Chapter One
Torches and Beacons

The communication network that is available to us today allows anyone to talk instantly to almost anyone else on the globe, as long as both are near one of the approximately 500 million telephones connected to the network. It is tempting to think that the inventions that have made this possible were all made within the last century. The need for effective communication with a distant party, however, did not suddenly start in 1876 when the telephone was first patented.[1] That need must have been felt every bit as much by the Egyptian Pharaohs, and their workers, as it is by us today.

How It Began

It is quite amazing to see how people have dealt with the problems of long-distance communication throughout history. References to telegraphic systems can be found in almost every period from which written records survive. A fairly obvious method to communicate is, of course, to hire somebody to deliver a message as fast as possible. Famous is the story of Phidippides, the runner who, according to legend, in 490 B.C. ran 490 B.C.
the 36.2 km (22.5 miles) from Marathon to Athens to warn the Athenians of an approaching Persian army.[2] The Persians, after having been defeated in the battle of Marathon, were on their way to what they hoped would be an undefended city.

The Greek historian Herodotus, who lived ca. 484–424 B.C., does describe an event like this in *The History*. But in his account, Phidippides did not run to Athens *after* the battle of Marathon was fought; he ran 240 km from Athens to Sparta *before* the battle started, to obtain the support of the Spartans. This is how Herodotus described it:[3]

1. The notes to this chapter start at p. 245.

> First of all, when the generals were still within the city, they sent to Sparta a herald, one Phidippides, an Athenian, who was a day-long runner and a professional. . . . This Phidippides, being sent by the generals, and after, as he said Pan had appeared to him, arrived in the city of Sparta the day after he had left Athens. He came before the rulers and said: "Men of Lacedaemon, the Athenians beg you to help them; do not suffer a most ancient city in Greece to meet with slavery at the hands of the barbarians."

Herodotus then describes the battle itself, where the Athenians successfully defeated the Persian army without the help of the Spartans. He continued:[4]

> With the rest of the fleet, the barbarians, backing water . . ., rounded Cape Sunium, because they wished to get to Athens before the Athenians could reach it. . . . They rounded Sunium, all right; but the Athenians, rushing with all speed to defend their city, reached it first, before the barbarians came, and encamped. . . . The barbarians anchored off Phalerum—for in those days that was the harbor of Athens—and, after riding at anchor there for a while, they sailed off, back to Asia.

There is no mention in Herodotus's account that Phidippides was the first to arrive back in Athens after the battle, and then died from strain, but it is possible.

It is not too surprising that references to runners or human messengers are plentiful throughout history. They were certainly common in the days of Herodotus. The first descriptions of ancient courier systems, however, date back still farther. A recent encyclopedia says:[5]

> As early as the second millennium B.C. in Egypt and the first millennium in China, relay systems were developed using messengers on horseback and relay stations situated on major roads.

In old records, references to messenger systems can indeed be found that date back almost 4,000 years to the Egyptian King Sesostris I, who
1928 B.C. reigned from 1971 to 1928 B.C.[6]

Messenger systems were also used in ancient Babylon. In his study of the history of intelligence-gathering methods, Francis Dvornik reported, for instance:[7]

> We learn from an inscription that Hammurabi's messengers rode the long distance from Larsa to Babylon in two days, traveling, of course, both day and night.

1750 B.C. Hammurabi was king of Babylonia from 1792 to 1750 B.C.

By the thirteenth century B.C. messenger services must have been quite routine. Dvornik, for instance, refers to a log that was kept by an Egyptian guard during the reign of King Merneptah (the successor of King
1225 B.C. Ramses II), from 1237 to 1225 B.C.[8] In the fragment of the log that is preserved, we find a record of all special messengers that passed through a guard post at the Palestinian border with Syria. According to the log at

least once or twice a day a messenger would pass through with either military or diplomatic missives.

Originally, the messengers traveled the normal roads between the main cities of the ancient empires. Their safety, however, was by no means guaranteed.[9]

> We read in the Babylonian archives, found in Boghazhöi, complaints about attacks by Bedouins on royal couriers, and of the closing of Assyria to Babylonian messengers.

This crime problem led to a decision by the early Babylonian kings to place royal guards at regular distances along the roads. These guards were originally intended only for the protection of travelers, but their presence led quite naturally to a number of major improvements in the messenger system. The first was the establishment of a relay system, where a message was passed from guard station to guard station, each time carried by a new runner. The second decision was to equip the guard posts with fire beacons, so that simple alarm or warning signs could be passed quickly from one end of the road to the other, without the need for a human runner.

Unfortunately, it can no longer be determined precisely when these two crucial improvements were made, but they were probably in place by 650 B.C. One of the records reproduced in Luckenbill, for instance, describes the way in which the inauguration of King Shams-shum-ukin of Babylonia was celebrated around that time:[10] 650 B.C.

> Beechwood was kindled, torches lighted. Every bêru a beacon was set up.

The *bêru* was an Assyrian distance unit, corresponding to a two-hour journey. It can be assumed that the beacons referred to here were not quickly improvised for the occasion, but part of a permanent network of roads and guard posts. To support this assumption, Dvornik and Fries quote from a letter containing a magical chant, found in the library of King Ashurbanipal who ruled Assyria from 668 to 626 B.C. It reads, in part:[11] 626 B.C.

> Well, my witch, who art kindling fire every bêru and who art sending out thy messengers every two bêrus, I know thee and I will post watchmen in order to protect myself.

Both beacon signals and courier systems were quite familiar, at least to this writer. We can even speculate that the guard posts were placed at one bêru intervals, and that every other guard post served as a relay station for messengers; but, of course, this is only speculation.

