THE EARLY HISTORY OF THE BINARY CODE

VOLKER ASCHOFF

From Francis Bacon's two letter alphabet to Baudot's binary telegraphic alphabet.

A NUMBER of years ago in a paper entitled "Origins of the Binary Code" [1], F. G. Heath described the development of the binary code from Francis Bacon's "two-letter alphabet" which was conceived at the beginning of the seventeenth century. Subsequently, Jacquardt's punch-card operated loom (1805) and Boole's logical algebra (1854) led to the introduction of a binary telegraphic alphabet by Baudot (1875). This paper is concerned with only the seventeenth and eighteenth centuries and will attempt to show, from examples of acoustical and optical telegraphs, that the use of the binary code in communications engineering can apparently be traced back to two entirely independent sources: in England, to Francis Bacon and John Wilkins, and in Europe, to Gottfried Wilhelm Leibniz.

From Bacon to Gamble and Murray

Francis Bacon (1561-1626), a highly placed English government official and philosopher, and a contemporary of Galileo and Kepler, occupied himself in his younger years as a student in Paris (1576-1579) with the encoding of secret messages. One of the methods he used to do this was to represent 24 letters of the alphabet by means of five-letter variations of only two letters. He published an example of this type of "two-letter alphabet" (alphabetum biliterarium) in his first attempt at systematizing all the sciences in 1605 [2]. Figure 1 shows an extract from this.

In a considerably expanded version of his work [3], Bacon also gave a detailed description of how the two-letter alphabet can be used as a secret code (Fig. 2).

A text, which should be kept as simple as possible, is set using two different type fonts, one of which stands for the code-element *a*, the other for the code-element *b*. In the example shown in Fig. 2, an instruction to flee is encompassed within a request to remain.

Bacon was fully aware that his five-letter binary code—as we would call it today—was also suitable for communicating messages over long distances. He writes explicitly:

"Neither is it a small matter these Cypher-Characters have, and may performe. For by this Art a way is opened, whereby a man may expresse and signifie the intentions of his minde, at any distance of place, by objects which may be presented to the eye, and accommodated to the eare; provided those objects be capable of a twofold difference onely; as by Bells, by Trumpets, by Lights and Torches, by the report of Muskets, and any instruments of like nature."

Thus, we may say that possible uses of binary codes in communication technology were first suggested more than 350 years ago. Before going into the question as to when this suggestion was actually put into practice for the first time, we should first refer briefly to similar proposals made by John Wilkins (1614-1672). Wilkins was a theologian and mathematician, a contemporary of Descartes, as well as co-founder and first secretary of the Royal Society. He published a volume in 1641, 15 years after the death of Bacon, which was entitled "Mercury or the Secret and Swift Messenger" [4].

The first half of this book deals with problems of encoding, the second with long-distance communications. In both parts, Wilkins explains Bacon's two-letter alphabet—and much else besides. In doing so, he in fact goes beyond Bacon's sugges-

A = a a a a a	H = a a b b b
B = a a a a b	I = a b a a a
C = a a a b a	K = a b a a b
D = a a a b b	L = a b a b a
E = a a b a a	M = a b a b b
F = a a b a b	N = a b b a a
G = a a b b a	O = a b b a b

Fig. 1. Francis Bacon's two-letter alphabet (1605).

Translated by Prof. H. D. Lüke, Department of Electrical Engineering of the Technische Hochschule, Aachen, Germany.

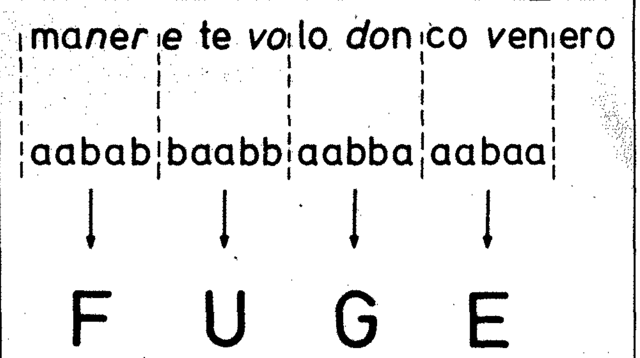

Fig. 2. Francis Bacon's secret code (1623).

tion by also employing three- and five-letter alphabets (Fig. 3), demonstrating for the first time that as the code-words become shorter. more code-elements are needed.

In connection with the two-letter alphabet, Wilkins points to two possible applications in the field of communications: an acoustical one using two bells of different pitch (or other loud sources of sound such as muskets, cannon, horns or drums) and an optical one with two kinds of torch, reminding his readers that, in this case, "fife shews" (five signals) must be given for each letter of the normal alphabet.

