

# Optical Telegraph Codes (Geheimschrift und Zeichensprache)

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## ABSTRACT

The coding techniques that were developed by Claude Chappe for use on the first French optical telegraph network from the late eighteenth century. The codes are then compared with an independently developed system that was developed for a different type of telegraph in Sweden by Abraham Niclas Edelcrantz at approximately the same time.

## 1. Introduction

When the first optical telegraph networks were constructed towards the close of the eighteenth century, very little was known about the precise way in which true long-distance communication across a chain of signaling stations could be implemented. As one discovered, this requires more than a mere encoding of words or letters into telegraph signs.

It had to be decided, for instance, how the speed of message exchanges could be optimized without increasing the chance of errors. It also had to be decided how one could recover from any possible type of transmission error, or how conflicts in transmissions had to be resolved. Solving these problems is hard. The same problems still exist today in modern computer networks. Today the basic techniques to solve them are taught in universities, and the correctness of a data communications protocol can often be verified mechanically. (Note 1) But none of this was, of course, known in the late eighteenth century. In retrospect, therefore, it is quite remarkable to see what kind of solutions the builders of the optical telegraph networks came up with.

The first person to recognize that the operation of any form of telegraphic device requires not just the encoding of messages but also the design of a control code to operate the line itself was the Englishman Robert Hooke. In his lecture to the Royal Society, held on 21 May 1684, Hooke detailed a clear set of control codes that cover most of the issues that need to be resolved. (Note 2) But Hooke's proposals were never put into practice.

It took another century before the first long chains of optical telegraph stations were operated, and all the remaining problems were straightened out. This was first done by the brothers Chappe in France, who started with their first experiments in the early 1790s. One of the Chappe brothers, Ignace, documented the early experiments in a book he wrote on his retirement in 1824. In it, he ridiculed those who thought they could build a telegraph network without careful consideration of the signaling codes that are needed to operate longer chains of stations. (Note 3)

Those who think they have invented a telegraph that can be used without preliminary instructions for the telegraph operators, are mistaken; they have probably never performed experiments with more than two or three stations.

## 2. The First French Code

The first code that was used on the French semaphore telegraphs in circa 1794, was a simple decimal system that had survived from the earlier experiments with optical signaling that the Chappes had performed with various devices since 1791. (Note 4)

An encoding table of 9,999 entries of letters, words, and phrases had been designed, with a numeric code assigned to each entry. The most frequently used words and phrases were placed at the top of the list, and giving the shortest encodings. The first nine entries, for instance, were the numerals from 1 to 9, which

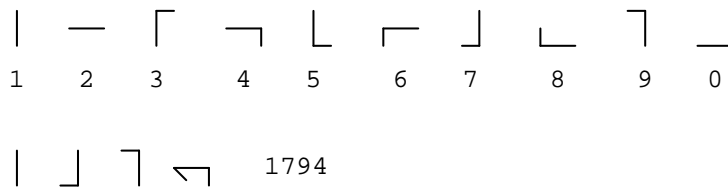


Figure 1 — Basic Code for Numerals, ca. 1794 (top).  
And the Number 1794 as Transmitted (bottom).

were encoded in one single semaphore sign. (Figure 1) The next 89 entries, numbered from 10 to 99, were encoded in two subsequent signs; the entries from 100 to 999 required three, and the remaining entries, from 1,000 to 9,999, four subsequent signs.

To transmit a word or phrase from the dictionary it sufficed to transmit the numeric code group, spelled out with the ten signs shown in Figure 1. To clearly separate the code groups from each other, the last sign of each group was made with the one of the unused indicators turned slightly away from the regulator, as also shown in Figure 1 (bottom). The total number of message (or correspondence) signals used was therefore twenty. In the first Chappe code there were also fourteen specific control signs. These signs always used both indicators, to look as distinct as possible from the correspondence signs (using just one indicator). The fourteen control signs were:

- Start of transmission
- End of transmission
- Suspension of transmissions for one hour
- Suspension of transmissions for two hours
- Synchronization, meant to allow the stations along the telegraph line to resynchronize their clocks
- Conflict, to indicate that two messages from opposite directions had arrived simultaneously at one station
- Priority, to indicate the precedence of one of the conflicting messages
- Acknowledgement, indicating the reception of a correctly deciphered message at the final destination
- Error, to cancel the last transmitted sign
- Idle, indicating the closing of the station or line
- Minor failure, to indicate a small problem with the telegraph, or the temporary absence of the operator
- Major failure, to indicate a more serious problem disabling the telegraph, requiring outside help
- Rain or fog restricting visibility, and
- Night transmission.

The last sign seems to indicate that the Chappe telegraph was also used at night, but this was not the case. The sign was probably added more to convince the funders of the telegraph network that night transmissions could in principle be added. In reality, most experiments with the use of the telegraph with lamps at night failed, and it never became a realistic alternative.

