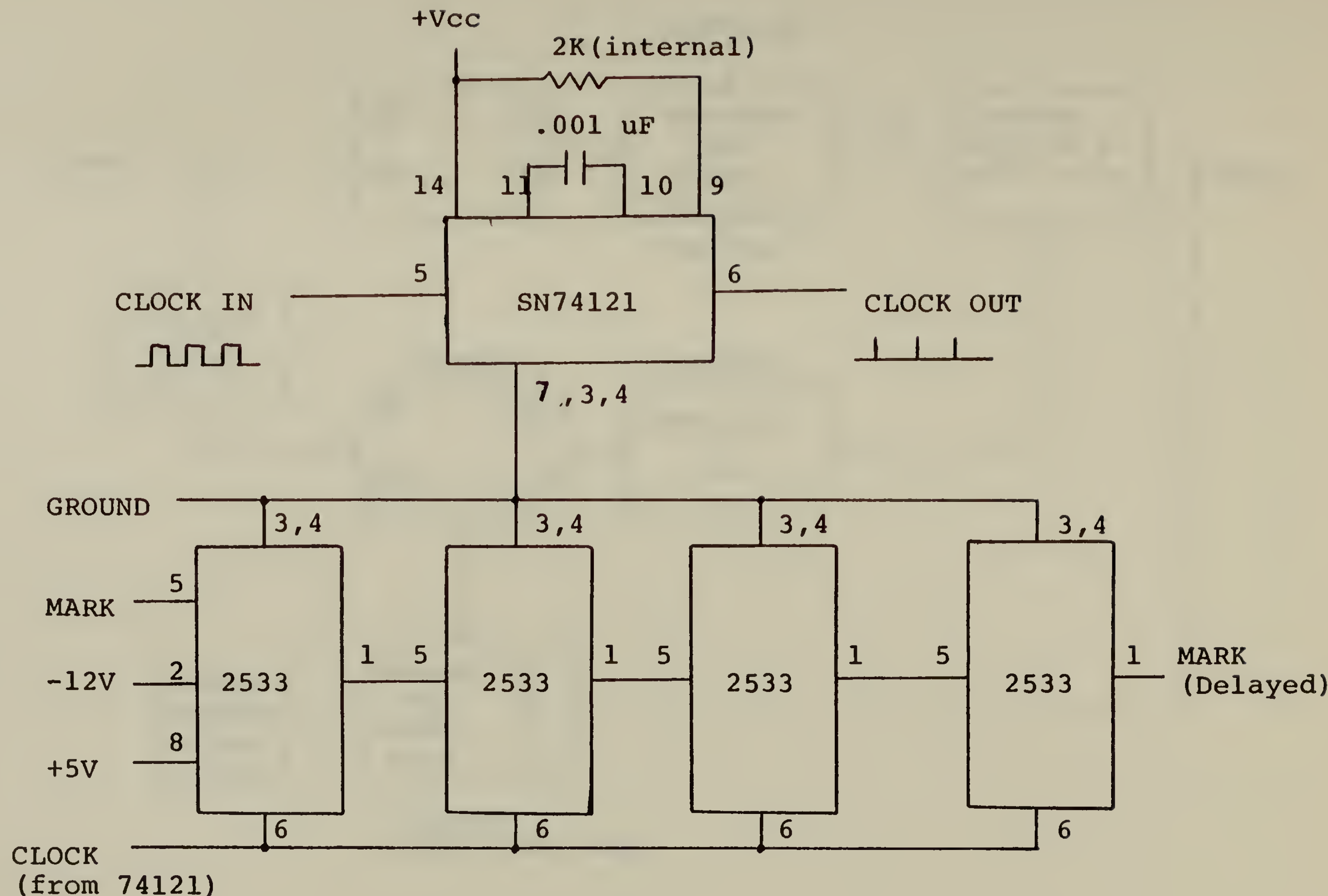


Figure 12.
Digital Delay Circuit

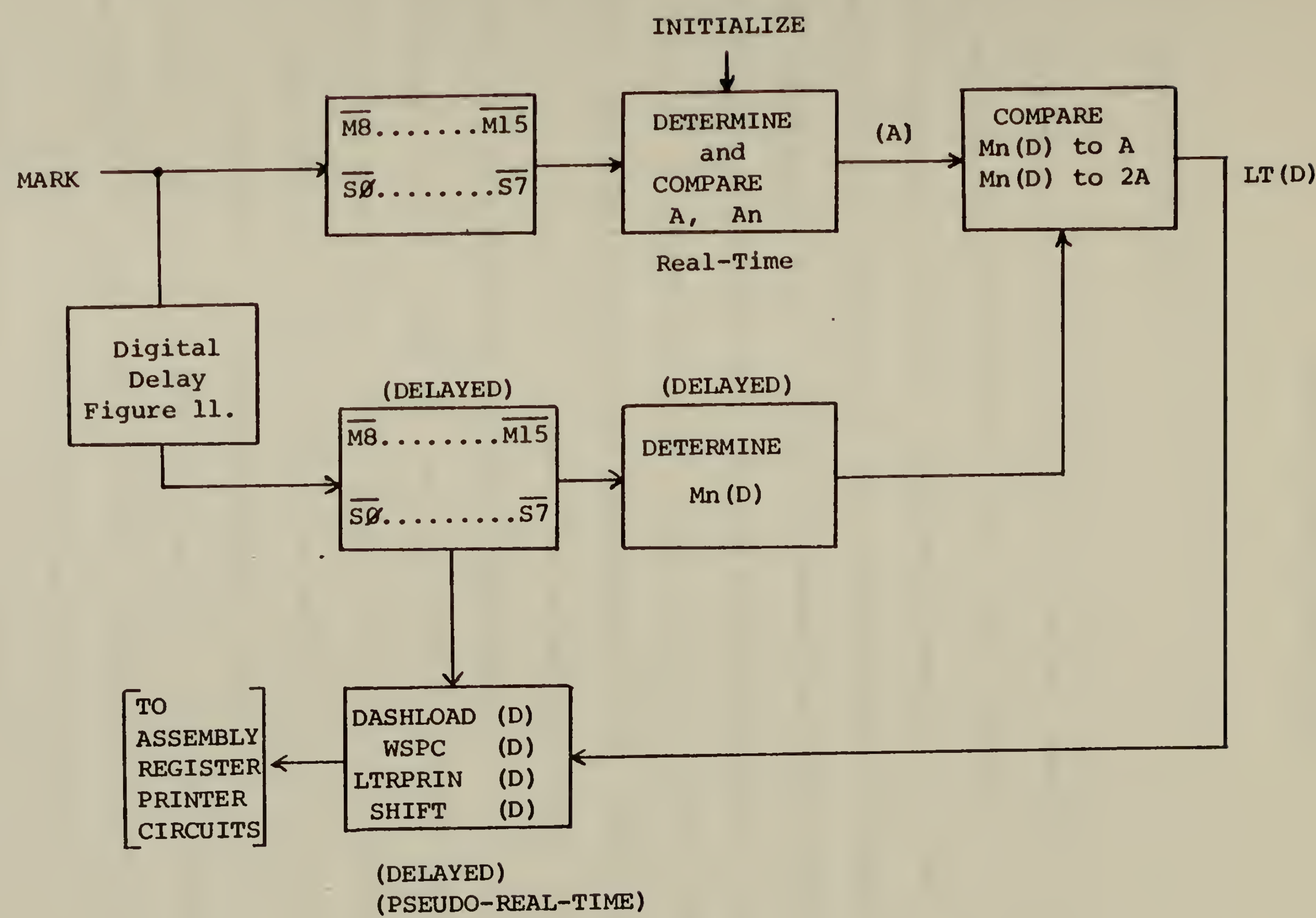


Figure 13.