The first practical application of the binary code in England came 150 years later, in connection with the French Revolutionary wars. The construction of the optical telegraph line from Lille to Paris by Claude Chappe and its successful operation in the summer of 1794 had caused world wide excitement. When the English found a sketch of Chappe's telegraph line on a French prisoner of war, the Duke of York, Commander in Chief of the British armies on the Continent, commissioned his chaplain, John Gamble (ca. 1760-1811), to write a memorandum on the various possibilities of correspondence by telegraph. Gamble, a theologian, had studied math at Cambridge. He maintained that "a machine could be built which could fulfill the purpose better than the French one."

After a critical review of several other proposals, Gamble came to the conclusion that the best solution lay in the creation of combinations of easily distinguishable signals. If each of the signals admits only 2 outward forms, then 4 signals will be needed to form 15 variations, and 5 signals to form 31 variations (Gamble leaves out the "rest positions"). His first design thus envisaged a scaffold with five window-like apertures ("divisions"), each of which can be opened or closed by means of "venetian blinds" (Fig. 4).

Some officers on the Duke of York's staff, having seen the practical demonstrations carried out with a small model, feared that from a great distance it would not be possible to distinguish the three central divisions from one another with sufficient accuracy. In order to meet this objection and to make his telegraph as simple as possible, Gamble switched to a four-letter binary code, since he had discovered that an alphabet of only 15 letters would be adequate if phonetic transcription were used (Fig. 5).

These considerations took place at a time when England's fear of a French invasion was increasing, and when the Admiralty in London was very interested in acquiring a system of rapid communication with the naval bases facing the French coast. In 1795 Gamble was commissioned to establish, with the support of the naval arsenal, a full-sized telegraph at Portsmouth to ascertain the distance over which signals could be accurately observed.

In a matter of weeks Gamble built a telegraph with a few ships' carpenters. This was 16 m high, (Fig. 6, left) and, depending on the weather, could be accurately observed from a distance of 16 to 20 km. He used an old top-mast from an 80-cannon ship as the right-hand vertical post and an old top-mast from a 50-cannon ship for the left-hand one. He also designed a less expensive variant about 12 m high (Fig. 6, center). Finally he built a "shutter"-telegraph (Fig. 6, right) consisting of a wooden frame over which black sail-cloth was stretched and which could be used independently of the background. Figure 7 illustrates how this worked. Practical experiments showed that this telegraph could be observed over distances of up to 9 km.

To keep the operation of the telegraphs as simple as possible, Gamble finally experimented with a "programme." The four divisions of the telegraph were numbered 1-4 from top to bottom. The respective combination was punched into ordinary music paper. At the transmitting end the combinations of figures could simply be shouted to the operating staff, and at the receiving end these could be punched into music paper once again. At each of the intervening stations, the positions observed from the previous station were to be registered mechanically (Fig. 8).

Armed with these results, Gamble returned to London at the end of August 1795 to report to the Admiralty. To his great surprise, he discovered that a decision had been taken there in the meantime to adopt a telegraph using a six-letter binary code (Fig. 9) which had been developed by Lord George Murray (1761-1803). The reason given for this decision was that this system allowed for the transmission of decimal numbers and a few operating signals as well as 24 letters of the alphabet.

Whether Murray's proposal had been influenced by Gamble's memorandum and his models, or whether the same basic idea had been taken up at the same time by inventors working independently cannot now be determined, any more

Code-Elements / Alphabet	a+b	a+b+c	a+b+c+d+e
A	a a a a a	a a a	a a
B	a a a a b	a a b	a b
⋮	⋮	⋮	⋮
L	a b a b a	c b b	c a
M	a b a b b	c b c	c b
⋮	⋮	⋮	⋮
Y	b a b b a	b c b	e c
Z	b a b b b	b c c	e d

Fig. 3. John Wilkins' two-, three- and five-letter alphabets (1641).