The Biblical book of Jeremiah, from ca. 588 B.C., also contains a clear reference to the relay system:[12] 588 B.C.

> One post shall run to meet another, and one messenger to meet another, to shew the king of Babylon [Nebuchadnezzar] that his city is taken.

King Cyrus the Great, who lived from 599 to 530 B.C., and ruled Persia the

530 B.C. last nineteen years of his life, was credited with improvements of the courier system. Xenophon (430–355 B.C.), writing more than a century later, described it in *Cyropaedia*, his biography of Cyrus, as follows:[13]

> We have observed still another device of Cyrus' for coping with the magnitude of his empire; by means of this institution he would speedily discover the condition of affairs, no matter how far distant they might be from him: he experimented to find out how great a distance a horse could cover in a day when ridden hard, but so as not to break down, and then he erected post-stations at just such distances and equipped them with horses, and men to take care of them; at each one of the stations he had the proper official appointed to receive the letters that were delivered and to forward them on, to take in the exhausted horses and riders and send on fresh ones. They say, moreover, that sometimes this express does not stop all night, but the night-messengers succeed the day messengers in relays, and when this is the case, this express, some say, gets over the ground faster than the cranes.

The system lasted. In *The History*, Herodotus describes with admiration
465 B.C. how the relay system functioned at the time that Xerxes ruled Persia, between 486 and 465 B.C.:[14]

> At the same time that he was doing these things, Xerxes sent to Persia to tell of the present calamity. Than this system of messengers there is nothing of mortal origin that is quicker. This is how the Persians arranged it: they saw that for as many days as the whole journey consists in, that many horses and men are stationed at intervals of a day's journey, one horse and one man assigned to each day. And him neither snow nor rain nor heat nor night holds back for the accomplishment of the course that has been assigned to him, as quickly as he may. The first that runs hands on what he has been given to the second, and the second to the third, and from there what is transmitted passes clean through, from hand to hand, to its end, even as among the Greeks there is the torch-race that they celebrate in honor of Hephaestus.

The phrase "neither snow nor rain nor heat nor night . . ." is familiar to New Yorkers: a slightly different, and not too literal, translation was used for an inscription over the width of the main U.S. Post Office in Manhattan (one city block wide). It reads "neither snow nor rain nor heat nor gloom of night stays these couriers from the swift completion of their appointed rounds." The Persian couriers, of course, did not walk rounds but ran a relay system, but the main idea is there.

The Romans adopted a similar system of relay stations. Originally, they used human runners to transport the messages.[15] Later, when the system became larger, they switched to couriers on horseback as in the Persian system. Suetonius, who lived from A.D. 70 to 150, described it in his biog-
A.D. 14 raphy of Augustus (63 B.C.–A.D. 14) in Book II of *The Twelve Caesars*:[16]

> To enable what was going on in each of the provinces to be reported and known more speedily and promptly, he at first stationed young men at short intervals along the military roads, and afterwards post-chaises [carriages]. The latter has seemed the more convenient arrangement, since the same men who bring the dispatches from any place can, if occasion demands, be questioned as well.

Each of the Roman relay stations kept a reserve of not fewer than 40 horses and riders.[17]

In an attempt to curb abuse, messengers, called *strators*, were issued special licenses from the Roman emperor that qualified them for the free exchange of horses at relay stations. Over the years, responsibility for the upkeep of relay stations became a hot political issue.[18] Roman rulers alternately strived either to delegate the responsibility to local communities, to reduce the tax burden on the state, or to transfer the responsibility back to the state, to secure more consistent maintenance. In the end, neither the state nor the local municipalities were willing to cover the expenses any longer, and the system perished.

The speed of the Roman relay system was approximately 80 km (50 miles) per day for regular mail, and twice that for express mail, although these numbers might be based on human runners instead of riders on horseback. In any case, the Roman system was never praised for its speed. Even the old historians poked fun at the system. Suetonius, for instance, wrote in his biography of Julius Caesar (100–44 B.C.) in Book I of *The Twelve Caesars*:[19]

> [He] often arrived at his destination before the messengers who had been sent ahead to announce his approach.

In the thirteenth century Marco Polo described another relay system that was used by the Mongol ruler Kublai Khan (1215–1294), grandson of the notorious Genghis Khan. Polo, who visited China between 1271 and 1295, A.D. 1280 described the system as follows:[20]

> Let us turn now to the system of post-horses by which the Great Khan sends his dispatches. You must know that the city of Khan-balik is a centre from which many roads radiate to many provinces, one to each, and every road bears the name of the province to which it runs. The whole system is admirably contrived. When one of the Khan's messengers sets out along any of these roads, he has only to go twenty-five miles [40 km] and there he finds a posting station, which in their language is called *yamb* and in our language may be rendered "horse post."
>
> . . . Here the messengers find no less than 400 horses, stationed here by the Great Khan's orders and always kept in readiness for his messengers when they are sent on any mission. And you must understand that posts such as these, at distances of twenty-five or thirty miles, are to be found along all the main highways leading to the provinces of which I have spoken. . . . The whole organization is so stupendous and so costly that it baffles speech and writing.

Later in his account Marco Polo points out that the 400 horses per post were not all present at the same time. At each time about 200 horses would be out in the meadows, regaining strength for a next tour of duty.