Implementation of Delay Modification

IV. TESTING AND EVALUATION

A. TEST PROCEDURES

Any test of an electronic Morse decoder is highly subjective; a particular test will have a different significance for every individual operator. The following tests were not designed to be exhaustively comprehensive; they were designed to establish some basis for comparison of experimental results for various modifications to the 230-D.

Three procedures were used in testing the 230-D. (1) Tests were performed using a keyboard Morse code generator at 12, 20, and 40 wpm. The purpose of this test was to establish the maximum decoder improvement that should be observed using machine perfect code. Higher speeds could have been used, but it was felt that this information would be superfluous. (2) Tests were performed using a recording of an automatically keyed broadcast message taken from a receiver with a 2.1 KHz bandwidth. Signal-to-Noise ratio was generally good even though fading, occasional noise bursts, and voice interference were all observed. (3) Tests were performed using a similar recording of two amateur operators. It should be noted that the sending abilities of these operators were not very good; the signals were typical of hand-sent Morse code that was (and is) available off-the-air. The purpose of tests (2) and (3) was to establish the effect of the modifications on typical off-the-air Morse code transcription.

The procedure used for test (1) was to transmit an individual character repeatedly until the decoder consistently responded correctly or definitely established a "not decoded" state. Following the alphanumeric test, a series of random five letter groups was sent in a similar fashion until the decoder responded consistently.

The "standards" of comparison for these tests are transcriptions made by the author. In these transcriptions, contextual spacing has been utilized to simplify reading of the transmitted text. For these comparisons, it should be noted that the 230-D will fail to recognize two or more long Morse characters that are run together. In these instances, a WORD-SPACE will be generated. This effect can be noted in the data tables at the end of this chapter.

B. TEST EVALUATION

It can be seen from test (1) that the first modification resulted in a basic reduction in the number of characters lost by the 230-D before correct translation began. It was noted that the first modification increased the decoder's susceptibility to noise. The added noise susceptibility was not deemed a significant complication, since plans called for the eventual addition of a pre-decoder processor similar to that used by Bell.[8] Further, test (1) shows that the

DELAY modification resulted in a MARKED improvement over both the original 230-D algorithm and the first modification to the basic algorithm.

Tests (2) and (3) showed some improvement with the basic algorithm modification. The following additional effects were observed upon implementation of the DELAY modification. (1) A reduction (in some portions of text) of noise effects was observed and was probably due to the sampling nature of the digital SSR's. This sampling property also had the opposite effect in some isolated cases. (2) A tendency to better differentiate WORD/LETTER space boundaries was observed in some marginal situations. This property made reading decoded text output somewhat easier.

TABLE II

TEST (1) - 12 WPM RESULTS

CHARACTER(S)	CHARACTERS LOST ORIGINAL	MODIFIED	DELAY
A	n.d.	1	0
B	1	1	0
C	1	1	0
D	1	1	0
E	0	0	0
F	1	1	0
G	n.d.	n.d.	n.d.
H	1	1	0
I	n.d.	1	0
J	n.d.	1	0
K	1	1	0
L	1	1	0
M	n.d.	n.d.	n.d.
N	n.d.	n.d.	n.d.
O	n.d.	n.d.	n.d.
P	n.d.	1	0
Q	n.d.	1	0
R	2	1	0
S	1	1	0
T	0	0	0
U	1	1	0
V	1	1	0
W	1	1	0
X	1	1	0
Y	1	1	0
Z	n.d.	1	0
1	2	1	0
2	1	1	0
3	1	1	0
4	1	1	0
5	1	1	0
6	1	1	0
7	1	1	0
8	1	1	0
9	n.d.	n.d.	n.d.
0	n.d.	n.d.	n.d.
.	1	1	0
,	1	1	0

TEST (1) - 12 WPM RESULTS
(CONTINUED)

	CHARACTERS LOST		
CHARACTER(S)	ORIGINAL	MODIFIED	DELAY
?	1	1	0
/	1	1	0
AA	1	1	0
AR	2	1	0
AS	1	1	0
BT	1	1	0
KN	1	1	0
SK	1	1	0
UMVOG	1	1	0
ZAWNA	1	1	0
MDYJR	2	2	0
XIBTF	1	1	0
SWEZC	1	1	0
LKHNA	1	1	0
WPMZL	2	1	0
PIJMG	1	1	0
MUPQJ	n.d.	3	2

TABLE III

TEST (1) - 20 WPM RESULTS

CHARACTER(S)	CHARACTERS LOST		
	ORIGINAL	MODIFIED	DELAY
A	n.d.	2	0
B	2	2	0
C	2	n.d.	n.d.
D	n.d.	4	2
E	0	0	0
F	2	1	1
G	n.d.	n.d.	n.d.
H	1	1	0
I	1	1	0
J	n.d.	n.d.	n.d.
K	n.d.	4	2
L	n.d.	1	0
M	n.d.	n.d.	n.d.
N	n.d.	n.d.	n.d.
O	n.d.	n.d.	n.d.
P	3	n.d.	n.d.
Q	n.d.	n.d.	n.d.
R	n.d.	3	n.d.
S	1	1	0
T	n.d.	n.d.	n.d.
U	1	1	0
V	1	1	0
W	8	n.d.	n.d.
X	2	2	0
Y	2	n.d.	n.d.
Z	n.d.	n.d.	n.d.
1	n.d.	n.d.	n.d.
2	n.d.	n.d.	n.d.
3	1	1	0
4	1	1	0
5	1	1	0
6	2	1	0
7	n.d.	n.d.	0
8	n.d.	n.d.	n.d.
9	n.d.	n.d.	n.d.
0	n.d.	n.d.	n.d.
.	n.d.	1	0
,	4	n.d.	n.d.

TEST (1) - 20 WPM RESULTS
(CONTINUED)

CHARACTER(S)	CHARACTERS LOST ORIGINAL	MODIFIED	DELAY
?	3	1	0
/	5	9	n.d.
AA	n.d.	1	0
AR	5	2	n.d.
AS	2	1	0
BT	2	1	0
KN	n.d.	n.d.	n.d.
SK	2	1	0
UMVOG	8	3	0
ZAWNA	2	n.d.	10
MDYJR	n.d.	n.d.	n.d.
XIBTF	3	2	2
SWEZC	2	5	4
LKHNA	3	3	0
WPMZL	5	n.d.	n.d.
PIJMG	n.d.	n.d.	n.d.
MOPQJ	n.d.	n.d.	n.d.

TABLE IV

TEST (1) - 40 WPM RESULTS

CHARACTER(S)	ORIGINAL	CHARACTERS LOST MODIFIED	DELAY
A	n.d.	5	2
B	6	3	0
C	7	n.d.	n.d.
D	18	5	3
E	0	0	0
F	5	2	1
G	n.d.	n.d.	n.d.
H	1	1	0
I	1	1	0
J	7	n.d.	n.d.
K	22	6	n.d.
L	4	3	0
M	n.d.	n.d.	n.d.
N	n.d.	n.d.	n.d.
O	n.d.	n.d.	n.d.
P	n.d.	n.d.	n.d.
Q	n.d.	n.d.	n.d.
R	11	5	n.d.
S	1	1	0
T	n.d.	n.d.	n.d.
U	5	2	0
V	5	1	0
W	21	n.d.	n.d.
X	5	3	0
Y	n.d.	n.d.	n.d.
Z	n.d.	n.d.	n.d.
1	n.d.	n.d.	n.d.
2	n.d.	4	n.d.
3	4	2	0
4	3	1	0
5	1	1	0
6	5	2	0
7	7	6	0
8	n.d.	n.d.	n.d.
9	n.d.	n.d.	n.d.
0	n.d.	n.d.	n.d.
.	n.d.	2	0
,	7	n.d.	n.d.