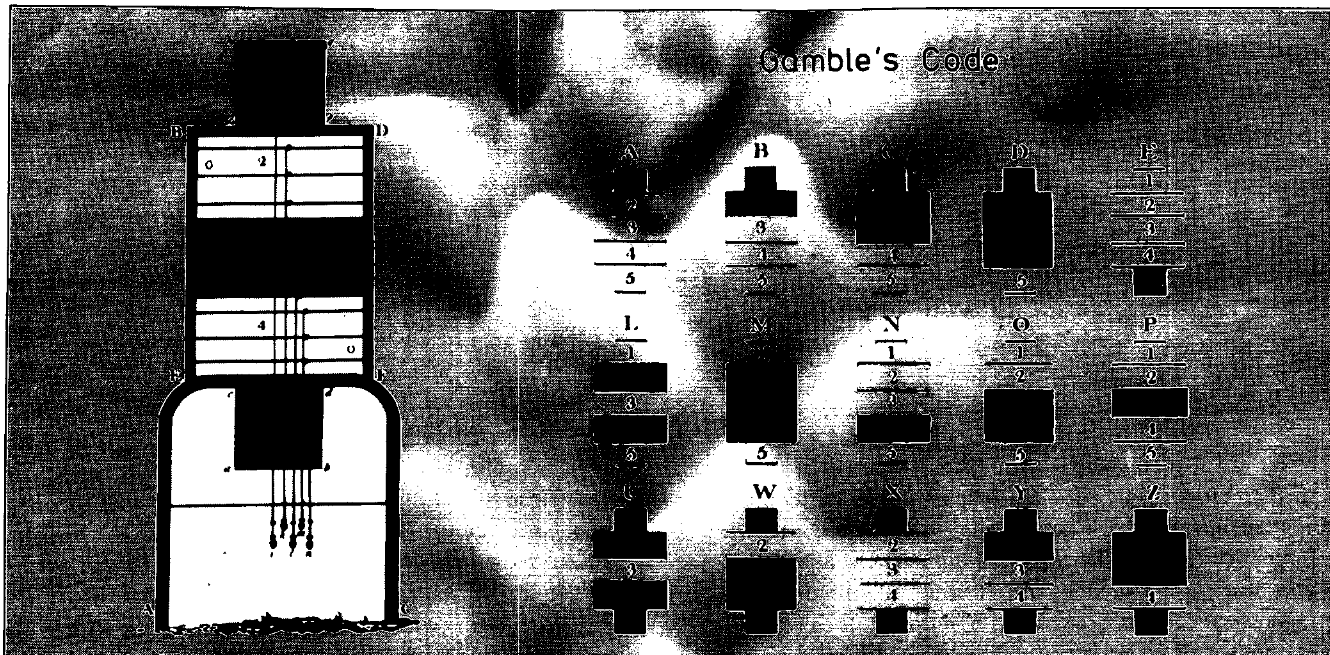

Fig. 4. Gamble's optical telegraph with five-letter binary code (1795).

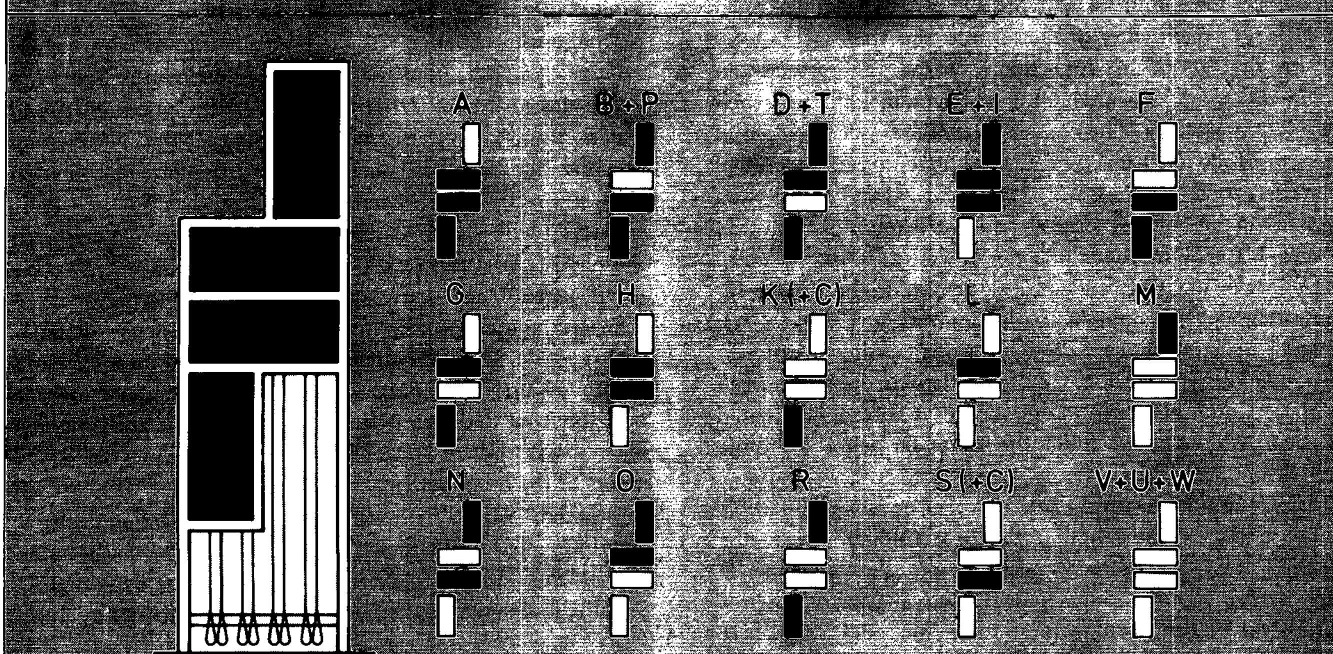

Fig. 5. Gamble's optical telegraph with four-letter binary code (1795).

than the true motives of the Admiralty to have the first telegraph line from London to Deal built by Murray.