The speed of the Great Khan's messengers was apparently almost twice that of the Roman's:[21]

> When the need arises for the Great Khan to receive immediate tidings by mounted messenger, as of the rebellion of a subject country or of one of his barons or any matter that many concern him deeply, I assure you that the messengers ride 200 miles [320 km] in a day, sometimes even 250. Let me explain how this is done. When a messenger wishes to travel at this speed and cover so many miles in a day, he carries a tablet with the sign of the gerfalcon as a token that he wishes to ride *poste haste*. If there are two of them, they set out from the place where they are on two good horses, strongly built and swift runners. They tighten their belts and swathe their heads and off they go with all the speed they can muster, till they reach the next post-house twenty-five miles away. As they draw near they sound a sort of horn which is audible at a great distance, so that horses may be got ready for them. On arrival they find two fresh horses, ready harnessed, fully rested, and in good running form. They mount there and then, without a moment's breathing-space, and are no sooner mounted than off they go again, taking the last ounce out of their horses and not pausing till they reach the next post, where they find two more horses harnessed as before.
>
> . . . in extreme urgency, they can achieve 300 miles. In such cases they ride all night long; and if there is no moon, the men of the post run in front of them with torches as far as the next post.

In parallel with the horse post, also a relay system of human runners was employed.[22] These runners, however, did not always carry grave news of rebellions and uproar. Marco Polo notes dryly that the Great Khan had found ways to take advantage of it for more pleasurable uses as well:[23]

> And in the fruit season it often happens that by this means fruit gathered in the morning in the city of Khan-balik is delivered on the evening of the next day to the Great Khan in the city of Shang-tu, ten days' journey away.

The *Pony Express*, which operated in the United States from April 1860
A.D. 1861 until October 1861, achieved comparable speeds to the Chinese horse post, but with more frequent switches. Each rider in the Pony Express relay rode approximately 150 km, and switched horses every 15 km. This system is said to have covered the 3,200 km distance from Missouri to California in about 10 days.

PIGEONS

Perhaps more inspiring than plain runners transporting messages, and just as old, is the description of a seemingly less reliable transmission
776 B.C. medium: the homing pigeon. It is said that the outcomes of the Olympic Games in ancient Greece, around 776 B.C., were sent to Athens by pigeons. But even in those days this must have been old news. As noted in a book
2900 B.C. by David Woods:[24]

> . . . in the days of the Pharaohs the Egyptians announced the arrival of important visitors by releasing pigeons from incoming ships. This may have been common as early as 2900 B.C.

The writer Harry Neal noted another ingenious use of pigeons from a few
2350 B.C. centuries later. He stated that King Sargon of Akkad, who lived ca. 2350

Figure 1.1 Pigeon Post, Woodcut from A.D. 1481.
(Coll. Bibl. de Genève, [Fabre 1963], p. 44)

B.C. in Mesopotamia, had each of his messengers carry a homing pigeon.[25] If the messenger was attacked en route, he released the pigeon. The return of the pigeon to the palace was taken as a warning that the original message had been "lost," and that a new messenger should be sent, presumably via another route.

Homing pigeons were also used by the Romans, around the fourth century A.D. In 1641, John Wilkins referred to it as follows:[26] A.D. 350

> Lypsius relates out of Varro, that it was usual for the Roman magistrates when they went unto the theatre, or other such public meetings, whence they could not return at pleasure, to carry such a pigeon with them; that if any unexpected business should happen, they might thereby give warning to their friends or families at home.

The system was still in use some eight centuries later. Woods reports that in the twelfth century Genghis Khan (1167–1227) used a pigeon relay A.D. 1200

system to communicate messages across Asia and much of Europe.[27] Fig-
A.D. 1481 ure 1.1 displays the use of carrier pigeons in a woodcut that appeared in 1481 in *Jean de Mandeville's Travels in the Orient.*

A.D. 1918 Another seven centuries later, in 1918, the British Air Force kept over 20,000 homing pigeons, handled by 380 pigeoneers. The system was organized by Colonel A. H. Osman. Woods quoted him as follows:[28]

> A small balloon was constructed with a metal [release-] band worked by clock-work. To this band was attached a small basket containing a single pigeon with a message holder on its leg, and to each basket was attached a small parachute. The balloons were liberated in favourable conditions of wind and at intervals automatically released from the special ring a single basket with a bird. These were dropped into Belgian and French territory when occupied by the Germans, and in French and Flemish a request was made to the finder to supply intelligence information that was needed, at the same time giving the finder hopefulness and cheer as to the ultimate success of the allies' cause and promising reward for the information supplied.

Woods adds a sobering note.

> The Germans tried to halt this activity by replacing captured pigeons with their own birds, and then arresting and shooting anyone foolish enough to sign his name and address to the note.

With this much history, it is not surprising that pigeons were still used in
A.D. 1981 1981 by a group of engineers at a Lockheed plant in Sunnyvale, California, to transmit negatives of drawings to a test station 40 km (25 miles) away. As Jon Bentley described it:[29]

> The pigeon took just half the time and less than one percent of the dollar amount of the car (the birds worked, literally, for pigeon feed). Over a 16-month period the pigeons transmitted hundreds of rolls of film and lost only two.

Pigeons and messengers have the advantage that a message need not be specially encoded, unless this is done for security. The problem is that the messages travel no faster than a horse can run, or than a bird wants to fly. Even the first ideas that were developed for alternative systems come very close to modern signaling methods.

Mirrors and Flags

It is easily confirmed that you can get anyone's attention quickly, even at large distances, by reflecting the sun into their eyes with a shiny surface. This could have been done also in antiquity, probably in a playful way, to amuse or to annoy. There are, however, indications that *heliographs* have a history of use for more serious signaling purposes as well.