TEST (1) - 40 WPM RESULTS
(CONTINUED)

	CHARACTERS LOST		
CHARACTER(S)	ORIGINAL	MODIFIED	DELAY
?	4	2	0
/	n.d.	5	n.d.
AA	n.d.	3	0
AR	n.d.	3	n.d.
AS	n.d.	2	.0
BT	4	2	0
KN.	n.d.	n.d.	n.d.
SK	n.d.	1	n.d.
UMVOG	12	7	4
ZAWNA	25	10	6
MCYJR	n.d.	n.d.	n.d.
XIBTF	15	3	2
SWEZC	15	10	0
LKHNA	n.d.	3	0
WPMZL	n.d.	10	10
PIJMQ	n.d.	n.d.	n.d.
MOPQJ	n.d.	n.d.	n.d.

TABLE V

TEST (2) - BROADCAST MESSAGE

OPERATOR TRANSCRIPTION

CQ CQ CQ VVV VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV
VVV VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV VVV VVV
DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV F DIRNSA ATTN A843
LIZ WHPN NPM 102131 TROPICAL STORM NORMA WARNING 05 HAS MOVE
D ASHORE 60 MILES WEST OF ACAPULCO AND DISSIPATED. THIS IS F
INAL WARNING ON TROPICAL STORM NORMA. BT BT UNCLAS //N03145/
/ DIRNSA ATTN A843 LIZ WMPN 2 NPM 102133 NORTH PACIFIC OCEAN
HIGH SEAS WARNING (EAST OF 150E) A. FLEWEACEN PEARL 101919Z
SEP 74 1. HIGH SEAS WARNING VALID 110000Z TO 111200Z A. SEAS
12 FT OR GRTR WITHIN 130 NAUTICAL MILES EITHER SIDE OF A LIN
E FROM 42N6 150.5E1 TO 47N1 161E8 MAX SEAS THIS AREA 14 FT.
B. SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES EITHER SIDE
OF A LINE FROM 39.5N7 142.5W2 TO 47.5N6 171W9 MAX SEAS THIS
AREA 16 FT. C. SEAS 12 FT OR GRTR WITHIN 100 NAUTICAL MILES
EITHER SIDE OF A LINE FROM 34N7 123.5W1 TO 42N6 127W0 MAX SE
AS THIS AREA 15 FT. 2. 24 HOUR FORECAST VALID 111200Z TO 120
000Z A. SEAS 12 FT OR GRTR WITHIN 150 NAUTICAL MILES EITHER
SIDE OF A LINE FROM 44N8 180/9 TO 46N0 163E0 MAX SEAS THIS A
REA 16 FT. B. SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES E
ITHER SIDE OF A LINE FROM 52.5N2 139W3 TO 46.5N5 168.5W0 MAX
SEAS THIS AREA 17 FT. C. SEAS 12 FT OR GRTR WITHIN 150 NAUT
ICAL MILES EITHER SIDE OF A LINE FROM 32N5 126.5W4 TO 44.5N3
126W9 MAX SEAS THIS AREA 17 FT. BT BT UNCLAS //N03145// DIR
NSA ATTN A843 LIZ WWPH 2 NPM 101919 WIND WARNING EFFECTIVE 1
10000Z SEP 74 1. FORECAST GALES WARNING WINDS NORTH NORTHWES
T TO NORTH NORTHEAST 35 TO 40 KTS FORECAST TO DEVELOP BY 111
200Z OVER WATER AREA BOUNDED BY 33.0N6 TO 43.0N7 BETWEEN 13
0.0W4 AND 120.0W3 SEAS 10 TO 15 FT. AREA STATIONARY BT AR

Note 1: Underlined portions of text indicate audio applied to the PVP was outside the passband; any response was due to noise or interfering signals.

TABLE VI

TEST (2) - BROADCAST MESSAGE

UNMODIFIED 230-D TRANSCRIPTION

EE 5Q V VVV VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VV
V VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV VVV VVV DE
NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV* DI RN SA ATTN A843 LIZ
WHPN NPM 102131 TROPICAL STORM NO"A WARNING 05 HAS MOVED ASH
ORE 60 MILES WEST OF ACAPULCO AND DISSIPATED. THIS IS FINAL
WARNING ON TROPICAL ETORM NORMA. BT BT UNCLAS //N03145// DIR
NSA ATT A843 LIZ WMPN 2 NPM 102133 NORTH PACIFIC OCEAN HIGH
SEAS WARNING]EAST OF 150E] A. FLEWEACEN PEARL 101919Z SEP 7
4 1. HIGH SEAS WARNING VALID 110000Z TO 111200Z A. SEAS 12 F
T OR GRTR WITHIN 130 NAUTICAL MILES EITHER SIDE OF A LINE FR
OM 42N6 150.5E1 TO 47N1 161E8 MAX SEAS THIS AREA 14 FT. B. S
EAS 12 FT OR GRTR WITHIN 250 NAUTICAL MIES EITHER SIDE OF A
LINE FROM 39.5N7 142.5W2 TO 47.5N6 171W9 MAX SEAS THIS AREA
16 FT. C. SEAS 12 FT OR GRTR WITHIN 100 NAUTICAL MILES EITHE
R SIDE OF A LINE FROM 347 123.5W1 TO 42N6 127W0 MAX SEAS THI
S AREA 15 FT { 2. 24 HOUR EFORECAST VALID 111200Z TO 120000Z
A. SEAS 12 FT OR GRTR WITHIN 150 NAUTICAL MILES EITHER SIDE
OF A LINE FROM 44N8 180/9 TO 46N0 163E0 MAX SEAS THIS AREA
16 FT. B. SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES EITHE
R SIDE OF A LITEI ET IE TIESTIII2 1 139W3 TO 46.5N6 167 E 4I
EVO MAX SEAS THIS AREA 17 FT. C. SEAS 12 FT OR GRTR WITHIN
150 NAUTICAL MILES EITHER SIDE OP Q LIN2 R3OM 32N5 126.5W4 T
O 44.5N3 126W9 MAX SEAS THIS AREA 17 FT. BT BT UNCLAS //N031
45// DIRNSA ATTN A 843 LIZ WWPH 2 NPM 101919 WIND WARNING EF
FECTIVE 110000Z SEP 74 1. FORECAST GALE WARNING WINDS NORTH
NORTHWEST TO NORTH NORTHEAST 35 TO 40 KTS FORECAST TO DEVELO
P BY 111200Z OVER WATER AREA BOUNDED BY 33.0N6 TO 43.0N7 BET
WEEN 130.0W4 AND 120.0W3 SEAS 10 TO 15 FT. AREA STATIONARY B
T AR

Note 1: Encircled portions of text indicate audio applied to the PVP was outside the passband; no response

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table V).

