The origin of the 1.42 unit stop element in the North American 5-bit teletypewriter system

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ABSTRACT

The teletypewriters commonly seen in police stations, newsrooms, airport operations offices, corporate communication centers, and the like for many years used a 5-bit character code and operated over a binary channel in bit-serial form, in what would be called in today's taxonomy of data communication the *asynchronous mode* (but "in the day" it was described as the "start-stop" mode).

Each character comprised 7 sequential binary elements; the first six (the "Start element" and five "Information elements") had the same duration, but (in the system most used in North America) the last one (the "Stop element") had a duration 1.42 times the duration of the earlier intervals.

Why this odd value?

In this article, the author gives his best outlook on the origin of this value, based on authentic historical documents he had reviewed in the 1960s.

Considerable background on the signal involved is provided.

1 THE TELETYPEWRITER SIGNAL

1.1 The "start-stop" teletypewriter mode

The teletypewriters commonly seen in police stations, newsrooms, airport operations offices, corporate communication centers, and the like for many years used a 5-bit character code and operated over a binary channel in bit-serial form, in what would be called in today's taxonomy of data communication the *asynchronous mode* (but "in the day" it was described as the "start-stop" mode).

In this mode, in any given system design there was a defined maximum character rate, but characters were not necessarily continuously sent at that rate. Rather, after one character was sent, the next could begin at any later time consistent with that maximum rate. This of course fit well into the scenario in which the text was entered manually on a typewriter-like keyboard.

1.2 The character format

For traditional reasons, the two states of the binary transmission channel were called “mark” and “space”.[1] The idle state of the channel, continuously in effect when no data was being sent, was *mark*.

When a character was sent, it began with an interval of the *space* state, whose role was to alert the receiving station that this was the beginning of a character. The duration of that “Start element” is “one unit”, the *unit* being the unit (!) in terms of which the durations of elements are stated on a normalized basis. To put this into practical perspective, in one common system (discussed in section 6), the unit duration is 22.0 ms.

The Start element is followed by five intervals, of duration 1.0 unit each (the “Information elements”), which carry the five bits of the character’s coded representation[2], being of state *mark* or *space* to convey the value of the associated bit as “1” or “0”, respectively.

The character ends with a “Stop element”, of the *mark* state. In the 5-bit teletypewriter system most used in North America, the duration of the stop element is specified as 1.42 units.

In figure 1, we see this format for two consecutive characters sent at the maximum specified character rate for the system in use.

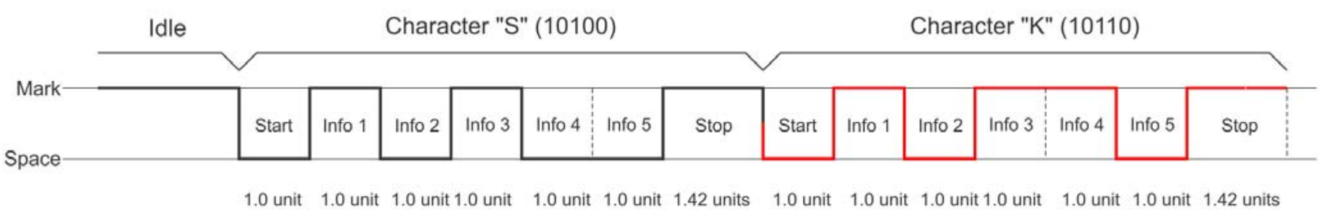

Figure 1. Teletypewriter signal–characters at maximum rate

The two characters (“S” and “K”) were chosen so that, for both, bit 1 was mark (1) and bit 5 was space (0) so that the end of the Start element and the beginning of the Stop element could be clearly seen. The two colors of the mark-to-space transition between the two characters is just to remind us that this is the end of the first character (shown in black) and the beginning of the second (shown in red).

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[1] In much writing “marking” and “spacing”, but I use here the more compact terms.

[2] The coded character set used was based on one developed by Donald Murray. But it is often, though erroneously, spoken of as the “Baudot” code, an *hommage* to French automatic telegraph pioneer J.M.E. Baudot, who developed a comparable, but totally different, coded character set.