This line was followed in succeeding years by further lines using Murray-telegraphs to Yarmouth, Portsmouth, and Plymouth (Fig. 10). These remained in use until the Paris Peace of 1814 [5].

Gamble, of course, was bitterly disappointed that he had been passed over when it came to the practical introduction of the optical telegraph in England. In justification of himself, he used his memorandum to write a detailed account of the various methods of communication by signal, which appeared in London in 1797 [6]. The work goes into great detail about the pre-history of signalling from classical antiquity to the end of the eighteenth century. It describes the considerations which led Gamble to propose an optical telegraph using binary coding.

From Leibniz to Bergsträßer and Chudy

On the 3rd of May, 1703, the German philosopher and mathematician Gottfried Wilhelm Leibniz (1646-1716) gave a lecture to the Royal Academy of Sciences in Paris entitled "Explication de l'aritmétique binaire." His text was published in the proceedings of the Academy for the year 1705 [7]. Figure 11 contains an extract from the table of the binary numbering system, which Leibniz had appended to this essay.

As can be seen from Leibniz's letters and handwritten notes, he devoted himself to this new method of mathematical calculation during his first stay in Paris (1672-1676). Bacon had developed his two-letter alphabet in Paris just one hundred years earlier with the aim of putting it to practical use for the purpose of encoding. Leibniz, however, was mainly interested in the special mathematical properties of the new numerical system. In a manuscript dated March 15, 1679 (in which he still spoke of "dyadic progression" and "dyadic systems"), he referred briefly to the possibility of developing a mechanical calculating machine which would work on a binary system. What fascinated him above all were the special periodicities of the numerical system, rather than its practical application. And from his later letters it becomes

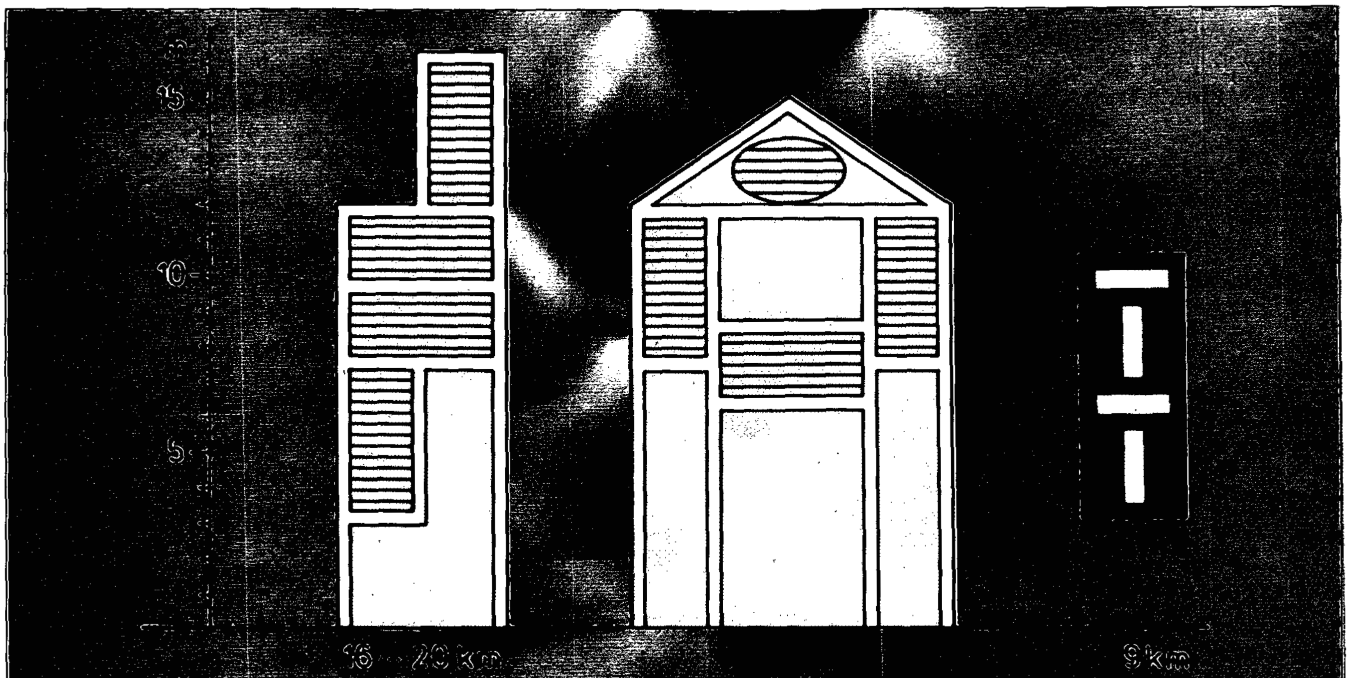

Fig. 6. Gamble's optical telegraphs at Portsmouth (summer 1795).