HELIOGRAPHS

Consider the following passage from Xenophon's *Hellenica* (sometimes
405 B.C. called *A History of My Times*), written in ca. 405 B.C.:[30]

> On the fifth day as the Athenian ships sailed up, Lysander gave special instructions to the ships that were to follow them. As soon as they saw that the Athenians had disembarked and had scattered in various directions over the Chersonese—as they were now doing more freely every day, since they had to go a long way to get their food and were now actually contemptuous of Lysander for not coming out to fight—they were to sail back and *to signal with a shield* when they were half-way across the straits. These orders were carried out and as soon as he got the signal, Lysander ordered the fleet to sail at full speed. Thorax went with the fleet. When Conon saw that the enemy were attacking, he signaled to the Athenians to hurry back as fast as they could come to their ships. But they were scattered in all directions . . . *[emphasis added].*

The phrase "to signal with a shield" is one of the earliest explicit mentions of a simple method of heliographic signaling, in this case with a burnished shield.

There are many other references to early signaling methods that may have been based on similar devices, but the oldest references are not too reliable. The writer Woods, for instance, stated that heliographs were used by the Romans between A.D. 26 and 37:[31] A.D. 37

> For nearly ten years during the reign of the wise but unpopular emperor Tiberius, Rome was ruled from the island of Capri. Each day he sent orders to the mainland by a type of "heliograph" which transmitted the sun's rays by means of a mirror of polished metal. Naturally this would not have been possible without a code, but no record exists of the means by which the emperor's commands were sent or received.

The original sources do not quite support this claim. There is a brief reference to a method of signaling in the biography of Tiberius (42 B.C.–A.D. 37) written by Suetonius, in Book III of *The Twelve Caesars*, but it is ambiguous. It is sometimes translated as:[32]

> Often, he would stand at the highest tower and peer at the signals he had sent to him, so that when anything had happened, messages would reach him without delay.

In a later translation, however, the complete passage appears as:[33]

> He thought, indeed, of taking refuge at the headquarters of some provincial army and had a naval flotilla standing by to carry him off the island; where he waited on a cliff top for the distant bonfire signals, announcing all possible eventualities, which he had ordered to be sent in case his couriers might be delayed.

Neither version seems quite right. A simple bonfire could have been used to give a straight warning signal that Tiberius would have wanted to monitor, but it could not easily be used to transmit "all possible eventualities." On the other hand, it is hard to imagine that a Roman emperor would trouble himself to learn a signaling code that is complex enough to transmit arbitrary messages.

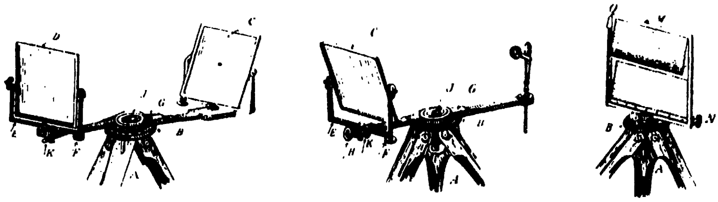

Figure 1.2 Heliographic Device.
(Source: [Hennig 1908], p. 43)

Woods also reported that in the eleventh century the Moors made use of heliographs in Algeria.[34]

A first clear description of a heliographic signaling method was published
A.D. 1292 in 1292 by the English author Roger Bako (often spelled Bacon, 1214–1292), in a work called *Opus Majus*.[35] There is, however, no record that it was actually used in this period.

Richard Hennig quoted a description of a heliograph from the sixteenth century author Khevenhiller. In *Annales Ferdinandei*, Khevenhiller described a device that had supposedly been used during the siege of a
A.D. 1598 Hungarian fortress in A.D. 1598:[36]

> . . . with an art, as described by an Englishman, consisting of two mirrors and a magnet [a compass?], with which one can, at a distance of many miles, give signals to each other in moon-light.

Hennig questions the feasibility of the method. Yet, if the "magnet" was really a compass, it could have been used by the two correspondents to locate each other, before signaling began. On a clear night, the light of the moon can be reflected as easily as the light of the sun during a clear day, so the device may actually have worked.

The design of a heliographic device was not reliably documented until
A.D. 1810 1810.[37]

> Professor [Carl Friedrich] Gauss of Gottingen, Germany, invented a device to direct a controlled beam of sunlight to a distant station. It included "silvered and unsilvered mirrors" fixed at right angles to each other. The operator looked in the unsilvered mirror at the distant station. Then he turned both mirrors so the sun's image (reflected faintly from the plain surface of the unsilvered mirror) was superimposed over the distant station, automatically directing the beam from the silvered mirror in the same direction.

Though the device built by Gauss (cf. Figure 1.2) was meant to be used for geodetic survey work, it would later be used extensively by the British and the American armies as a so-called "wireless" field telegraph.

In 1869 Henry C. Mance adapted Gauss's design by adding a movable mirror that could be used to signal Morse code.[38] Since Mance was stationed in India at the time, the first body to adopt the new device in 1875 was the Indian government. It is said to have been in almost constant use by the British in India until roughly 1890. A.D. 1869

In 1851 Charles Babbage, the builder of the so-called *analytical engine*, a precursor of the modern digital computer, also entered this arena with the invention of a "light-flashing machine," which he named an *occulting telegraph*. This is how Babbage described it.[39] A.D. 1851

> I then, by means of a small piece of clock-work and an argand lamp, made a numerical system of occultation, by which any number might be transmitted to all those within sight of the source of light.