We start with the channel idle, in which it is in the *mark* state. The two characters than ensue as described just above.

The period of the *mark* state that is the Stop element will of course be prolonged if the next character is not sent as soon as permissible (*mark* being the "idle state"). We see that in figure 2.

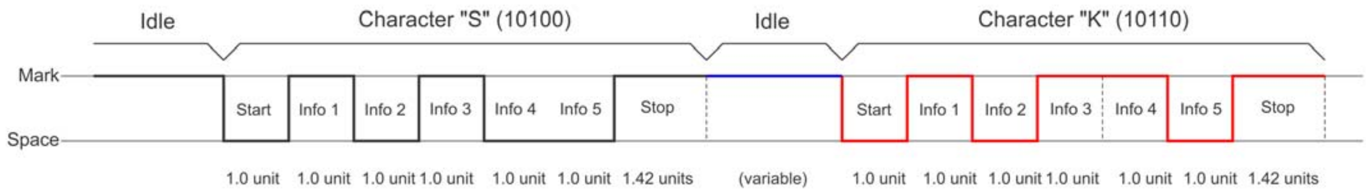

Figure 2. Teletypewriter signal–characters with idle period between

Again to put this into practical perspective, for the specific system mentioned just above, with a unit length of 22.0 ms, the maximum character rate is about 6.13 characters per second (ch/s) or about 368 characters per minute (ch/m).

We see in figure 2that the Stop element of the first character (having the "idle" state) blends with the idle period (if any) between characters. Thus the Stop element can be looked at as enforcing a "minimum permissible idle period" between characters that are actually 6.0 units long (although the situation is not usually discussed that way). That outlook is shown (for both situations) in figure 3333.

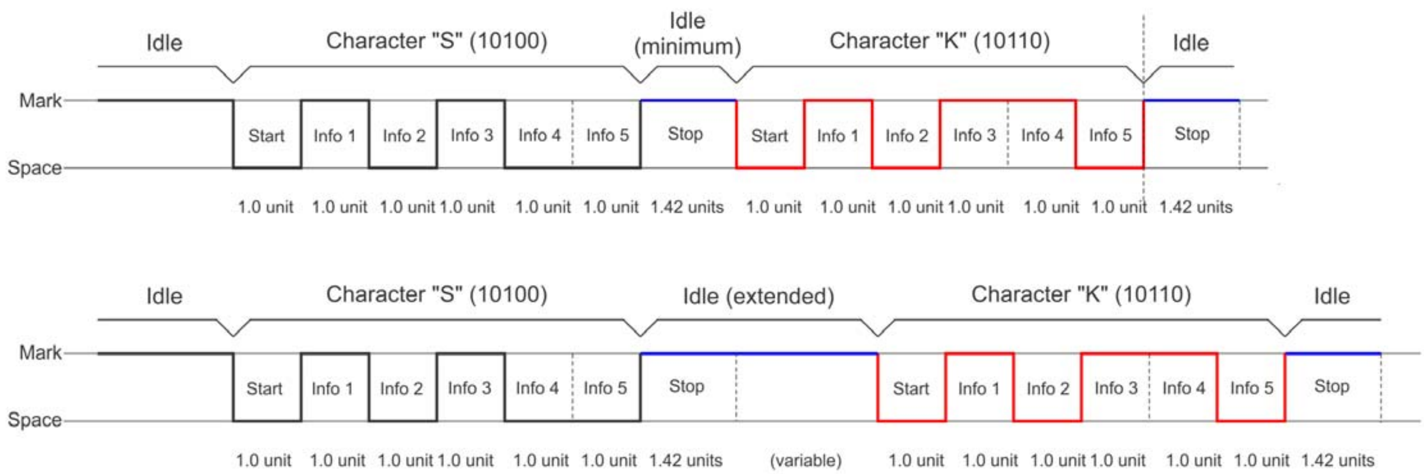

Figure 3. Alternate outlook on the Stop element

In the top picture, we see the "idle" interval at its minimum permissible value (namely the duration of the Stop element). In the second picture, it has been extended by the delay in commencement of the second character.