TABLE VII

TEST (2) - BROADCAST MESSAGE

230-D (MODIFIED SPEED TRACKER) - TRANSCRIPTION

CG CG CQ VVV VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV
VVV VVV DE NPM/NPG NPM/NPGNPM/NPG CQ CQ CQ VVV VVV VVV DE N
PM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV F DINSA ATTN A843 LIZ WH
PN NPM 102131 TROPICAL STORM NORMA WARNING 05 HAS MOVED ASHO
RE 60 MILES WEST OF ACAPULCO AND DISSIPATED. THIS IS FINAL W
ARNING ON TROPICAL ETORM NORMA. BT BT UNCLAS //N03145// DIRN
SA ATTN A843 LIZ WMPN 2 NPM 102133 NORTH PACIFIC OCEAN HIGH
SEAS WARNING]EAST OF 150E] A. FLEWEACEN PEARL 101919Z SEP 7
4 1. HIGH SEAS WARNING VALID 110000Z TO 111200Z A. SEAS 12 F
T OR GRTR WITHIN 130 NAUTICAL MILES EITHER SIDE OF A LINE FR
OM 42No 150.5E1 TO 47N1 16lE8 MAX SEAS THIS AREA 14 FT. B. S
EAS 12 FT OR GRTR ≛ITHIN 250 NAUTICAL MILES EITHER SIDE OF A
LIE FROM 39.5N7 142.5W2 TO 47.5N6 171W9 MAX SEAS THIS AREA
16 FT. C. SEAS 12 FT OR GRTR WITHIN 100 NAUTICAL MILES EITHE
R SIDE OF A LINE FROM 34N7 123.5W1 TO 42N6 127W0 MAX SEAS TH
IS AREA 15 FT" 2. 24 HOUR FORECAST VALID 111200Z TO 1200007
A. SEAS 12 FT OR GRTR WITHIN 150 NAUTICAL MILES EITHER SIDE
OF A LINE FROM 44N8 180/9 TO 46N0 163E0 MAX SEAS THIS AREA 1
6 FT. B. SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES EITHER
SIDE OF A LIT E12 139W3 TO 46.5N5 16G E 4 E EV0 MAX
SEAS THIS AREA 17 FT. C. SEAS 12 FT OR GRTR WITHIN 150 NAUT
ICAL MILES EITHER SIDE OF A LINE FROM 32N5 126.5W4 TO 44.5N3
126W9 MAX SEAS THIS AREA 17 FT. BT BT UNCLAS //N03145// DIR
NSA ATTN A843 LIZ WWPN 2 NPM 101919 WIND WARNING EFFECTIVE 1
10000Z SEP 74 1. FORECAST GALE WARNING WINDS NORTH NORTHWEST
TO NORTH NORTHEAST 35 TO 40 KTS FORECUST TO DEVELOP BY 1112
00Z OVER WATER AREA BOUNDED BY 33.0N6 TO 43.0N7 BETWEEN 130.
0W4 AND 120.0W3 SEAS 10 TO 15 FT. AREA STATIONARY BT AR

Note 1: Encircled portions of text indicate audio applied to the PVR was outside the passband; no response

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table V).

TABLE VIII

TEST (2) - BROADCAST MESSAGE

230-D (DELAY MODIFICATION) - TRANSCRIPTION

CQ CQ CQ VVV VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV
VVV VVV DE NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV VVV VVV DE
NPM/NPG NPM/NPG NPM/NPG CQ CQ CQ VVV* DIRNSA ATTN A843 LIZ W
HPN NPM 102131 TROPICAL STORT NORMA WARNING 05 HAS MOVED ASH
ORE 60 MILES WEST OF ACAPULCO AND DISSIPATED. THIS IS FINAL
WARNING ON TROPICAL ETORM NORMA. BT BT UNCLAS //N03145// DIR
NSA ATTN A843 LIZ WMPN 2 NPM 102133 NORTH PACIFIC OCEAN HIGH
SEAS WARNING]EAST OF 150E] A. FLEWEACEN PEARL 101919Z SEP
74 1. HIGH SEAS WARNING VALID 110000Z TO 111200Z A. SEAS 12
FT OR GRTR WITHIN 130 NAUTICAL MILES EITHER SIDE EOF A LINE
FROM 42N6 150.5E1 TO 47N1 161E8 MAX SEAS THIS AREA 14 FT. B.
SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES EITHER SIDE OF
A LINE FROM 39.5N7 142.5W2 TO 46.5N6 171W9 MAX SEAS THIS ARE
A 16 FT. C. SEAS 12 FT OR GRTR WITHIN 100 NAUTICAL MILES EI
THER SIDE OF A LINE FROM 34N7 123.5W1 TO 42N6 127W0 MAX SEAS
THIS AREA 15 FT. 2. 24 HOUREFORECAST VALID 111200Z TO 12000
0Z A. SEAS 12 FT OR GRTR WITHIN 150 NAUTICAL MILES EITHER SI
DE OF A LINE FROM 44N8 180/9 TO 46N0 163E0 MAX SEAS THIS ARE
A 16 FT. B. SEAS 12 FT OR GRTR WITHIN 250 NAUTICAL MILES EIT
HER SIDE OF A LIT FE F IE FTI ETTE E EE 139W3 TO 46.5N6 16GE
E IIIT0 MAX SEAS THIS AREA 17 FT. C. SEAS 12 FT OR GRTR WIT
HIN 150 NAUTICAL MILES EITHER SIDE OF A LINE FROM 32N5 126.5
W4 TO 44.5N3 126W9 MAX SEAS THIS AREA 17 FT. BT BT UNCLAS //
N03145// DIRNSA ATTN A 843 LIZ WWPN 2 NPM 101919 WIND WARNIN
G EFFECTIVE 110000Z SEP 74 1. FORECAST GALE WARNING WINDS NO
RTH NORTHWEST TO NORTH NORTHEAST 35 TO 40 KTS FORECAST TO DE
VELOP BY 111200Z OVER WATER AREA BOUNDED BY 33.0N6 TO 43.0N7
BETWEEN 130.0W4 AND 120.0W3 SEAS 10 TO 15 FT. AREA STATIONA
RY BY AR

Note 1: Encircled portions of text indicate audio applied to the PVP was outside the passband; no response

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table V).

TABLE IX

TEST (3) - AMATEUR RADIO OPERATORS

OPERATOR TRANSCRIPTION

Amateur Radio Operator #1

<u>RR SAM W6NL DE W6N</u>YG U SOUND VY YOUNG HI. BT WELL I FEEL THA
T WE NEED LESS HAMS NOT MORE. WE NEED QUALITY NOT QUANITY. B
T HAM RADIO IS A VY S HARD HOBBY TAKE A LOT OF STUDY. BT BT
BT Q BT MY XYL IS TELLING BT BT BT BT BT BT BT OK ON UR CLUB
HE. BT IM FER A LOT OF GUD CW ACTIVITY JUST HRD SUMON RUN A
VFO OVER THE FREQ RA BT THINK WE NEED TO GET TOUGHER ON HAM
S HAVE LICING RENEW BY UPDATED TESTS EVERY 2 YRS. BT TO PLAY
AROUND WITH EQUIPTMENT THAT WE CANT FIX OR UNDERI UNDERSTAN
D IS BAD FER THE HOBBY. BT I WRITE TO W6UF BILL HE A VY INTE
RESTING PERSON I TOLD BILL, THAT EIMC EIMAC TUBEIS TUBES CAU
SE QRM HI HI SO NW IM QRU W6NL DE W6NYG KN

Amateur Radio Operator #2

<u>W6NYG DE W6NL</u> HI BT BT ES THAT IS WHY WE HV A LOT OF POOR AM
ATEURS NW BUT THEY HAVE TO BE TRAINED ABT IT AT.L AND THAT P
ART, IT IS UP TO US TO HELP AS MUCH AS POSSIBLE BT BUT DONT
FERGET THAT SOME OF THESE YOUNG ONES ALSO KNOW A HEA HECK OF
A LOT MORE ABT THE LATEST SA STUFF THAN WE DO BT HI THEY GE
T IT IN SCHOOL ES SOME HEP TO A LOT OF THINGS WE ARE BEHIND
IN BT BT BT THAT IS MY EXPERIENCE ANYWAY BT BT I AM NOT SO M
UCH ON ANYTNG BUT TUBES SETS HI BUT GUESS THAT IS NOT THE CA
SE WID EVERYONE TT IS FER SURE BT HI SO GUESS IF WE TRY TO T
EACH EM WHAT WE KNOW TT IS ABT ALL WE CAN DO ABT T IT HI BT
BT WELL WONT HOLD U ANY LONGER NW FRANN E E E E E FRAT FRANK
BT BT TNX FER QSO HV ENJOYED IT BCNU W6NYG DE W6NL K

Note 1: Underlined portions of text indicate audio applied to the PVP was outside the passband; any response was due to noise or interfering signals.