A copy of the device was presented to the Duke of Wellington.[40] In 1852, Babbage also sent descriptions to, among others, Louis Napoleon in France, and to representatives in the United States.[41] The American Congress later appropriated $5,000 for experiments with Babbage's telegraph.

Babbage also described another "sun-flashing" machine, which resembles Gauss's design more closely. The codes he proposed to use with such telegraphs, however, were only rudimentary.

The American army made an extensive use of heliographs in the 1880s, in combination with a Morse code. It is unclear if they were based on Babbage's proposal or Henry Mance's. In 1886 heliographs were used by General Nelson Miles, in his battles with native Americans in Arizona. He built a total of 27 signaling stations, 40 to 50 km (25 to 30 miles) apart. Between 1 May 1886 and 30 September 1886 a total of 2,276 messages with 80,012 words were transmitted over this network.[42] The heliograph is said to have averaged some 16 words per minute. A.D. 1886

FLAGS

Signals can, of course, also be given with coded flags. What would be the first recorded use of a flag signal?

The first reference is rather ambiguous. It can be found in the *The Lives of The Noble Grecians and Romans*, by the Roman historian Plutarch (A.D. 46–120), who referred to an event that took place in 410 B.C. In the chapter on Alcibiades he wrote:[43] 410 B.C.

> Upon his first appearance, both sides formed a false impression; the enemy was encouraged and the Athenians terrified. But Alcibiades suddenly raised the Athenian ensign in the admiral ship, and fell upon those galleys of the Peloponnesians which had the advantage and were in pursuit.

Alcibiades had defected from the Athenian camp and fought against them in previous battles. So, when his battle ship appeared at a new battle scene, it was not clear which side he was going to take. The raising of the flag with the Athenian symbol cleared all doubt. This can hardly be considered a general method for communication, but it is not unlikely that flags of various kinds were already in use at this time to communicate standard battle orders from an admiral's ship to the fleet.

It would take a considerable time before flag signals were codified and standardized.

A.D. 900 There are indications that in the late ninth century A.D. the Byzantine Navy had started developing a more systematic approach. Very little documentation seems to have survived. Dvornik wrote:[44]

> During naval operations, the captains of the ships were expected to observe the "pamphylus" of the admiral, who gave orders by signaling from different sides and heights of the central flagship with banners of various colors, or with fire and smoke. A whole code of signals existed with which the commanders and their crews had to be acquainted. Part Nineteen of the strategic treatise ascribed to the Emperor Leo the Wise (A.D. 866–912) gives numerous instructions as to the kinds of signals to be used and how the signaling should be handled. Unfortunately, the need for secrecy prevented the author from explaining the various signals then in use.

In fourteenth century Europe, things were not much more advanced than in the time of Alcibiades. Woods wrote:[45]

> A.D. 1337 Between 1337 and 1351 the British Navy lists two signals in their old "Black Book of the Admiralty." The first was to hoist a flag of council high in the middle of the mast, to notify all captains to come aboard the admiral's flagship for a meeting. Hoisting another flag aloft reported the sighting of the enemy.

By the late seventeenth century things still had not progressed much. A
A.D. 1673 code book issued for the British Navy in 1673 defined 15 different flags, each with a single predefined meaning, which was probably not too different from what had been used since antiquity.

A.D. 1738 The first significant improvement was made in 1738, when the Frenchman de la Bourdonnais introduced a numerical code for flags. He proposed to use ten colored flags to indicate the numbers from zero to nine. With three sets of such flags, all separately colored, 1,000 code combinations could be made. The Frenchman Ignace Chappe (Claude Chappe's brother, see Chapter Two) wrote in 1824 that he considered it a regrettable mistake that the system of de la Bourdonnais had never been adopted by the French Navy.[46]

A.D. 1763 In 1763, another Frenchman, Sebastian Francisco de Bigot, the founder of the Marine Academy in Brest, published a new code book *Tactique Navale ou Traite des Evolutions et des Signaux*. The book, for the first time ever, specified a true protocol for the use of coded flags.

De Bigot's book had three parts. The first, and largest, part listed 336 distinct flag signals for signaling predefined events or commands from ship to ship. It introduced some important protocol rules, such as the definition of a "preparatory signal flag" for synchronization, the requirement that a receiver acknowledge all signals received by repeating them, and the use of "repeater vessels" to allow for broadcasting signals to an entire fleet. The second part of the book, *Table de Manieres*, contained an alphabetical index of all signals listed in the first part. Each signal was given a number, allowing for a quick cross-referencing of related signals. The third part of the book gave standard maneuvering diagrams for ships. As Woods noted:[47]

> Thus the book permitted a captain to look up an unknown signal in the index of part 2, locate the meaning from part 1, and study the evolution from the diagram in part 3. Cannon, flares, and lights were supplied for transmitting an identical code during night or fog.

Although the book was translated and published in England in 1767, it took more then two decades before the British Navy developed a comparable system with numeric codes. In 1790, the British admiral Lord A.D. 1790 Richard Howe became commander-in-chief of the British Channel Fleet, and introduced a new signal book, which became known as *The Howe Code*.[48] Howe's code used ten colored flags to represent the numbers from zero to nine, and six additional flags to represent a small number of special control codes, e.g., for acknowledgements, and terminations. The numerical flags were used in combination with a small dictionary of 260 numbered entries, which was extended to 340 entries in 1799.