1.3 The modulation rate

With a format such as this, the critical property affecting whether the transmission channel would be able to handle a signal train of a certain speed is the duration of the shortest element of which the signal is composed. In most cases, it is the inverse of this minimum duration that is cited or specified (the value then of course increasing with the rate at which characters are sent).

This property is called the *modulation rate* of the signal, and is denominated in the unit *baud* [3], which is an *inverse second* (s^{-1}). Often the term "baud rate" is used for "modulation rate". For a unit length of 22.0 ms, the modulation rate is about 45.45 bauds.

2 THE SENDING DISTRIBUTOR

A traditional way of generating a "start-stop" serial teletypewriter character train is with a *serializer* called a *sending distributor*. In its classical form, this is a motor-driven commutator with a clutch and/or latch arrangement so that it can be released to turn one revolution at a time. We see a schematic portrayal in figure 4.

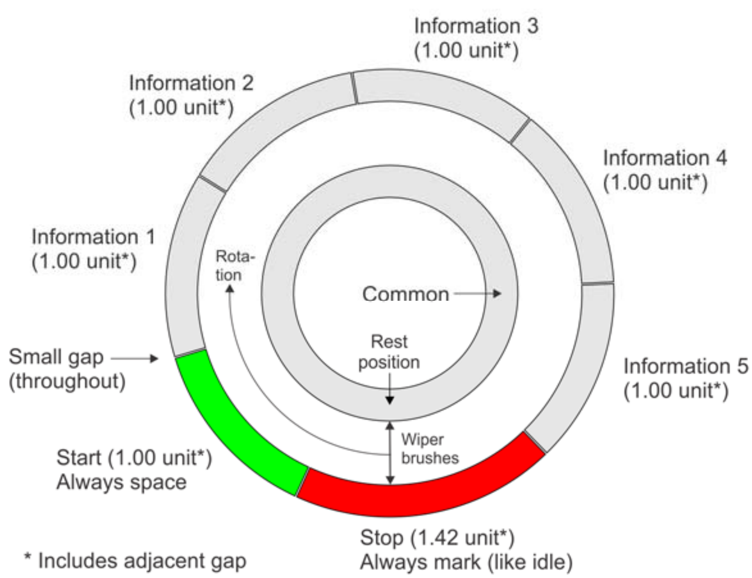

Figure 4. Illustrative sending distributor

It is typically made of a ring of brass segments (and a "common ring") fastened to an insulating phenolic plate. (This form of distributor is often described as a "faceplate distributor".) In its ideal form (as shown here), there is a very small gap between adjacent segments (as they must be electrically independent). The illustration shows the arrangement for a system with a 1.42 unit Stop element.

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[3] Named in honor of you-know-who.

The angular extents of the segments are proportional to the length (in "units") of the various elements of a character, scaled so the total is (necessarily) 360°.

A rotating arm, driven by a speed-controlled motor through a clutch and/or latch mechanism, carries a pair of interconnected "wiper brushes", which contact the common ring and the segments. With the distributor idle (the clutch/latch not tripped), the brush pair rests in a position essentially as suggested in the figure.

We can think of the common ring as connected to the outgoing data channel. The "Start" segment is connected to the voltage that represents space, and the "Stop" segment to the voltage that represents mark. When a character is being sent, the five "Information" segments are connected to either the mark or space voltage depending on the value of the corresponding bit of that character's coded representation (1 or 0, respectively).

When a character is to be sent (perhaps the operator has pressed a key on the keyboard), the clutch/latch releases the arm, which begins to rotate. As the outer brush traverses the segments, the serial signal described earlier is generated.

The location of the rest position–a bit before the beginning of the Start element–gives a short delay before the start transmission of a character (from an idle condition), and is intended to be certain that the arm is "up to speed" before the sending of the character commences.

This has no effect on continuous transmission, where the arm does not stop, and the line is held in the marking state between characters only for the intended duration (that of the "Stop element").