TABLE X

TEST (3) - AMATEUR RADIO OPERATORS

UNMODIFIED 230-D TRANSCRIPTION

Amateur Radio Operator #1

E S E F Y G U S OUNDVYY:NGHI.= WELL I FEE L THAT WE NE E DLE
S HAM_NOT MORE (WE NEE D QUA LIT Y NOT QUANIT Y= HAM RADIOI
S AVYS <D H OBBY TA KE ALOT OFSTUD Y = = = Q_MY XYL ISTELLIN
G E UT E E = EH E E E E I E =H E E E R E AI I E E E E E E EE
E E E = = OCONIE E F HI $UB EHE . = IM FEREA LOT, G? CWACTI
VITY_STHRD SUMON RUN RVFO OVERTSEIFE EE E S- ENEED TO GET T
OUGH ERON H AMS HAVE LICING RE NEW BY UPDATED TEST S E VERY2
YRS . =TOPLAY AR:ND WITH EQU IPT MENT TH ATWE CANTFIX OR UND
ER I T UNDERSTANDI S BAD FERTHE H OBB Y.BT I WRIT E E E 6UF
B ILL HE AV Y INT E R EST ING PERSON I T OLD B ILL , THAT E
I M C E I M AC E I BE S CAUSE QRT HI HI SONW IM;< W6NLDEW6NY
GKN

Amateur Radio Operator #2

EICH EE= = ES THATIS 6Y WE HV A LOT , POOEN AMATE_S N W BU T
TH EY H AVE TO BE T ENAINED AB TITAT .L AND TH ATP < T , IT
IS_P TO US TOH ELP AS MU<5 AS POSSIBLE = BUT DONTF ERGET TH
AT SOME, THEY:NG ONES .SOKNOWAH EA HECK , AL OT MORE AB T
TH E ED LATEST S T SA STFF THAN WE D O = H EE THEY G ET I T
IN SC H OOL ES SO< E H E P TO A LOT , TH INGS WE <E B EH A B
E H IND I IN = = = THATIS MY EXP E R T EN C E ANYWAY = = I
AM N OT S S O NU C H ON ANYTNGBUTTUBES S ETS H EE BUT G UESS
THETIIS N O T THE CASE WI D EVERY ONE TT ISFERSE = = SO GUE
SS IF WE TRYE T_T E A 6H E M 6 ATWE KNOW TTIS AB T.L WECANDO
TITH EE= = W E ED L WONTH_DUANYLONGE RNWFRANN E E E E E E E
RAT FRANK E = = THXFEENOSO HVE NJO(DIT ESBC)6NNU W6N YG DE H
L < K

Note 1: Encircled portions of text indicate audio applied to the PVP was outside the passband; no response

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table IX).

TABLE XI

TEST (3) - AMATEUR RADIO OPERATORS

230-D (MODIFIED TRACKER) - TRANSCRIPTION

Amateur Radio Operator #1

K E S E Y G USOUNDVYY:NGHI.= WELL I FEE L THAT WE NE E DLESS HAM_NOT MORE " WE N E E D QUA LIT Y NOT QUANITY.= HAM RADIO IS AVYS HARD HOBBY TA KE ALOT OFSTUD Y_= = = Q (MY XYL ISTE LLING = (here noise drives the tracker up and the 230-D must be re-initialized) O S(UB EHE . E IM F;EA LOT, GUD CWACTIVI TY &STH RD SUM JN RUN AVFU O VE HE FET EE E I- ENEED TO GET T OUGH ERON H AMS HAVE LICING RE NEWBY UP DATED TEST S E VER 2YRS. =TOPLAY AR:ND WITH EQU IPT MENT TH ATWE CANTFIX OR UND ER I T UNDERSTANDIS BAD FER THE H OBB Y.BT I WRITE E IE 6UF BILL H E A V Y INT E R EST ING PERSON I T OLD BILL , TH AT E I M C E I S A * E E E BE S CAUSE QRT HIHI SONW IM:U < W6NLD EWoMYGKN

Amateur Radio Operator #2

EIGH EE B_= ES THAT IS 6 Y WE HV A LOT , POOEN AMATEURS N W BUT TH EY H AVE TO BE T ENAINED AB TITAT . LAND NH ATP < T , IT IS P TO US TOHELP AS MU<S AS P OSSIBLE = BUT DONTF ERGET TH AT SOME , THESE Y:NG ONES .SO KNOWAH E A HECK , AL OT MO RE AB T TH E ED ATEST S T SA S TEE THAN WE D O = H EE THEY G ET I TIN SC HO OL ES SO<E H E P TO A LOT , TH INGS WE <E B EH A b E H IND I IN BTE = = THATIS MY ExP E R IE NCE PYWAY = = I AM NOT I SO MU CH ON ANYTNGBUTTUBES S ETS H EE BUT G UE SS THETTIS NOT THE CASE WI D EVERYONE TTISFERS E = E = SO GU ESS IF WE TRYE T T E A / H E M 6 ATWE KNOW TTIS AB T.L WECAN DOAB TITHEE= = W E ED L WONTH_DUANYLONGE RNWFRANN E E E E E FRN FRANK F = = TNXFER_O HVE NJO(DIT ES BC$ 6NNU W6N YG DE N L < K

Note 1: Encircled portions of text indicate audio applied to the PVP was outside the passband; no response

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table IX).

TABLE XII

TEST (3) - AMATEUR RADIO OPERATORS

230-D (DELAY MODIFICATION) - TRANSCRIPTION

Amateur Radio Operator #1

S EYG USOUNDVYY:NGHI.= WELL I FEE L THAT WE NE E DLESS HAM_N
OT M ORE " WE NE E D QUA LIT Y NOT QUANIT Y .= HAM RADIOIS A
VYS HARD H OBBY TA KE ALOT OFST UD Y = = = Q I MYXYL ISTELLI
NG RI E = TES E E U E =SE E E E ENE E E SN I E E E IE E E E
= = O CO MIT OG I M EH;@ UC E V E .= AM YIPEA LO TE, GUD CWA
CTIVITY &STHRD SUMON RUN AVFO U VE_HE FS E E STS ENEED TO GE
T T OUGH ERON H AMS HAVE LICING PE NEW BY UP DATED TEST S E
VERY 2 YRS. =TOPLAY AR:ND WITH EQU IPT MENT TH ATWE CANTFIX
OR UNDER I T UNDERSTANDI S BADFERTHE HOBB Y.= I WRITE E E 6U
F BILL HE AVY INT E R ESTING PERSON I T OLD BILL , THAT E I
M C E I MAC E E FEE E BES CAUSE QRIE H IHI SONW IM;U< W6MYG
KN

Amateur Radio Operator #2

IIG H EE= = ES THAT IS 6 Y WEHV A LOT , POOEN AMATEURS NW BU
T THEY H AVE TO BE T ENAINED AB TITAT .L AND TH ATP < T , IT
IS_P TO US TOH ELP AS MU<5 AS P OSSIBLE = BUT DONTFERGET TH
AT SOME , THESE Y:NG ONES .SO KNOWAH E A HECK , AL OT MORE A
B T TH E ED ATEST S T SA S TEF THAN WE DO = H EE THEY G E T
I TIN SC H OOL ES SO< E H E P TO A LOT , TH INGS WE < E B EH
A B E H IND I IN =E = = THATIS MYEXP E RI E NCE PYWAY = = I
AM N OT I SO MU C H ON ANYTNG BUTTUBE S S ETS H EE BUT G UE
SS THETTIS N OT THE CASE WI D EVERYONE TT ISFERS E = = SO GU
ESS IF WE TRYE T T E A CH E M 6 ATWE KNOW TTIS AB T.L WECAND
O TITH EE= = W E ED L WONTH DUANYLONGER NWFRANN E E E E E E
FRAT FRANK E = = TNXFER QSO HVENJO{DIT ES BCS 6NNU WoN YG DE
_NL < K

Note 1: Encircled portions of text indicate audio applied to the PVP was outside the passband; no reponse

Note 2: Underlined portions of text indicate discrepancies with Operator Transcription (Table IX).