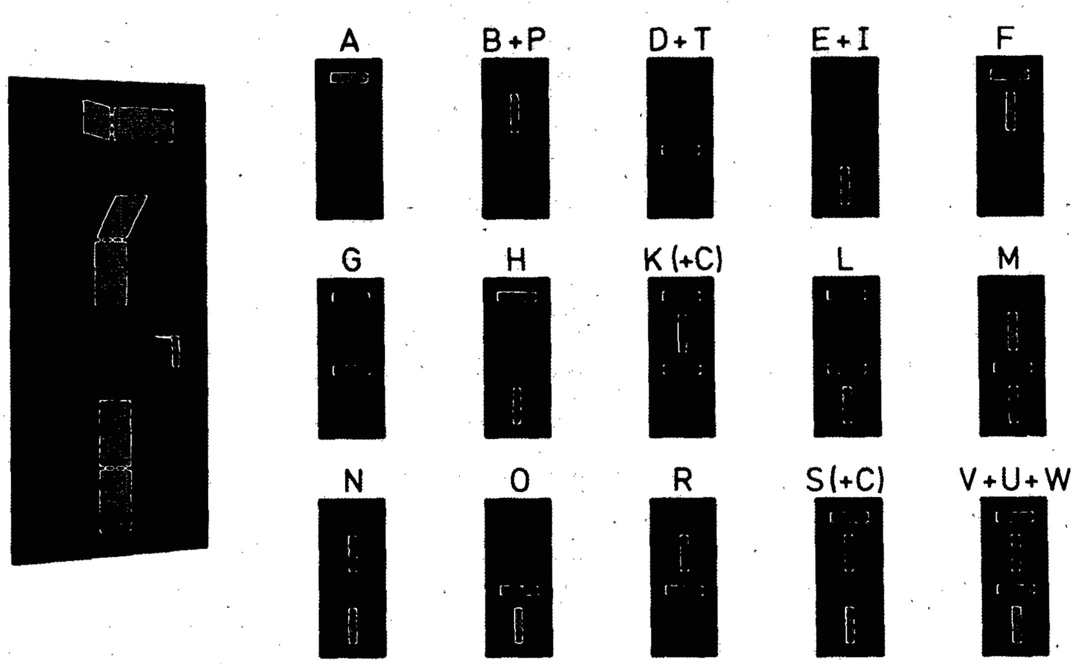

Fig. 7. Gamble's shutter telegraph (1795).

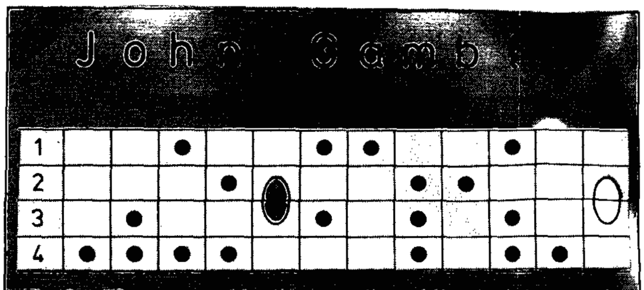

Fig. 8. "Programme" for the operation of Gamble's telegraph.

clear that he was also captivated by the philosophical implications of dyadics [8]: *Atque haec est origo rerum ex Deo et nihilo*, "The origin of things is from God and from nothingness."

Although it is clear that counting and calculating with only two symbols, *nought* and *one*, were known from 1705, no suggestions as to possibilities of application in the field of communications were made until near the end of the eighteenth century. In 1785 J.A.B. Bergsträßer (1732-1812), headmaster of Hanau grammar school, began publication of a voluminous work on what he called "Synthematographics" (in German, *Synthematographik*) [9]. By this Bergsträßer means "the art . . . of writing according to agreed signals just as well as one can record the articulated sounds of a language on paper." The central point of his argument, rendered somewhat obscure by all too frequent digression, is the proposal to produce "synthematographic" dictionaries which would contain and number all important concepts. These would transmit figures corresponding to the concepts by means of a series of acoustical or optical signals [10].