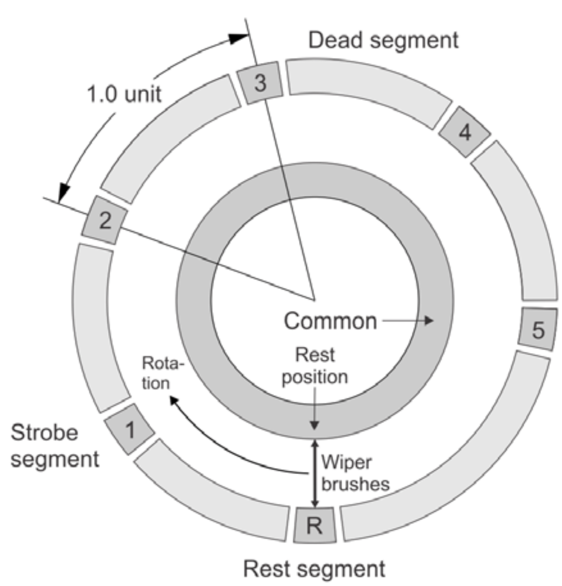

Figure 5. Illustrative receiving distributor faceplate

3 AT THE RECEIVING END

At the receiving station, we have a *deserializer,* called the *receiving distributor* (which conceptually might be a device much like the sending distributor shown above). We see an illustrative one schematically in Figure 5.

Like the sending distributor, when idle this is held in a certain position ("rest") by a clutch/latch arrangement. Starting with the line idle (in the mark state), when the state changes to space (from the Start element of the first character), the clutch/latch is released and the receiving distributor's brush arm begins to rotate.

At the instant that should be the center of each of the Information elements, the line state is "strobed", by the brush contacting a rather short segment, and captured. The five captured bits are then decoded and cause the represented character to be printed.

The drive speed of the receiving distributor is a bit greater than the drive speed of the sending distributor (and the short contact segments that do the "strobing" are spaced accordingly). As a result, the arm of the receiving distributor should arrive back at the rest position about 0.5 unit times into the Stop element of the character.

The line state then, observed through a small "Rest" segment at that position, should be mark, which makes the clutch/latch "catch" the distributor shaft at the rest position. It remains in the rest position until the next change of the line state to space, which will occur at the beginning of the Start element of the next character. At that time the shaft is released and begins to rotate.

Thus the receiving station "resynchronizes" with the transmitted character stream at the beginning of each character.

This operation is shown on a timeline in figure 6.

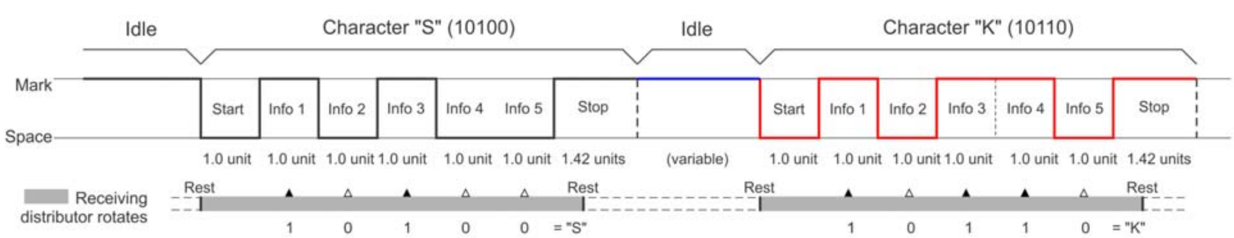

Figure 6. Receiving distributor operation

The gray bars indicate when the receiving distributor shaft is rotating. The triangles indicate the points at which the line state is "strobed", and their color shows whether they find that state to be mark (black) or space (white). The results in binary terms, and the decoded result, are shown below.

