Number 54: Measuring Code Speed:
(TechTalk #129)
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INTRODUCTION:
"Words per minute" (WPM) is a term often used to describe the speed at which CW is transmitted. In this article it will be defined, as will another term ***"Code groups per minute"*** (CGPM). Both terms are used by the FCC. Over the years the FCC has required, or given code tests, at speeds of 5 WPM, 13 WPM, 16 CGPM, 20 WPM 20 CGPM and 25 WPM for amateur and commercial operators. What are the differences between WPM and CGPM? What is the Farnsworth system of speed for CW? Hopefully these will be answered in this article.

Last month's Heathkit article on the HD-10 Electronic Keyer resulted in a discussion on how the dot-widths were obtained in **TABLE III** in that article. The table is repeated here as **TABLE I.** "WPM" was added to the title of the table to distinguish it from **TABLE II** to be presented later.

TABLE I gives the relationship between dots and dashes in international Morse code. If a dit (dot) is 1 unit long, then a dah (dash) is 3 units long and the space between a dit and dah is the same length as a dit. The space between characters is 3 dits long and the space between words is 7 dits long. The time length of one unit (one dit) is noted as 1T.

Of course, no CW operator can effectively send with such timing accuracy. Often operators using a hand key or bug have a rhythm, a 'signature', or 'fist', that other operators can easily recognize. A bug takes some of that signature away, but the rhythm may still be recognizable. A fully electronic key takes more away, leaving the operator sending in control only of the space between characters (inter-character space) and the space between words (inter-word space). Still, some signature probably exists.

Computer generated code, can be very precise in timing. It is often used to send "perfect code" for practice and for testing.

Words Per Minute:
"Words per minute" is quite arbitrary; the length of words vary significantly. Thus a standard word was designated for calculating WPM. That word is **PARIS**. If you send it using the definition of the length of T in **TABLE I** and include the 'inter-word' space,

Morse Code WPM Timing Basics

The timing of an international Morse code sentence is based on the "T-Unit" which is the length of a dit in milliseconds (mS). Here are the defined lengths for other parts of the International Morse code:

Dit length:	1T (by definition)
Dah length:	3T
Intra-character space [a]:	1T
Inter-character space [b]:	3T
Inter-word space:	7T

[a] The space between dits and dahs within a character.
[b] The gap between the characters of a word.

Here are values of T for some common speeds:

5 WPM	240.00 mS.
10 WPM	120.00 mS.
13 WPM	92.31 mS.
18 WPM	66.67 mS.
20 WPM	60.00 mS.
25 WPM	48.00 mS.

Caution: These 'T' values are only good for determining WPM. A second code speed exists, 'code groups per minute' (CGPM) which has slightly shorter values for 'T'.