### 3. Revision of the French Code

The Chappe telegraph could be set in 256 different positions: 8 positions for each indicator, and 4 positions for the main regulator. Not all of those could be used for signaling though. The positions where the indicators extended the regulator, or where hidden behind it, were almost indistinguishable and not used for regular correspondence. Excluding these positions reduced the number to 196 ( $7 \times 7 \times 4$ ).

In all codes (including the first one from 1794) the meaningful telegraph signs were further restricted to those in which the regulator beam was either horizontal or vertical. This limited the number of possible

signs to 98 ( $7 \times 7 \times 2$ ). From these 98 combinations, four others were either deleted or reserved for special purposes (about which more below), so that the true code-space consisted of just 94 usable signs.

The telegraph signs with a tilted regulator beam did not go unused though. These positions were used by the operator while setting new signals. To form a signal, the regulator beam was first tilted to the right or to the left, with both indicators folded in. Next, the indicators were turned to a new position. And the signal was completed by returning the regulator to a horizontal or vertical position.

From the 94 available telegraph signs, the first code from 1794 used just 34: ten for the numerals, ten more for a numeral that appeared at end of a series, and the fourteen control codes. This still left most signs unused. As a result, telegraph transmissions were considerably slower than they could be, and speed was, also then, of the essence. As a result, the decimal code was abandoned in 1795, after the first line from Paris to Lille had been in operation for less than a year. A new code, that could make a more optimal use of the available code space, was needed.

Claude Chappe briefly considered switching from a base-ten (decimal) encoding to a base-twenty encoding, which would increase the number of signs used to 54 ( $2 \times 20 + 14$ ). The revised code that was adopted in 1795 was setup quite differently. In a way, it adopted a base-94 coding method, which naturally employed all the 94 usable signs.

The new code had two main parts, or 'divisions.' The first division defined 94 different signs encoding the alphabet, the numbers from zero to nine, and some frequently used syllables. Each sign from this division was set, following the rules for the formation of signals, and then 'closed' by folding in the two indicators. The horizontal and vertical double-closed positions were normally outside the set of 94 'usable' signs that formed the basis for the code books.

The second division consisted of a code book of 94 pages with 94 signs each, defining more syllables and commonly used words. Each entry from this code table was again transmitted as a code pair. The first sign of the pair now gave a line number from the code book, and the second sign gave the page number.

In 1799 three more divisions were added to the set, with more signs for common names of places and people, etc. The codes in the third division were preceded by the horizontal, double-closed signal; those in the fourth division were preceded by the vertical double-closed signal; and those in the fifth division by a reserved signal borrowed from the first division.

All codes from the first and second division, therefore, required two signs; those from the third and fourth division required three signs, and those from the fifth division required four signs to be completed. Each of the signs, furthermore, normally required two semaphore movements to be set (the tilted position and the final horizontal or vertical position). The transmission of a complete sign from the fifth division of the code books, therefore, required a total of eight movements of the telegraph. The more frequently occurring codes from the first division, however, required just three movements: (1) setting the signal in the tilted position, (2) carrying the signal to completion, and (3) folding in the indicators to close the signal. The coding of words based on their frequency of occurrence is an elegant early example of a data compression technique that is still used today.

#### **4. A Comparison of the French and Swedish Codes**

Although Claude Chappe was undeniably the first person to work out the details of signaling codes when he started building his network in the period 1793-1794, he was not the only one. Almost immediately after the success of Chappe in France became known in other countries, similar efforts were undertaken. This was in particular true for Sweden, where Abraham Niclas Edelcrantz began experimenting with his own optical telegraph designs within weeks after hearing the first reports of Chappe's work in France. Edelcrantz had only superficial knowledge of Chappe's design, and almost certainly knew very little of the details of the signaling protocols that Chappe had worked out. By necessity, he had to rediscover all the principles of signaling protocols independently; the only difference with Chappe perhaps being that at least Edelcrantz knew that the problems could indeed be solved. The only other thing that Chappe and Edelcrantz had in common was that they were both familiar with the work of Robert Hooke from 1684. (Note 5)

It is especially interesting, therefore, to compare the solutions that the Chappe and Edelcrantz discovered independently. There were fourteen control signals both in Edelcrantz's and in Chappe's first code. Six control signals were defined unambiguously, with almost the same meaning in both codes. They were used

to indicate the start and the end of message transmissions (Speech or Activity and Closing signals), and to signal error conditions and suspensions (for instance due to fog or mechanical failures).

Eight control signals were defined only by Edelcrantz, but not in Chappe's first code. They were used for flow control (Repeat, Wait, and Attention signals), to delimit signal groups (Word delimiter), to switch from one coding table to another, and to perform rate control signals (Faster and Slower). The Repeat and Wait signals were added by Chappe in 1809. The Attention signals and the Word delimiter signal may have been present in Chappe's code under different names. The code used by Edelcrantz for switching from one encoding method to another, was not used in the French codes, or at least it was not documented. The codes for rate control (Faster and Slower) also appeared in the French code tables around 1840.