4 ON THE DURATION OF THE STOP ELEMENT

What might cause the designers of a particular start-stop teletypewriter system to choose a certain duration for the Stop element (which we recall is actually just the minimum allowable idle period between characters)? Two factors are in opposition:

- The longer the Stop element, the more rapidly will the receiving end be able to regain proper synchronization if synchronization had been lost owing to temporary "garbling" of the signal in the transmission channel when sending characters continuously at or near the maximum rate for the system.

- The shorter the Stop element, the more characters can be sent per second for a given channel modulation rate.

So, was a model of this analyzed with the usual thoroughness of the AT&T Development and Research Department (one of the two predecessors of Bell Telephone Laboratories), with collected data on the distribution of "garble" occurrences on a large sample of actual transmission channels? And was a Stop element duration of 1.42 units found to produce the best value of some carefully-crafted metric of overall synchronization performance? Of course, much work of that type was done.[4] But as we will see shortly, this property seemingly arose from a much more pragmatic event.

5 THE REAL REASON

5.1 Introduction

I had begun the study of teletypewriters while in college (not through any of my engineering courses, but rather outside that), and like many actually in the industry, I was curious as to where this odd-seeming parameter came from.

But a number of years later, in the mid 1960s, when I was an engineering supervisor at Bell Telephone Laboratories (where I was not officially much concerned with teletypewriter matters), I got a call from another engineer who had apparently heard of my earnest interest in the history of teletypewriters and their systems. He said that he had come upon (likely while clearing out a file cabinet in an office he had inherited) a document he thought might be of interest to me. He said he would send it over through the interoffice mail.

[4] The author in fact did some such work at Bell Laboratories in about 1960 and again in about 1965.

5.2 Eureka!

Eureka! This was a memorandum that seemed to me to give the answer to this conundrum. Sadly, I do not today have that document, nor did I write at the time any synopsis of it. So what follows is what comes to me now through the fog of time.

5.3 The story

The memorandum described in some detail an early trial of a start-stop teletypewriter system conducted by AT&T in Boston. (I cannot recall the year, but it was likely between 1905 and 1910.)

The engineer of the system, contemplating the matter of what duration to use for the stop element, and perhaps having had some information on earlier synchronization tests and the like, seemingly chose (likely fairly arbitrarily) 1.50 units. The total character length would have then been 7.50 units.

Often in these activities fully detailed “manufacturing” style drawings for the parts were not made. Rather, the engineers relied on the considerable design skill of the model makers to bridge the gap from the properties specified by the engineers to the precise design of the parts to be made for the prototypes to be tested.

Apparently the engineer in this case calculated the necessary angular extents of the seven segments of the sending distributor, and the model maker then decreased those extents by a tiny amount to allow a tiny gap between the adjacent segments (since he of course realized that they could not be allowed to come into electrical contact), and made the segments to suit.

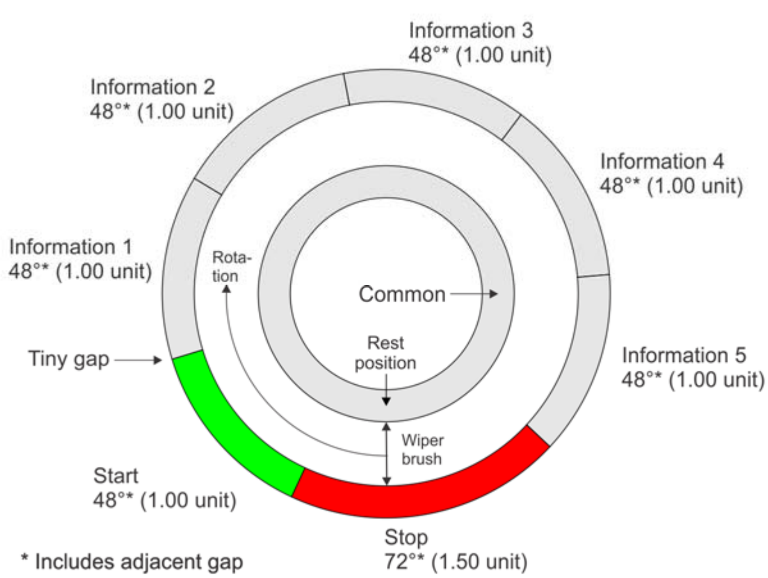

Figure 7. Boston trial sending distributor–first version (imagined)

Figure 7 shows schematically what I imagine this distributor's faceplate may have been like.