TABLE I

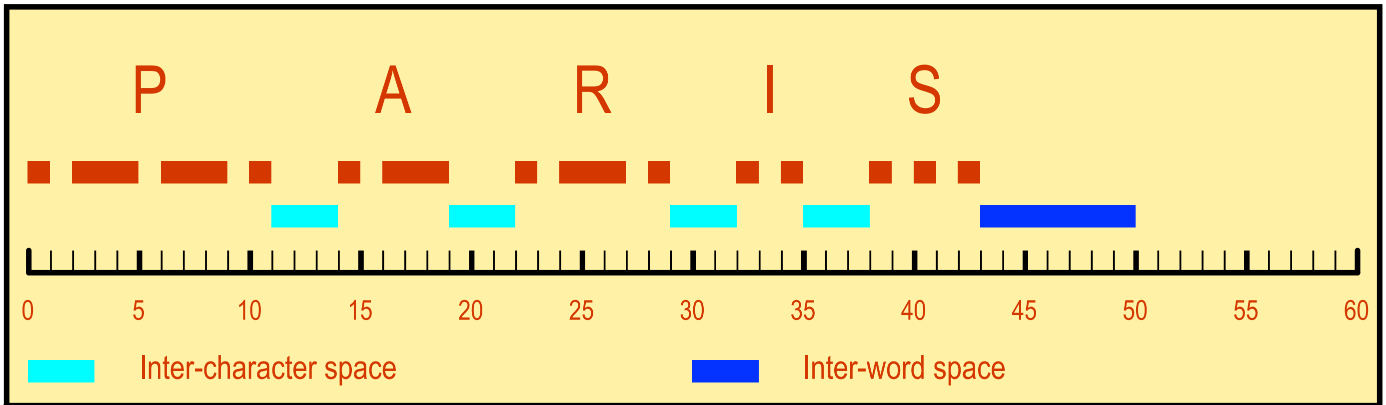

Figure 1: The standard word for calculating WPM is PARIS. As shown, it is exactly 50 T-units of time long.

PARIS is exactly 50 T (dit) lengths long (**Figure 1**). Based on this standard word, the length T in milliseconds can be calculated for any given WPM and vice-versa. The derivation is simple:

The length of a 'word': $L_w = 50T$ in milliseconds (mS) and:

Words Per Minute: $WPM = \frac{1_{min}}{L_w}$

Thus:

$$WPM = \left(\frac{1_{min}}{50T_{ms}}\right)\left(\frac{60_{sec}}{1_{min}}\right)\left(\frac{1{,}000_{ms}}{1_{sec}}\right)$$

$$WPM = \frac{60{,}000_{ms}}{50T_{ms}} = \frac{1{,}200}{T} \qquad (1)$$

And so: $$T = \frac{1{,}200}{WPM} \qquad (2)$$

Equation (2) is the one used to calculate the values in Table I.

Only WPM based Morse code was used by the FCC for amateur code testing. Formerly, when code testing was required, tests of 5 WPM - Element 1A, 13 WPM - Element 1B and 20 WPM Element 1C were given [FCC Title 47 § 97.21(a)(b)(c){1986}]. WPM is currently also used for some commercial code testing, specifically 20 WPM - Telegraphy Element 2, and 25 WPM - Element 4 *, [FCC Title 47 § 13.203(b)]. Telegraphy characters used in WPM testing are: all characters of the alphabet, the numbers 0 – 9, punctuation period, comma, and question mark, as well as prosigns *DN*, *AR*, *BT* and *SK*. Punctuation and prosigns each count as two characters.

Code Groups Per Minute:

"Code groups per minute" is another speed standard. It is used mostly for commercial code testing, specifically Telegraphy Element 1, 16 CGPM and Element 3 *, 20 CGPM [FCC Title 47 § 13.203(b)]. These tests are given using groups of five characters. The characters are random and consist of the same set used for WPM testing.

Like WPM, "Code groups per minute" is also based on a standard 5 character word. That word is **CODEX**. If you send it using the definition of the length of T in **TABLE I** and include the 'inter-word' space, CODEX is exactly 60 T (dit) lengths long (**Figure 2**).

Following the previous derivation:

$$CGPM = \frac{60{,}000_{ms}}{60T_{ms}} = \frac{1{,}000}{T} \qquad (3)$$

Or: $$T = \frac{1{,}000}{CGPM} \qquad (4)$$

*** These elements are no longer in use.**

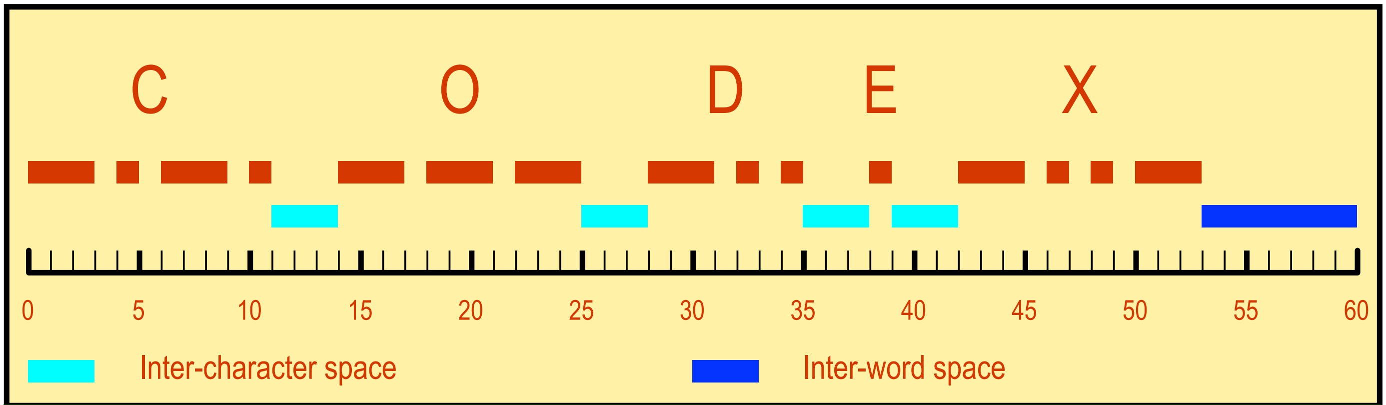

Figure 2: The standard word for calculating Character Groups Per Minute is CODEX. As shown, it is exactly 60 T-units of time long.

Equation (4) is the one used to calculate the values in Table II.

Character groups per minute mimic an encoded message sent using standard letters, numbers and punctuation formed into five-character groups. This was a common way to send encoded commercial or military messages in past times. The encoding used is independent of the message and the message contents is unknown to the CW operators handling the message.

Farnsworth System (WPM):

"The Farnsworth System of International Morse" code was developed by Donald. R. Farnsworth, who taught radio telegraphy at the Illinois Institute of Technology in the early 1940s.

The Farnsworth system is based on two different code speeds. One is the overall speed the code is being sent at; the other is the speed each character is being sent at. If the overall speed is 10 WPM, but each character is sent at 20 WPM there will be longer delays between characters and words. The person learns the rhythm of the fast code characters early, and has more time to recognize each character. As the overall speed increases, only the time between characters and words are shorter. The characters continue to sound unchanged. Farnsworth timing is displayed as two numbers such as W_O/W_C. The first or upper number W_O is the actual overall code speed in WPM; the second number W_C is the character speed in WPM. as an example 10/20 means the overall speed is 10 WPM but the

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[a] The space between dits and dahs within a character.
[b] The space between characters of a word.

(The T-Units above are identical to WPM T-units)

Here are values of T for some common speeds:

5 CGPM	200.00 mS.
10 CGPM	100.00 mS.
13 CGPM	76.92 mS.
18 CGPM	55.56 mS.
20 CGPM	50.00 mS.

Caution: These 'T' values are only good for determining CGPM. A second code speed exists, 'words per minute' which has slightly longer values for 'T'.

TABLE II

code characters are being sent at 20 WPM.

TABLE III breaks down PARIS into its five T-unit types. The top three use 31 total T-Units. That is the number of T-units used for dits, dahs and intra-character spaces for PARIS. They are designated by T_C-units as they make up the T-Units for the character speed. The remaining 19 are designated $\boldsymbol{T_F}$ and are available to be lengthened to slow down the code to the overall transmission speed. Even though the inter-character and inter-word can be adjusted, the ratio between them needs to remain the same:

(Inter-character : Inter-word = 3 : 7).

T-Unit Types	P	A	R	I	S	ICS	IWS	Total T-Units
Di(t)s (x 1):	2	1	2	2	3	–	–	T = 10
Dahs (x 3):	6	3	3	0	0	–	–	T = 12
Intra-Character Spaces (x 1):	3	1	2	1	2	–	–	T = 9
Total T-Units at character speed:	9	4	5	1	2	–	–	***31***
4 Inter Character Spaces (x 1):	–	–	–	–	–	12	–	T = 12
1 Inter-Word Spaces (x 7):	–	–	–	–	–	–	7	T = 7
Total Farnsworth T-Units	–	–	–	–	–	12	7	***19***
Totals:	20	9	12	4	7	12	7	T = 50