The range of the dictionary was extended considerably in 1800 by Admiral Sir Home Popham.[49] Popham's new signal book, *Telegraphic Signals of Marine Vocabulary*, was adopted officially by the British Royal Navy in 1803. In Popham's code, the ten colored flags from the Howe code were A.D. 1803 designated to represent either the numerals from zero to nine, or the letters A to K in a single flag hoist, the letters I and J sharing a flag. Fifteen combinations of two flags gave the remaining letters of the alphabet. The code also included an index of 3,000 numbered sentences and phrases, in three series. Each series had its own indicator flag; the signals in each series were made with combinations of three flags, hoisted together.

Fifty copies of Popham's code book were issued to the British fleet at Cadiz in early September 1805.[50] The battle of Trafalgar, which took place the A.D. 1805 next month, put the new code to its first test. Flag signaling codes were used extensively by both the French and the British, as indicated by the following description.[51]

> Accordingly he [French admiral Villeneuve] hoisted the signal to weigh anchor, and at six in the morning of 19 October the [British] frigate Sirius, waiting outside Cadiz, signaled to the fleet below the horizon "Enemy have topsails hoisted." An hour later it hoisted signal no. 370, "Enemy ships are coming out of port." The hoists were made to the next frigate in the signaling chain, Euryalus, which in turn signaled no. 370 to Phoebe with the accompanying admonition—superfluous in a service schooled to such discipline—"Repeat signals to lookout ships west." And so no. 370 traveled down the chain, from Phoebe to Naiad, Naiad to Defence (a line-of-battleship), Defence to Colossus and Colossus to Mars, standing in Nelson's line of battle itself, 77 km (48 miles) from the mouth of Cadiz harbour. The news reached Nelson at 9:30. He

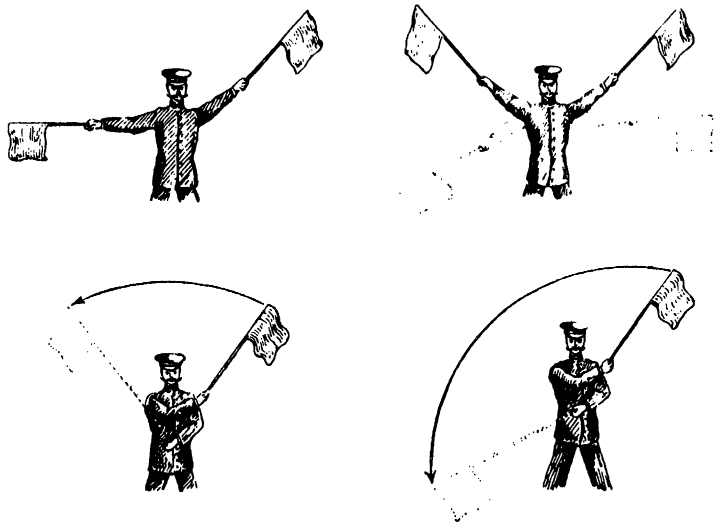

Figure 1.3 Wig-Wag Flag Signaling.
(Source: [Hennig 1908], p. 45)

immediately ordered "General chase southeast" and steered to place the fleet between Cadiz and the Straits of Gibraltar. The opening move of the battle of Trafalgar had begun.

Just before the battle, Nelson signaled a final instruction that would become famous in Britain: "England expects that every man will do his duty." Since it was not one of the predefined phrases, it had to be spelled out with individual flag hoists. Of the nine words, eight were in the code book and could be signaled with single hoists of three flags each. The word "duty," however, was not in the code, and had to be spelled out with single- and double-flag hoists.

After the battle, Popham's code became known as the *Trafalgar Code*, an
A.D. 1813 indication that it was considered a success. In 1813 Popham issued new signal books, extending the range to 6,000 predefined sentences and phrases, and 60,000 words.

WIG-WAG

All the flag signaling methods mentioned so far clearly dealt with ship-to-ship communications, and were not intended to be used on land. In 1856 an American army doctor named Albert James Myer (1827–1880) changed that with a system he called *wig-wag signaling*. He proposed a method of signaling with either flags or torches, which allowed for two basic motions, that is, a wave of the flag or torch to the left or to the right. Myer's code also defined the acknowledgement of messages, using special codes for signaling "not understood," or "understood."

The wig-wag method was adopted by the American Army in January 1860. Myer even obtained a U.S. patent, No. 252, for his system titled *An improved system of signaling.*[52] The patent issued on 29 January 1861. Even though the simpler Morse code already existed, it did not replace Myer's code until 1886, some twenty-five years later. A.D. 1860

Flag signaling was standardized in 1857 with the publication of a first international code. It was last revised in 1934. A.D. 1934

So far, we have seen four different methods for sending messages over a long distance: runners, pigeons, heliographs, and flags. Each of these methods has a much longer history than one would expect. At least two of these methods led to the development of sophisticated, semi-permanent, signaling networks, such as the courier relay systems of the Persians and the Romans, and the heliograph networks used by the Americans in Arizona.

There are two other signaling methods that we have not discussed in detail yet, each also with a remarkably long history: fire or light signals, and semaphores. Both of these methods would reach a level of sophistication that was not reached by any other method.

Fire Beacons

Many Americans can quote the lines of Longfellow's ballad celebrating the ventures of the American patriot Paul Revere (1735–1818):[53]

> One if by land, and two if by sea
> And I on the opposite shore will be
> Ready to ride and spread the alarm
> Through every Middlesex village and farm.

The poem refers to a simple code that had been used in 1775 by Revere during the Revolutionary War. Here is how Revere described it in a letter he wrote later to Dr. Jeremy Belknap:[54]

> If the British went out by water, to show two lanterns in the North Church steeple; and if by land, one as a signal, for we were apprehensive it would be difficult to cross the Charles River or get over Boston Neck.