In the fifth and final installment of his work which appeared in 1788, Bergsträßer deals with the question of whether a numerical system should be chosen other than decimal numbering, in order to be able to represent the concepts collected and numbered in the "signal books" with as small a number of signals as possible: "Leibniz's dyadic system offers—as anyone can see—the simplest of numbering systems, but in higher figures it is inordinately long." After referring to "Weidler's Dodecadic system" (twelve-figure system) and "Weigel's tetradic system" (four-figure system), he proposes one he has invented himself and which he calls "Tessaropentas." This uses products of 4 and 5 and their powers, 1, 4, 20, 100, 500, etc., as numerical units. He sees the advantage of his system in the relative simplicity with which it can be adapted to the normal decimal system, so that calculation can easily be done in one's head.

For exceptional cases in which it is not the numbered concepts in the signal book which are to be transmitted, but items of news letter by letter, Bergsträßer returns to a binary method: "If in synthematographics someone does not wish to go beyond transmitting the alphabet, then we can recommend to him nothing simpler than the following small table of the dyadic system." Figure 12 shows an extract from this table, which represents a binary counting code for 24 letters and which both in its arrangement and in the way it is written keeps to Leibniz's table exactly.

Bergsträßer does not discuss the question of which signals are to be used in practice to transmit a binary code in his "Synthematographics." Not until 1795, in a work published in Frankfurt on long-distance signalling codes, does he express an opinion on "the method of indicating the alphabet by two characters using rockets: in my method the rocket without sound = 0, with sound = 1" [11]. More concrete proposals as to the practical application of a binary telegraph code are to be found in the volume "Description of a Telegraph which was Invented in Pressburg, Hungary, in the Year 1787." The author of this work is the Hungarian composer Jószef Chudy (ca. 1750-1813). The frontispiece bears the note, "Printed with the proceedings of the Royal University," but there is no indication of the year of publication. A Hungarian literary encyclopedia places the work in 1796 [12].

In his preface, Chudy assumes that his telegraph is similar to one "presented to great applause last summer in Potsdam in the presence of his Majesty the King of Prussia, which is illuminated by five characters." He is apparently referring to Achard's optical telegraph, which does not use a binary system, but rather a five-element code. Since Achard had demonstrated his telegraph in the spring of 1795, the refer-

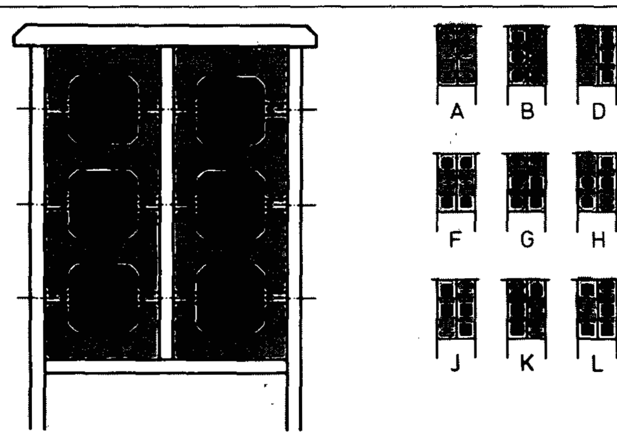

Fig. 9. Lord George Murray's optical telegraph (1795).

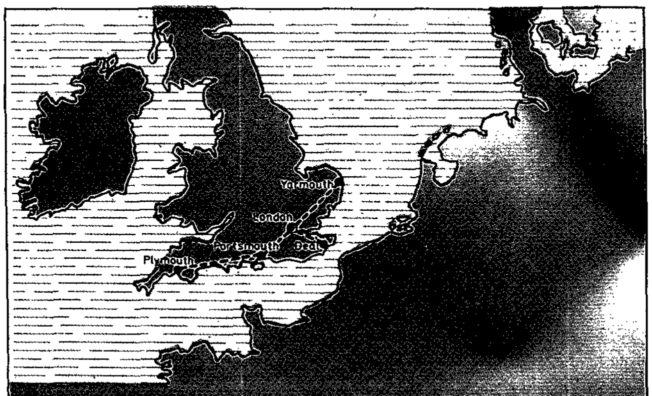

Fig. 10. Optical telegraph lines in England between 1795 and 1814.

0	0	I000	8	I0000	16
I	1	I00I	9	I000I	17
I0	2	I0I0	10	I00I0	18
II	3	I0II	11	I00II	19
I00	4	II00	12	I0I00	20
I0I	5	II0I	13	I0I0I	21
II0	6	III0	14	I0II0	22
III	7	IIII	15	I0III	23

Fig. 11. Leibniz's binary system (1705).

ence by Chudy would tend to confirm that his book appeared in 1796 [13].