TABLE III

Calculating T_F:

From equation (2) the time it takes sending the standard word PARIS at the overall speed (W_O) is:

$$50T_O = \frac{(50)1{,}200}{W_O} = \frac{60{,}000}{W_O} \quad \text{in mS}$$

And, the time used by the actual characters sent at W_C is:

$$31T_C = \frac{(31)1{,}200}{W_C} = \frac{37{,}200}{W_C} \quad \text{in mS}$$

The difference in these two times is the total amount of time that needs to be spent in inter-character and inter-word spaces (T_{diff}):

$$T_{diff} = \frac{60{,}000}{W_O} - \frac{37{,}200}{W_C} \qquad \text{in mS}$$

Since any number divided by itself is one, and a number does not change when multiplied by one, let's multiply each element by one:

$$T_{diff} = \left(\frac{60{,}000}{W_O}\right)\left(\frac{W_C}{W_C}\right) - \left(\frac{37{,}200}{W_C}\right)\left(\frac{W_O}{W_O}\right)$$

and then simplify the equation to:

$$T_{diff} = \frac{60{,}000W_C - 37{,}200W_O}{W_O W_C} \qquad \text{mS} \quad (5)$$

T_{diff} is the total time for *19* T_F-units. So each T_F-unit is:

$$T_F = \frac{T_{diff}}{19} \quad \text{in mS} \qquad (6)$$

The four Farnsworth inter-character spaces in milliseconds are each three T_F-units long:

$$T_{IC} = 3T_F \ \text{ in mS} \qquad (7)$$

And the Farnsworth inter-word space in milliseconds is seven T_F-units long:

$$T_{IW} = 7T_F \text{ in mS} \qquad (8)$$

An Example (10/20 WPM):

From Equation (2), the length of time in mS for each dit and intra-space character will be

$$T_{DIT} = T_{IAC} = \frac{1{,}200}{20} = 60mS$$

Each dah will be:

$$T_{DAH} = 3\left(\frac{1{,}200}{20}\right) = 180mS$$

Before the inter-character spacing and inter-word spacing can be calculated T_{diff} must be solved using Equation (5):

$$T_{diff} = \frac{60{,}000(20) - 37{,}200(10)}{(20)(10)}$$

$$T_{diff} = \frac{1{,}200{,}000 - 372{,}000}{200}$$

$$T_{diff} = 4{,}140 \text{ mS}$$

So the 19 T_F-units take-up 4,140 mS and each T_F-unit then is:

$$T_F = \frac{4{,}140}{19} = 217.89 \text{ mS}$$

Using Equation (7), the length of an inter-character space can be determined:

$$T_{IC} = 3T_F = 653.68 \text{ mS}$$

Using Equation (8), the length of an inter-word space can be determined:

$$T_{IW} = 7T_F = 1{,}525.26 \text{ mS}$$

Checking the Results:
It's always important to check your results to be sure no error crept in. Ten "PARIS" words sent at Farnsworth 10/20 speed should add up to 1 minute of time (60,000 mS) The check follows in **Table IV**.

Name	Quantity	Length (mS)	Total (mS)
DITS	100	60.00	6,000
IAC	90	60.00	5,400
DAHS	40	180.00	7,200
IC	40	653.68	26,147
IW	10	1,525.26	15,253
		Total:	60,000

TABLE IV - Check of the Results

SYMBOLS & DEFINITIONS

T	Length in milliseconds (mS) of one dit in either PARIS or CODEX.
T_F	Length in mS of one Farnsworth time-unit.
T_{IC}	Length in mS of three Farnsworth time-units that is one Inter-Character space.
T_{IW}	Length in mS of seven Farnsworth time-units that is one Inter-Word space.
T_{diff}	In Farnsworth timing, the difference between the overall time of the word and the sum of the time of the dits, dahs and intra-character spaces that makes up the word, in mS.
T_{IAC}	Length in mS of the intra-character gap; the gap between two elements (dits and dahs) that make up a character. Usually the same as the length of a dit.
W_C	Character speed in Farnsworth timing in WPM.
W_O	Overall speed in Farnsworth timing in **W**PM.
G_C	Character speed in Farnsworth timing in C**G**PM.
G_O	Overall speed in Farnsworth timing in C**G**PM.
CGPM	Character Groups Per Minute
WPM	Words Per Minute
mS	milliseconds.
IAC	IntrA Character space.
IC	Inter Character space.
IW	Inter Word space