The engineer, examining this prototype, seemingly observed that a bit larger gap between adjacent segments would be advisable. His concern was probably that graphite particles that wore from the brushes (which were made of graphite, like the commutator brushes in a DC motor, to minimize frictional wear on the segments) could pile up in the gaps and thus "short" adjacent segments together. He perhaps observed that a gap of at least 0.5° would be desirable to avert this.

Seemingly the model maker, perhaps not understanding exactly what the engineer had in mind, took the first six segments as they were and relocated then on the insulating panel, now with 0.5° between them.

Of course, this meant that the Stop segment was too large to fit in the remaining space. The model maker, probably aware that the duration of this segment's element, unlike for the other six, was rather arbitrary, cut it down to fit the space available. The resulting size of the Stop element (including allowance for the adjacent 0.5°gap) corresponded to 1.42 units. The total character length then was 7.42 units.

The resulting layout, as I imagine it, is shown in figure 8.

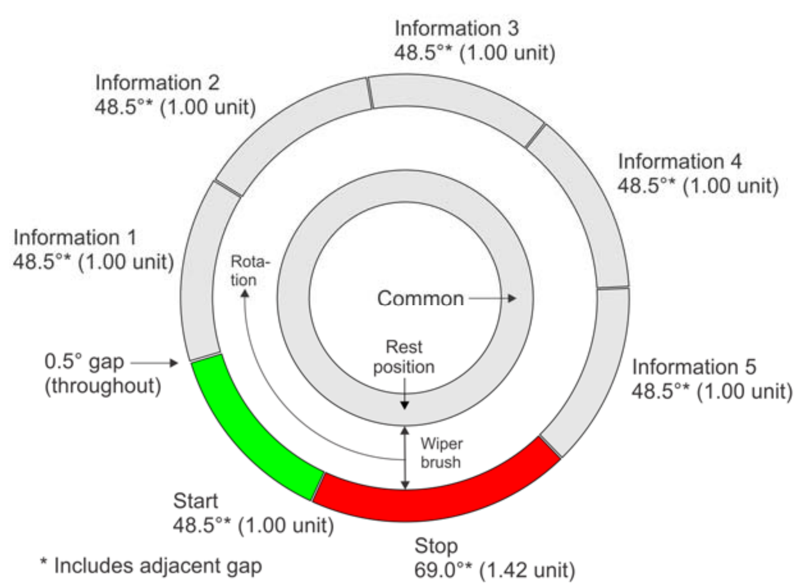

Figure 8. Boston trial sending distributor–later version (imagined)

And this seemingly was the birth of the 1.42 unit long Stop element, which continued in use in the North American 5-bit teletypewriter systems for the many decades in which they were used.

5.4 Reconstruction

A numerical reconstruction of this scenario by this author, predicated on a universal intersegment gap of 0.5°, led to a Stop pulse length of almost exactly 1.42 units.

It is also conceivable that, for example, the initial gap was 0.5° and the new gap was 1.0°, which would have led to essentially the same result.

5.5 Effect on element timing

For a given rotational speed of the distributor, that change in the spacing of the first 6 segments would have slightly thrown off the time spacing of the elements of the generated signal. But the motors used for these distributors were probably motors with very accurate (and easily adjustable) centrifugal governors for speed control. To attain the intended element duration very closely would have only been a matter of adjusting the governor to suit.

6 PROPERTIES OF ACTUAL SYSTEMS

6.1 Introduction

A popular North American teletypewriter system was said to operate at a speed of "60 words per minute" (WPM), where such reckonings were predicated on a "word" comprising an average of five letters plus the associated Space character (six characters altogether). Thus this would imply a maximum character rate of 360 characters per minute (ch/min). The unit length for this system was defined as 22.0 ms. That would correspond to a modulation rate of 45.45 bauds.