A detailed discussion of Chudy was published by Lósy-Schmidt in the Magyar Posta in 1932 [14]. For both the optical telegraph he described and for the acoustical telegraph proposed, Chudy used a five-element binary code, whose tabular representation corresponds exactly to Bergsträßer's binary counting code, and therefore to Leibniz' manner of writing. However, Chudy's alphabet is somewhat more extensive than that of Bergsträßer, containing *y*, which is missing in Bergsträßer, a long and a round *s*, and in addition the vowels *á*, *ó* and *ú*.

The optical telegraph (Fig. 13) consists of a cupboard, the front side of which contains five "windows" side by side, which can be closed by shutters. Behind these windows there are lamps. So that one may clearly distinguish which windows are open and which are closed at any one time, there are two more windows above and below the central window, one of which has to be opened to ensure spatial orientation. Depending on which of the windows is open, letters or figures—to use our present day terminology—are transmitted.

Figure 13 is simplified to the extent that the shutters are shown here as slides, operated by means of simple rope tackles; Chudy's description, on the other hand, mentions keys (like those of an organ).

Chudy offers two solutions for acoustical telegraphy (Fig. 14): the use of two differently tuned drums or bells, one of which (tuned high) stands for *nought*, while the other (tuned low) stands for *one*; or the use of only one drum or bell with a double strike for *nought* and a single strike for *one*.

How Chudy arrived at his proposals can no longer be ascertained today. Among the subscribers to Bergsträßer's "Synthematographics" in the year 1785 was "Wenger, director of the National Schools in Pressburg," so that we may assume that the late fascicles went to Pressburg, too. But Chudy dates his invention to the year 1787, and Bergsträßer only published his binary code in the last part of 1788. Furthermore, Chudy writes about the book: "I do not dare to call this work my invention, but I am convinced that it is neither borrowed nor stolen."

In his preface Chudy mentions the "Synthematographics" and writes: "Since it had become known that the famous Mr. Bergsträßer represents synthematographics not only by rockets and gunshots, but also by tones, I was seized by curiosity to study this tone-language, since music is my favorite study, and to my surprise I found not only sublime simplicity in the tones, but also the application and things like that which perhaps nobody else had yet discovered."

But he then goes on: "Whether this is what Mr. Bergsträßer produced I cannot say, any more than I know whether this is what has been shown in various places on the occasion of the presentation of the French telegraph." From the manner in which he described his code, we may, however, assume that the original idea goes back—directly or indirectly—to Leibniz's dyadic system.

The last example to which we shall refer leaves this an open question. In the autumn of 1794, a few weeks after Chappe's telegraph line from Lille to Paris went into operation, Abel Burja (1752-1816) gave a lecture on telegraphy or the art of teleprinting to the Royal Prussian Academy of Sciences in Berlin. The lecture appeared in print the same year [15]. Having devoted an historical retrospective to Polybius's torch telegraphy, Burja elucidates a method he has conceived, "which requires only 4 torches, as long as one can ensure that the signs can be placed at higher or lower positions alternately (using a blind)." Figure 15 shows his code.

Since at least two different signals always have to be shown, in order to distinguish between "high" (long mark) and "low" (short mark), Burja is not able to employ a systematically constructed binary code. But this external difficulty apart, we have the impression that Burja's binary code—and Burja was a professor of mathematics at the Royal Military Academy—was also inspired by Leibniz's dyadic system.

Conclusion

The history of technology can be written from many different points of view. It can limit itself to the simple description of the historical succession from the invention to the further development of particular instruments, machines, or apparatus; or it can attempt to trace the relationships between

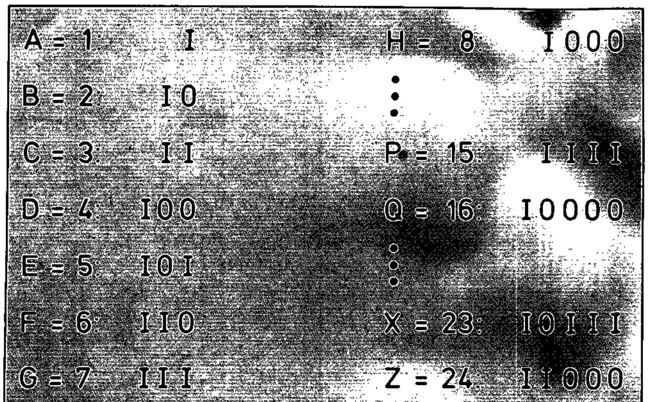

Fig. 12. Bergsträßer's binary counting code (1788).