This was, of course, not the first time that a light signal was used to encode a message. A first reference to the systematic use of fire signals to transmit messages can be found in descriptions of the siege of Troy by the Greek army, which is now assumed to have taken place in approximately 1184 B.C. At least three different sources, Homer, Aeschylus, and Vergil, describe such signaling methods, sometimes in elaborate detail. 1184 B.C.

One of the oldest sources is Homer's *Iliad*, written in approximately 700 B.C. It contains the following passage:[55]

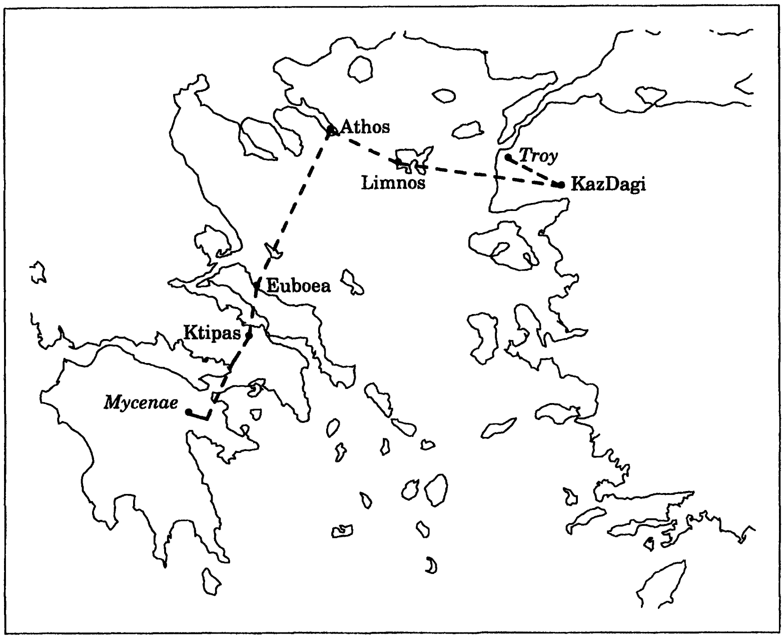

Figure 1.4 The Line of Beacons from Troy to Mycenae.

> Thus, from some far-away beleaguered island, where all day long the men have fought a desperate battle from their city walls, the smoke goes up to heaven; but no sooner has the sun gone down than the light from the line of beacons blazes up and shoots into the sky to warn the neighbouring islanders and bring them to the rescue in their ships.

Two other passages can be found in the play *Agamemnon*, written by the Greek dramatist Aeschylus, who lived 525–456 B.C. Aeschylus described how fire beacons were used to signal the fall of Troy to Mycenae, over a distance of roughly 600 km. This is how the play begins:[56]

> Watchman—I pray the gods a deliverance from these toils, a remedy for my year-long watch, in which, couching on my elbows on the roofs of the Atreidae, like a dog, I have contemplated the host of the nightly stars, and the bright potentates that bear winter and summer to mortals, conspicuous in the firmament. And now I am watching for the signal of the beacon, the blaze of fire that brings a voice from Troy, and tidings of its capture; . . .

A little further, the line of beacons is described in detail.[57]

> Chorus—And at what time hath the city been sacked?
>
> Clytaemnestra—I say in the night that hath now brought forth this day.
>
> Chorus—And what messenger could come with such speed?
>
> Clytaemnestra—Vulcan [Hephaestus], sending forth a brilliant gleam from

Table 1.1 Aeschylus's Line of Beacons.

Location	Modern Name	Altitude (m)	Distance (km)
Troy	Troy	100	0
Mt. Ida	Kaz Dagi	1774	55
Lemnos	Skopia at Limnos	430	154
Mt. Athos	Athos	2033	70
Macistus	Kandilion at Euboea	1209	177
Messapius	Ktipas	1020	30
Cithaeron	Elatias	1410	25
Mt. Aegiplanetus	Mt. Jeraneia	1370	30
Arachnaean Hgt	Arna	1199	50
Mycenae	Mycenae	150	20

> Ida; and beacon dispatched beacon of courier-fire hitherward. Ida, first to the Hermaean promontory of Lemnos, and third in order Athos, mount of Jove [Zeus], received the great torch from the isle, and passing over so as to ridge the sea, the might of the lamp as it joyously traveled, the pine-torch transmitting its gold gleaming splendor, like a sun, to the watch towers of Macistus. And the watchman omitted not his share of the messenger's duty, either by any delay, or by being carelessly overcome by sleep; but the light of the beacon coming from afar to the streams of the Euripus gives signal to the watchmen of Messapius, and they lighted a flame in turn and sent the tidings onward, having kindled with fire a pile of withered heath.
>
> And the lamp in its strength not yet at all bedimmed, bounding over the plain of the Asopus, like the bright moon to the crag of Cithaeron, aroused another relay of the courier fire. And the watch refused not the light that was sent from afar, lighting a larger pile than those above mentioned; but it darted across the lake Gorgopis, and having reached mount Aegiplanetus, stirred it up in unscathing strength, they send on a mighty beard of flame, so that it passed glaring beyond the headland that looks down upon the Saronic frith, then it darted down until it reached the Arachnaean height, the neighboring post of observation, and thereupon to this roof of the Atreidae here darts this light, no new descendant of the fire of Ida.
>
> Such, in truth, were my regulations for the bearers of the torch fulfilled by succession from one to another; and the first and the last in the course surpassed the rest. Such proof and signal do I tell thee of my husband having sent me tidings from Troy.