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

It has been shown that a delay modification to a Morse decoder algorithm operating at the MICRO[3] level can enhance decoding ability. This lends credibility to the contention that MARK/SPACE history alone will not provide sufficient information for even an excellent decision algorithm. Some information about the present character is necessary, and some information about "future" characters would be desireable.

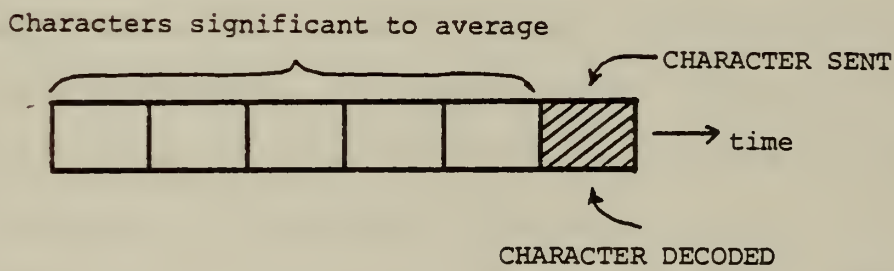


FIGURE 14
NORMAL HISTORY DECISIONS: significant element decisions are based on the nature of previous characters alone.

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[3] MICRO algorithms operate on an element-to-element basis while MACRO algorithms work on variable length "strings" of elements. The latter is generally considered more successful in decoding accuracy, but is much more complex in physical implementation.

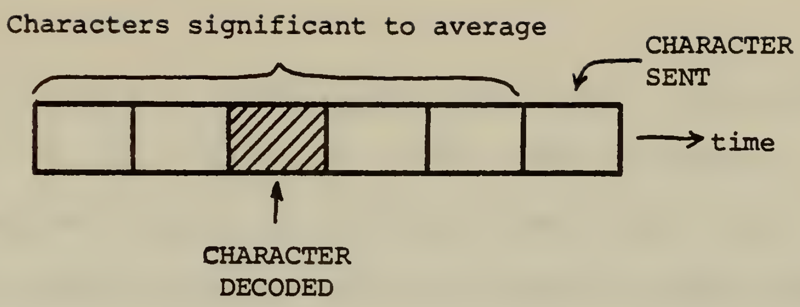


FIGURE 15
DELAY DECISIONS: significant element decisions are based on the nature of past, present, and "future" characters.

A delay in processing element information in the decoder is used while allowing the averaging process to operate on these same elements in real-time. Although decoding does not immediately take place after a character is sent (real-time), the proper timing sequences are faithfully maintained and the characters are decoded in "pseudo" real-time.

Since most elementary algorithms base decisions on the "history" of the elements, it would seem worthwhile to consider modification of existing circuits to allow the use of delayed processing. The actual quantity of delay to be used for optimum contribution to the algorithm will depend upon: (1) the nature of the algorithm, (2) the nature of code, and (3) the clocking speed available for the shift registers.

The delay modification permits consideration of past, present, and future elements; this effectively transforms a MICRO-algorithm into a combination MICRO/MACRO-algorithm.

It is of interest to note that the greatest apparent improvement (Test 1) occurred at the 12 wpm speed. For the original 230-D: twelve characters were not successfully decoded (due to all dash or high dash content), three characters required two or more Morse repetitions to begin decoding, and only two characters (E and T) began decoding immediately. After the tracker modification: only six characters failed to decode successfully and no other character required more than one Morse unit to begin decoding correctly. The most significant improvement came with the delay modification: the same six characters (from the modified tracker results) remained undecoded, but ALL remaining characters were decoded immediately!

The results for 20 wpm and 40 wpm are similarly encouraging, but not as dramatic. This is due, in part, to the fact that the digital speed tracker is initially set for 10.5 wpm and does not have to adjust radically for the 12 wpm code. A longer static shift register line should produce results at 20 wpm and 40 wpm that are comparable to the 12 wpm observations. Optimization would need to be performed to account for the new MARK delay and the resulting longer averaging interval for speed fluctuations.

Finally, this thesis has not SOLVED the problem of lost characters in decoding; it has contributed to a significant reduction in these losses.

B. RECOMMENDATIONS

Devices using variations of both MICRO and MACRO approaches are being presented continually. The physical implementation of a MICRO algorithm generally has a cost advantage while the MACRO techniques maintain the advantage in degree of successful decoding. On closer inspection, it is easily observed that most decoding algorithms leave much to be desired. The most sophisticated algorithm eventually fails due to Chisholm's Law of Human Interaction. (There will ALWAYS be someone sending Morse code that will tear up the algorithm!)

The recent upsurge in microcomputer usage offers a viable and inexpensive approach to the optimization of decoding algorithms. It would seem wise to invest in one of the more flexible units to make software algorithm changes prior to the actual hardware work. In addition, microcomputers can be used to attack some of the problems attendant to Morse code reception (e.g. drifting receivers, chirping transmitters, noise, etc.). To some extent, these microcomputers might even be programmed with a limited contextual analysis ability designed to detect probable errors in a hardware (or software) decoder.

There is much left to be done in the area of Morse translation before complete automation should be attempted. The following areas are representative of projects currently under development or that should be considered for further work: (1) audio filters capable of tracking a drifting receiver/transmitter, yet capable of providing a passband narrow enough to be consistent with the Morse signal bandwidth; (2) segregation of Morse signals in a common passband by frequency or keying characteristics; (3) segregation of Morse signals from non-Morse signals; (4) "fist" identification; and (5) contextual analysis.

Finally, a few comments are in order regarding previous methods for comparing operator transcribed Morse to machine decoded output. With few exceptions, experienced operators have been used to generate "standards" for comparison to machine decoding. Little consideration has been made for errors in transmission that the sending operator may have made and that went undetected by the receiving expert. A different approach to this comparison technique would be to allow the sending operator to copy his own text (at a different speed or frequency, if necessary) and compare this result to the machine output and the expert's transcription. Above all, persons doing the final evaluation of the tests should be knowledgeable in Morse from on-the-air experience rather than from book-derived expertise. Not that the "book-experts" lack knowledge or ability; rather, they lack real-world experience using their knowledge of Morse. Morse by sight is completely different from Morse by ear.

APPENDIX A

INTERNATIONAL MORSE CODE LISTING

CHARACTER	REPRESENTATION	230-D visual display
A(8)	.-	A
B(12)	-...	B
C(14)	-.-.	C
D(10)	-..	D
E(4)	.	E
F(12)	..-.	F
G(12)	--.	G
H(10)	....	H
I(6)	..	I
J(16)	.---	J
K(12)	-.-	K
L(12)	.-..	L
M(10)	--	M
N(8)	-.	N
O(14)	---	O
P(14)	.--.	P
Q(16)	--.-	Q
R(10)	.-.	R
S(8)	...	S
T(6)	-	T
U(10)	..-	U
V(12)	...-	V
W(12)	.--	W
X(14)	-..-	X
Y(16)	-.--	Y
Z(14)	--..	Z
1(20)	.---- (cut .-)	1
2(18)	..--- (..-)	2
3(16)	...-- (...-)	3
4(14)	....- (....-)	4
5(12)	..... (.....)	5
6(14)	-.... (-....)	6
7(16)	--... (-...)	7
8(18)	---.. (-..)	8
9(20)	----. (-.)	9
0(22)	----- (-)	0

The figures in parentheses represent the number of "dots" (bits, bauds) that are required in time to send the character. This number includes the 3 unit letter space following a character.