Ten "PARIS" words result in 100 dits, 90 intra-space characters (IAC), 40 dahs, 40 Farnsworth inter-character spaces (IC), and 10 Farnsworth inter-word spaces (IW).

Farnsworth System (CGPM):
The Farnsworth system can also used for

T-Unit Types	C	O	D	E	X	ICS	IWS	Total T-Units
Di(t)s (x 1):	2	0	2	1	2	–	–	T = 7
Dahs (x 3):	6	9	3	0	6	–	–	T = 24
Intra-Character Spaces (x 1):	3	2	2	0	3	–	–	T = 10
Total T-Units at character speed:	9	11	5	0	9	–	–	***41***
4 Inter Character Spaces (x 1):	–	–	–	–	–	12	–	T = 12
1 Inter-Word Spaces (x 7):	–	–	–	–	–	–	7	T = 7
Total Farnsworth T-Units	–	–	–	–	–	12	7	***19***
Totals:	20	22	12	1	20	12	7	T = 60

TABLE V

learning the Morse code using CGPM instead of WPM:

Solving for T_{diff} using the values in **Table V**, which is similar to **Table III**, gives:

$$T_{diff} = \frac{60{,}000G_C - 41{,}000G_O}{G_O G_C} \quad \text{mS} \quad (9)$$

The only change between solving for Farnsworth WPM and CGPM is a different value for T_{diff}. This results in new values for T_F, T_{IC} and T_{IW}, but Equations (6), (7) and (8) remain the same.

T_F-unit is: $$T_F = \frac{T_{diff}}{19} \text{ mS long}$$

The four Farnsworth inter-character spaces in milliseconds are each three T_F-units long:

$$T_{IC} = 3T_F$$

And the Farnsworth inter-word space in milliseconds is seven T_F-units long:

$$T_{IW} = 7T_F$$

The derivation is left for an exercise for the reader.

An Example (10/20 CGPM):
From Equation (4), the length of time in mS for each dit and intra-space character will be:

$$T_{DIT} = T_{IAC} = \frac{1{,}000}{20} = 50mS$$

And each dah will be:

$$T_{DAH} = 3\left(\frac{1{,}000}{20}\right) = 150mS$$

Before the inter-character spacing and inter-word spacing can be calculated T_{diff} must be solved using Equation (9):

$$T_{diff} = 3{,}950 \quad \text{and} \quad T_F = 207.89$$

Thus:

$$T_{IC} = 623.67 \quad \text{and} \quad T_{IW} = 1{,}455.23$$

All in milliseconds.

The reader can confirm these numbers using a table like **Table IV**.

More on the Farnsworth System:
The ARRL uses the Farnsworth System to send its code practice and code proficiency transmissions at speeds below 18 WPM. At and above that speed the code is sent in the normal fashion with inter-character spaces 3 dits long and inter-word spaces. 7 dits long.

If you're just starting to learn the code, the Farnsworth system is recommended. Many people learning code hit a plateau around 10 WPM. At that speed, counting dots starts becoming difficult, and many new students do that, often subconsciously. With the Farnsworth system you start recognizing characters by their rhythm instead of counting dits at the very beginning.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the April 2024 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.

REVISIONS:

A (6/13/24):
This revision is a correction of the the original article published in the April 2024 Issue of RF:

Page 1 starting on column 1 last paragraph:

Was: Often operators using a hand key or bug have a rhythm, a 'signature' that others operators can easily recognize.

Is: Often operators using a hand key or bug have a rhythm, a 'signature', or "fist", that other operators can easily recognize.

de AF6C