Similarly, ten control codes were used in Chappe first code, but not in Edelcrantz's. They were used to signal the correct reception of a complete message, various types of suspensions (e.g., because the operators were absent from their post . . .), night transmissions, adjournments, and priority messages. Some of these codes may again have appeared under a different names in Edelcrantz's code. Two codes (*Harmonie* and *Monitif d'Harmonie*) were used in the French system for the resynchronization of clocks in the stations along the telegraph lines. They were not used in the Swedish codes. Instructions for the Swedish system dating from 1837, however, state that the clocks were implicitly resynchronized at the start of each transmission series, thus achieving the same effect as the Harmonie signals.

Two signals in the first French code for announcing night transmissions (from Paris to Lille or vice versa) have no counterpart in any of the Swedish codes, but they also disappeared from the revision of Chappe's code that was published in 1809, and were probably never used.

Four of the remaining codes were soon added to the Swedish code tables. In 1808, for instance, four different adjournment or suspension signals had been defined. Priority signals, finally, were added the Swedish codes in 1808.

### **Protocol Initialization**

In the Swedish codes communication was initiated by the sender with a specific control signal called the Speech signal. It was acknowledged by the receiver with the Attention signal. In the French code there were two separate Speech or Activity signals: one for messages originating in Paris, and one for messages originating at the station at the remote end of a line (virtually all lines terminated at Paris). The Chappe code says explicitly that the Activity signals could not be generated by intermediate stations, which means that they were not allowed to carry on an independent conversation. This restriction did not exist in the Swedish network.

### **Error Control**

The error control methods initially proposed by Edelcrantz and Chappe were based directly on Hooke's proposal from 1684. There was a single control signal in each code that signified an error condition. The signal was used to invalidate (erase) the last signal sent.

### **Rate Control**

In his first code Edelcrantz adopted Hooke's suggestion for control codes that could adjust the speed of transmissions. He defines control signals for slowing down a fast sender, and for speeding up a tardy one. Even today, rate control methods are considered an advanced feature of a computer communications protocol, not to be found in many systems. Similar signals cannot be found in the French codes until circa 1840.

### **Flow Control**

Edelcrantz used a Repeat signal to request retransmissions of a missed signal. The code was followed by the codes for a three-digit number that referred to a location of a signal in the logbook of transmitted messages that was kept at the sender and receiver. Such a *selective repeat* mechanism was reinvented almost 170 years later in data communications protocols, and is still considered a more advanced alternative to a simpler flow control strategy known as *go-back-n*.

In the French code, a Repeat and a Correction signal were added in 1809, but it is not well-documented how these signals were used. It appears that they were of a more basic type, perhaps only to indicate the

retransmission of larger portions of a message at the initiative of the sender (similar to the go-back-n technique).

Both Edelcrantz and Chappe defined control signals to suspend transmissions for short or long-term reasons, reminiscent of modern day *stop-and-wait* protocols. There is no explicit mention of signals in either code that can be used to resume transmissions, but an exchange of the standard speech and attention signals could have served that purpose.

## **5. Conclusion**

The signaling techniques and coding methods developed by Claude Chappe in France and Abraham Edelcrantz in Sweden in the late eighteenth century contain many elements that have only recently been rediscovered in modern computer communication protocols design. Even sophisticated methods for rate control and flow control, such as elective repeat retransmissions, were used on the optical telegraph networks. This dates their discovery to almost two centuries before the first computer networks were built.

## NOTES

1.

See, for instance, Gerard J. Holzmann,  
“Design and Validation of Computer Protocols.”  
Englewood Cliffs, N.J.: Prentice Hall, 1991.

2.

See “The Use of Optical Telegraphs in England and Elsewhere”  
(Die optische Telegraphie in England und anderen Ländern)  
This catalogue.

3.

Ignace Chappe,  
“Histoire de la télégraphie” (History of telegraphy).  
Paris: L’Imprimerie de Crapelet (first edition, 1824).  
As quoted in:  
Gerard J. Holzmann and Bjorn Pehrson  
“The Early History of Data Networks.”  
Los Alamitos, Ca.: IEEE Computer Society Press, 1995.

4.

“La Télégraphie Chappe.”  
A collection of papers on the Chappe system  
written by twelve French authors on the occasion  
of the bi-centennial celebration of the first  
experiments in 1793.  
*Fédération Nationale des Associations de Personnel  
des Postes et Télécommunications pour la Recherche Historique.*  
Nancy, France: Editions de l’Est, 1993.  
ISBN 9-782869-551428

5.

Edelcrantz documented his designs in a booklet that  
was published in 1796 in Stockholm titled “A treatise  
on Telegraphs.”  
A first English translation of the work appears as  
Chapter 4 in “The early history of data networks” (see Note 3).