APPENDIX B

MORSE CODE SPEED STANDARDS

Telegraph signals are characterized by element time durations equal to, or greater than, the shortest dot interval. Telegraph speed is generally expressed as the inverse of the dot interval in seconds. One dot-per-second will be one baud.

There are many speed "standards" for Morse code; each is based on the type of traffic being sent. This appendix will discuss the three most common currently in use.

(1) AVERAGE WORD STANDARD

Since the number of dots and dashes varies for different characters, the use of an average duration may be desired. For English plaintext, a character's average length (not including its associated LETTER SPACE) is roughly 9 dots and an average word is five letters. (For International Morse the average character is close to 11 dots.) Therefore, "N" wpm= N[(5x9)+7] = 52N dots/minute. This corresponds to 1154/N milliseconds per dot. (e.g. at 20 wpm, 1 dot = 57.5 msec.)

(2) PARIS (50 baud) STANDARD

The most common speed standard in use is the PARIS standard. The word PARIS consists of 50 bauds (including a seven unit WORD-SPACE and four LETTER-SPACES). If ten PARIS words can be sent in one minute, the speed is 10 wpm. Therefore, "N" wpm= 50N dots/minute. This corresponds to 1200/N milliseconds per dot. (e.g. at 20 wpm, 1 dot = 60 msec.)

(3) CODEZ (60 baud) STANDARD

Most military stations use a standard based on the 60 baud word CODEZ. Using CODEZ, the speed in wpm APPEARS to be much faster. The use of CODEZ, as opposed to PARIS, is a result of two different types of code transmission. In the military, five letter coded groups are prevalent, while amateur and commercial users transmit plaintext containing a higher ratio of E's and I's. The CODEZ standard is used to compensate for this difference. Therefore, "N" wpm = 60N dots per minute. This corresponds to 1000/N milliseconds per dot. (e.g. at 20 wpm, 1 dot = 50 msec.)

An example of the PARIS/CODEZ difference is:

60 wpm(PARIS) = 20 msec/dot = 50 wpm(CODEZ)

APPENDIX C

MORSE SIGNAL BANDWIDTH

There is widespread (and uninformed) belief that the Morse coded CW signal has essentially a zero bandwidth. The following argument demonstrates how the bandwidth of a Morse coded CW signal is dependent on code speed.

To calculate the bandwidth of a Morse signal, the autocorrelation function will be of value.

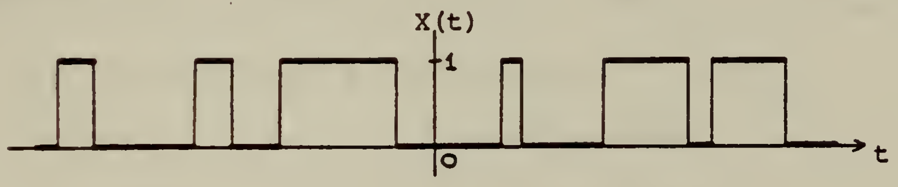


Figure 16. Random Morse Signal

At any instant of time, X(t) assumes a value of "0" or "1" with equal probability. X(t) makes independent random traversals from one level to the other.

$$X = 0 \cdot P(X=0) + 1 \cdot P(X=1) = P(X=1) = 1/2$$

Assume that the probability of "k" traversals in "T" seconds is given by the Poisson distribution:

$$P(k,T) = \frac{(aT)^k}{k!} \exp(-aT)$$

where a= the average number of TRAVERSALS per unit of time. Define X1=X(t) as a discrete random variable having values "0" and "1". Similarly, define X2=X(t+T). The possible outcomes of an experiment involving X1 and X2 are: (0,0), (0,1), (1,0), (1,1). The A.C.F. (autocorrelation function) $R_x(T) = \overline{X1 \cdot X2}$. Therefore,

$$R_x(T) = (0 \cdot 0)P(X1=0,X2=0) + (0 \cdot 1)P(X1=0,X2=1)$$
$$+ (1 \cdot 0)P(X1=1,X2=0) + (1 \cdot 1)P(X1=1,X2=1)$$

$$\text{so,} \quad R_x(T) = P(X1=1,X2=1)$$

This is the probability that X1=1 and that an EVEN number of traversals occur between (t) and (t+T).

$$P(X1=1,X2=1) = P(X1=1,k=\text{even}) = P(X1=1)\ P(k=\text{even})$$

Since the traversals are independent of level,

$$R_x(T) = (1/2)P(k=\text{even})$$

and, P(k=even) in the interval T =

$$\exp(-a|T|) \sum_{\substack{k=0 \\ k=\text{even}}}^{\infty} \frac{a|T|^k}{k!}$$

Where the magnitude sign converts T to an interval of time.

$$\sum_{\substack{k=0 \\ k=\text{even}}}^{\infty} \frac{(a|T|)^k}{k!} = \frac{1}{2}\left[\sum_{k=0}^{\infty} \frac{(a|T|)^k}{k!} + \sum_{k=0}^{\infty} \frac{(-a|T|)^k}{k!}\right]$$

$$= (1/2)\ [\exp(a|T|) + \exp(-a|T|)]$$

$$R_x(T) = (1/4)[1 + \exp(-2a|T|)]$$

The power spectral density function $G_x(f)$ is obtained from:

$$\mathfrak{F}[R_x(T)] = \frac{1}{4}\left[\delta(f) + \frac{4a}{4a^2 + (2\pi f)^2}\right]$$

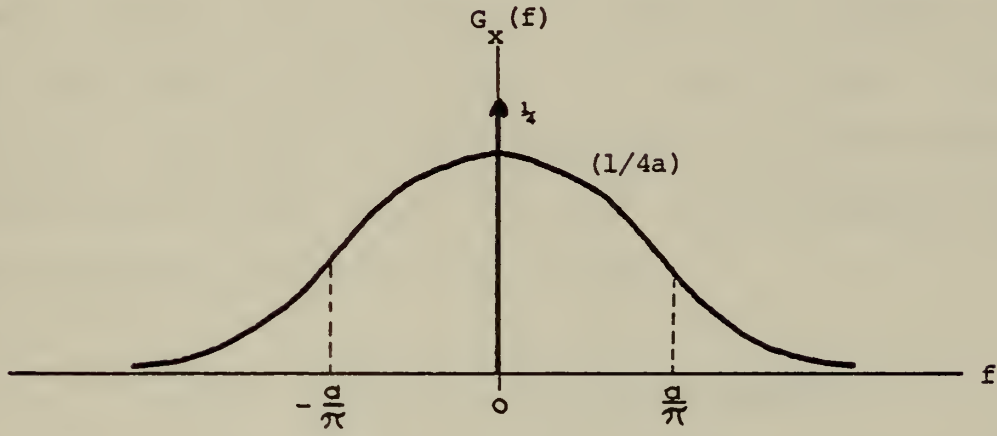


Figure 17

POWER SPECTRUM OF THE MORSE SIGNAL

Solving the equation, the 3 dB bandwidth for the Morse signal is $(2a/\pi)$. Since the word PARIS contains 28 traversals, this would indicate a 3 dB bandwidth of 5.9 Hz for a 20 wpm signal. Further analysis reveals that, for 95% power of a Morse signal at 20 wpm, Bandwidth = 52.8 Hz. This figure closely agrees with the "standard" used by Bell.[8]

APPENDIX D

TYPICAL ALGORITHMS USED BY AUTOMATIC DECODERS

(1) IDEAL DOT ALGORITHM

All MARK/SPACE decisions are based on an element-to-element basis. For example, if the first element is less than (1/2) that of the second, it was a dot. Similar decisions are made for the spaces and are highly dependent on the nature of the code being sent. This algorithm tends to be extremely susceptible to noise.