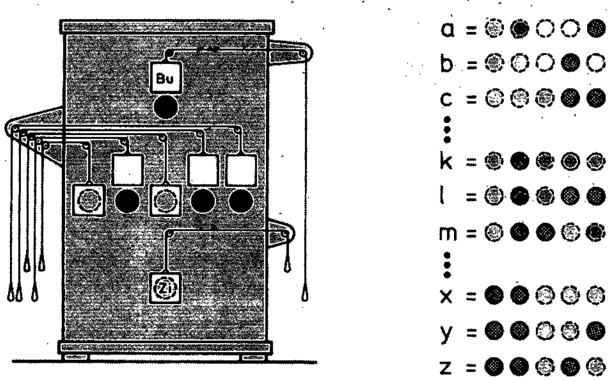

Fig. 13. Chudy's optical telegraph (Bu: letters, Zi: figures).

Fig. 14. Chudy's acoustical telegraph code: a) using 2 drums, b) using a bell.

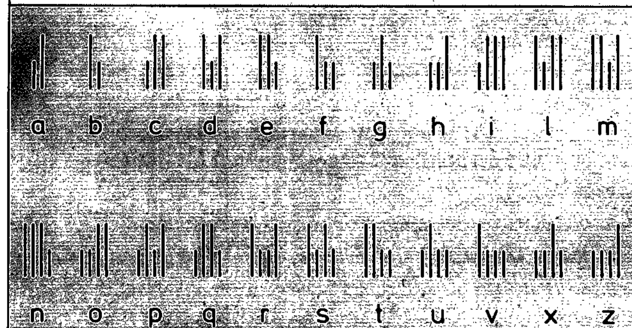

Fig. 15. Abel Burja's binary telegraphic code (1794).

progress in natural science and technical development. However, it can also investigate the philosophical sources from which an invention originates [16]. This paper does this in connection with the introduction of binary codes in acoustical and optical telegraphy at the end of the eighteenth century. The study of the contemporary sources demonstrates that the use of combinations of simple Yes-No decisions can apparently be traced back to two roots, whose concepts were quite different, but whose practical application produced the same results.

References

[1] F. G. Heath, "Origins of the binary code," *Scientific American*, vol. 227, pp. 76-83, 1972.
[2] F. Bacon, *Two books on the proficience and the advancement of learning*, London, 1605.
[3] F. Bacon, *De dignitate et augmentis scientiarium*, London, 1623.
[4] J. Wilkins, *Mercury, or the Secret and Swift Messenger*, London, 1641.
[5] G. Wilson, *The Old Telegraphs*, London: Phillimore, 1976.
[6] J. Gamble, *Essay on the different modes of communication by signals*, W. Miller, London: 1797.
[7] J. Boudet, *Histoire de l'Academie Royal des Sciences*, Année, 1703, Paris, 1705.
[8] Herrn von Leibniz *Rechnung mit Null und Eins*, Berlin und München: Siemens AG, 1966.
[9] J. A. B. Bergsträßer, *Über . . . eine Korrespondenz in ab- und unabsehbare Weiten der Kriegsfälle oder über Synthematographik*, Hanau, 1785-1788.
[10] V. Aschoff, *Die Synthematographik des J. A. B. Bergsträßer*, Technikgeschichte, vol. 42, no. 3, pp. 203-212, 1975.
[11] J. A. B. Bergsträßer, *Über Signal-Order- und Zielschreiberei in die Ferne oder über Synthematographe und Telegraphe in der Vergleichung*, Frankfurt, 1795, Andreä.
[12] G. Pál, *Magyar irok élete és munkai*, Budapest, 1942.
[13] V. Aschoff, *Franz Karl Achard und die optische Telegraphie*, Technikgeschichte, vol. 44, pp. 246-254, 1977.
[14] E. Lósy-Schmidt, *Chudy József optikai és akustikai távírója*, Magyar Posta, vol. 6, pp. 1-20, 1932.
[15] A. Burja, *Abhandlung von der Telegraphie oder Fernschreibekunst*, Berlin, 1794, Vossische Buchhandlung.
[16] V. Aschoff, *Die Rolle der Phantasie in der Geschichte der Nachrichtentechnik*, Technische Mitteilungen, vol. 72, pp. 675-684, 1979.

Volker Aschoff received the Dipl.-Ing. and Dr.-Ing. degree in electrical engineering from the Technische Hochschule Karlsruhe, Germany, in 1932 and 1936, respectively. From 1937 to 1945, Dr. Aschoff worked for the AEG-Company, Berlin, and until 1950 for the Zeh-Company, Freiburg in Germany. He was involved in the planning and design of multiplexing equipment.

In 1950, he joined the faculty of Electrical Engineering of the Technische Hochschule (Technical University), Aachen, Germany, where he was Full Professor of Communications until 1975. Since that time, Prof. Aschoff has published extensively on the early history of communications. ■