Considering a character length of 7.42 units, this in turn would imply a maximum character rate of 367.55 characters per minute (ch/m), which would be 61.25 WPM. The actual (maximum) character rate usually quoted for this system is 368 characters per minute (ch/m).

6.2 Actual vs. defined values

However, the exact nominal speeds and unit lengths in actual equipment often differ slightly from the "defined" values as result of pragmatic considerations such as practical gear ratios from synchronous drive motors.

The "poster boy" for generating this signal with a "faceplate" sending distributor of the type described above is the Teletype Corporation

Model 14 Transmitter Distributor [5] (which reads paper tape and sends a serial teletypewriter signal).

When operating from 120 V, 60.00 Hz AC, using a synchronous AC motor, the exact character rate of that unit (when sending continuously) is 368.18 ch/m (61.36 WPM). With a character length of 7.42 units, that would give a modulation rate of 45.53 bauds (and thus a unit length of 21.96 ms). All those values are only trivially different from the “defined” values for that system.

A much faster system, made possible by the development (by Teletype Corporation) of the model 28 teletypewriter (which could print at character rates up to 10 ch/s), was spoken of as the “100 WPM system”. That implied a maximum character rate of 600 ch/m.

The Model 14 Transmitter Distributor, when equipped to operate in this system (with a synchronous motor operating from 60.00 Hz AC), had a maximum character rate of 600.0 ch/m, “100 WPM” on the nose. Its modulation rate was 74.2 bauds. Both those values were exactly “as specified”.

The Model 28 Transmitter Distributor used a mechanical system of cams to generate the serial signal, rather than a faceplate distributor, but again in the “100 WPM” mode, with a synchronous AC motor, operating from 60.00 Hz AC, its continuous-transmission character rate was exactly 600.0 ch/m.

6.3 The “gap” in actual practice

In a distributor faceplate assembly of a typical Model 14 Transmitter Distributor, the gap between adjacent segments is about 2°, more generous than the 0.5° gap believed to have been used in the Boston trial. To visualize this, note that in Figure 5 the gaps are all 2°.

Usually there is a small window cut though the insulating baseplate under each gap to allow particles wearing off the carbon brush to fall through the baseplate, rather than piling up in the gap between the segments (perhaps eventually leading to a “short”).

7 AN ALTERNATIVE PRACTICE

Teletypewriter systems operated by Western Union in North America often used the 45.45 baud modulation rate but with a character length

[5] Here, for historical reasons, “transmitter” means a paper tape reader with electrical output, but does not imply it generates the serial line signal. “Distributor” of course refers to the serializing device discussed above. Thus the device with this compound name reads paper tape and generates a serial teletypewriter signal.

of 7.0 units. This gave a maximum character rate of about 428.6 ch/min. The advantage of course was that, for a given modulation rate, the maximum character rate was about 17% greater.

This speed was rarely characterized in terms of "words per minute". That value would have been about 71.4 WPM.

In general, 7.42 unit and 7.0 unit equipment operating at the same modulation rate could interoperate, owing to the general principle of start-stop operation.

It was generally considered that a system operating with a 7.0 unit character length would be inferior, insofar as recovery of synchronization after a line "garble" when operated at or near the full character rate, to a system using a 7.42 unit character length.

8 ELSEWHERE IN THE WORLD

In the international standard for a 5-bit signal of this general type, the duration of the stop element is specified as 1.50 units. The lowest standard rate has the unit length specified at 20.0 ms, giving a modulation rate of 50.0 bauds. The maximum character rate is 400 ch/s (often called "67 WPM").

For operation in teletypewriter systems following that standard, North American teletypewriter equipment, with a character length of 7.42 units, may be equipped with gears giving a maximum character rate of almost exactly 404 ch/m, leading to a modulation rate of almost exactly 50 bauds.

9 OTHER STORIES

As with so many things seen through the fog of history, other authors have described different scenarios for the origin of the 1.42 unit length of the Stop pulse. I am in no position to critique those. I was not personally present during any of the scenarios.

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