(2) DOT-PERIOD AVERAGE ALGORITHM

All decisions are based on a quantity representing the dot plus its subsequent space. In an average, this quantity is approximately equal to 2 x (dot). Again, all decisions are based on the same quantity, and will be dependent on the nature of the code. This algorithm is somewhat less susceptible to noise effects, but generally fails to consider the effect of poor spacing formations.

(3) MARK-SPACE AVERAGE ALGORITHM

This technique is documented in reference [1]. The average algorithm is a variation of the DOT-PERIOD algorithm. Here, ALL marks and spaces are initially assigned a name (dot,dash,element space, etc.) according to a fixed formula. As each type of MARK/SPACE begins to accumulate in its "bin", the formula is changed to a more representative mathematic relationship giving more noise immunity. The decisions here are two-dimensional in nature and are illustrated in figures 2, 4, and 6.

(4) SLIDING WINDOW ALGORITHM (MAUDE)

This algorithm was first presented in the late 1950's. Its main feature is the ability to store strings of characters, analyze the string's statistics, and use those statistics to decode the elements in the string. As more code characters are available, the "window" moves in time, and the process continues. The significant difference here is the ability to decode the same character more than once in different strings and compare the results for accuracy. Although claimed accuracy was high, real-time off-the-air Morse was not used in the original tests.

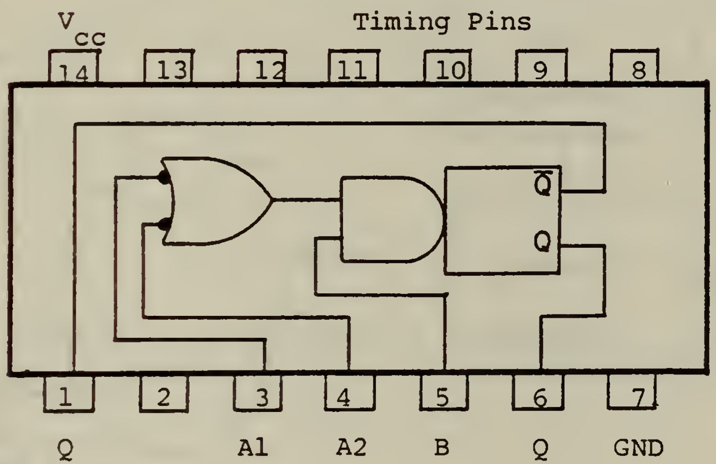
There are a great many more algorithms possible. Some use a priori knowledge of the characteristics of the code to aid in simplification; others use extremely complex mathematical models to describe the nature of the signal patterns. The algorithms mentioned in this appendix all use the dot as a reference in some fashion. This should not be interpreted as an inference that the dash is not used; on the contrary, the dash IS used in some algorithms. The use of the dash or an elementary space as the reference is not as popular as the use of a dot, since the dot reference algorithms seem to yield better results.

APPENDIX E

INTEGRATED CIRCUIT CHARACTERISTICS

The digital delay circuit shown in figure 11 utilizes a 74121 monostable multivibrator integrated circuit and a 2533 MOS static shift register. This appendix contains pertinent information about each of these devices.

SN74121 Monostable Multivibrator

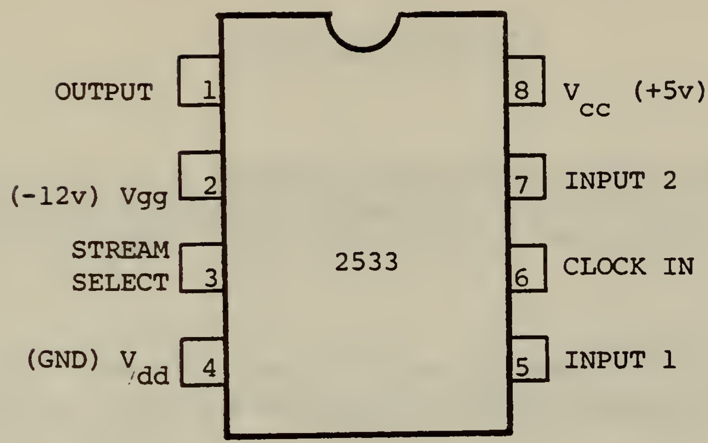


1. B is a positive Schmitt-trigger input for slow edges or level detection, and will trigger the one-shot when B goes to logical 1 with either A1 or A2 at logical 0.

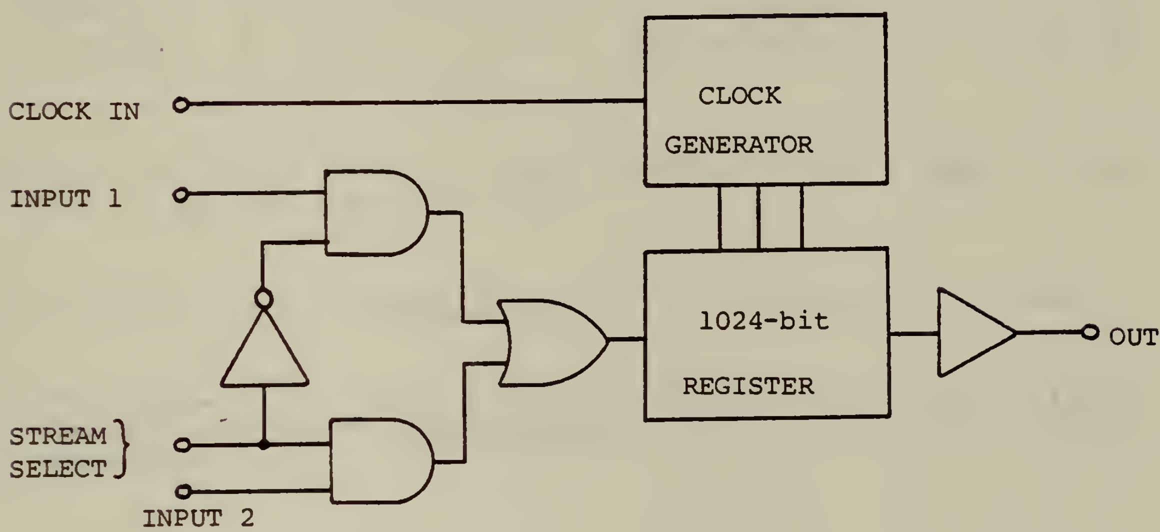
2. External timing capacitor may be connected between pin 10 and pin 11. With no external capacitance, an output pulse width of 30 nsec is typically obtained.

3. To use the internal timing resistor (nominally 2K), connect pin 9 to pin 14.

2533 1024-bit Static Shift Register



STREAM SELECT = 0, INPUT 1 selected
= 1, INPUT 2 selected



1. All inputs of this Static Shift Register, including the clock, can be driven directly by bipolar DTL/TTL integrated circuits without external interface components. The output is push-pull, providing a fanout of one normal TTL load.

2. The three clock phases used in the static register cells are generated by an on-chip generator. This clock generator is controlled by a single DTL/TTL logic level input.

3. Data is entered when the clock is at a logic 1. Data is shifted when the clock goes low.

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