Later in the story, Clytaemnestra's enthusiasm about her husband's return apparently diminishes somewhat. When Agamemnon finally returns to Mycenae, he is murdered by Clytaemnestra and her lover.

The locations of the beacon stations can be found on modern maps, although some of the names have changed. Richard Hennig, in 1908, calculated the approximate distances between the stations that Aeschylus names.[58] Volker Aschoff also listed the approximate altitudes and verified the feasibility of a communication across this line.[59] The information is summarized in Table 1.1.

The inclusion of Mount Athos in the chain is the hardest to understand. It appears that a beacon placed at the 792 meter high Mt. Kochylas at the island of Skyros could have replaced the beacon at Athos, and perhaps also the one at Lemnos, by signaling directly to Mount Ida. Nevertheless, with the given altitudes, each beacon along the line that Aeschylus specified, would indeed have been visible from its neighboring stations. Aschoff calculated that on a clear night a stack of wood of roughly 5 to 10 meters high suffices to produce enough brightness to bridge the longest link in the chain, from Athos to Macistus.[60] This is well within the realm of possibility. It is not likely, though, that such a system could have been used for anything other than the transmission of a pre-arranged signal.

The Roman poet Vergil, who lived 70–19 B.C., described another use of fire signals during the siege of Troy. This is from *The Aeneid*:[61]

> And now from Tenedos set free
> The Greeks are sailing on the sea
> Bound for the shore where erst they lay
> Beneath the still moon's friendly ray
> When in a moment leaps to sight
> On the King's ship the signal light
> And Sinon, screened by partial fate
> Unlocks the pine-wood prison's gate
> The horse its charge to air restores
> And forth the armed invasion pours
> Thessander, Sthenelus, the first
> Slide down the rope: Ulysses curst
> Thoas and Acamas are there
> And great Pelides youthful heir
> Machaon, Menelaus, last
> Epeus, who the plot forecast
> They seized the city, buried deep
> In floods of revelry and sleep
> Cut down the warders of the gates
> And introduce their banded mates.

The "pine-wood prison" is the Trojan Horse in which the eight Greek soldiers were hiding, waiting for Sinon to release them so that they could unlock the gates of Troy from the inside.

The use of beacons or fire signals is mentioned in many sources. The Bibl-
742 B.C. ical book of Isaiah, written between 742 and 701 B.C., says, for instance:[62]

> One thousand shall flee at the rebuke of one; at the rebuke of five shall ye flee: till ye be left as a beacon upon the top of a mountain, and as an ensign on a hill.

588 B.C. Similarly, in the book of Jeremiah, from approximately 588 B.C.:[63]

> O, ye children of Benjamin, gather yourselves to flee out of the midst of Jerusalem, and blow the trumpet in Tekóa, and set up a sign of fire in Beth-Kérem; for evil appears out of the North, and great destruction.

Similar references can be found also in the Talmud.[64]

The use of beacons must have been a standard part of daily life; at least it is described as such in many places. Herodotus casually refers to it a few times in his book *The History*. For example, he describes an event that
481 B.C. took place in 481 B.C., like this:[65]

> Of all these things [the loss of three ships to the Persians], the Greeks who were stationed at Artemisium were informed by beacon fires from Sciathus; when they did learn of them, they took fright and changed their anchorage

> from Artemisium to Chalcis, to keep guard over the Euripus, while they left day-watchmen on the heights of Euboea.

And in another book from this series, he describes how the Persian general Mardonius communicated with Xerxes, some 300 km away:[66]

> A terrible longing had seeped into his [Mardonius's] heart to take Athens a second time. It was partly arrogant pride and partly that he saw himself proving to the King (who was in Sardis), through beacon fires across the islands, that he had taken Athens.

Thucydides, another Greek historian, living from 460 to 399 B.C., referred to beacons in a similarly casual way. In the *History of The Peloponnesian War*, he wrote:[67] 440 B.C

> Beacons were lit to warn Athens of an enemy attack, and a panic broke out which was as great as any in the course of the war. For the people in the city thought that the enemy had already sailed into Piraeus, and in Piraeus people thought that they had taken Salamis and were just on the point of sailing into the harbour.

Such matter-of-fact references return a few more times. For instance:[68]

> The Athenians were at Sestos with eighteen ships. Informed by the fire signals and observing also that many fires were suddenly appearing on the shore held by the enemy, they realized that the Peloponnesians were sailing in, and set off that very night.

And the more intriguing statement:[69]

> The Peloponnesians, however, having spent the time up till midday in laying waste the land, sailed away again, and about nightfall were informed by fire signals that a fleet of sixty Athenian ships was approaching from the direction of Leucas.

Could it be that the actual number of ships was part of the message transmitted? Alas, Thucydides does not elaborate. In one place, he does note that the beacon fires were not always reliable:[70]

> Fire signals of an enemy attack were made [from Plataea] to Thebes [for assistance against a plot of captives to escape from the city]; but the Plataeans in the town also displayed a number of fire signals from their own walls, having them all ready made for this very purpose, so as to make the enemy's signals unintelligible, to stop help coming from Thebes, and to prevent the Thebans from having a true idea of what was happening, until their own men who had gone out had escaped and got into safety.

All systems described thus far seem somewhat ad hoc, being primarily used to send a single predefined alarm, victory, or attack signal. Three things are still lacking that are essential for something that we could recognize as telegraphic correspondence: (1) a permanent installation, or network of signaling points, spread out over a larger area, (2) a capability for two-way communication, and (3) an encoding system that allows for the transmission of either single letters or arbitrary words and phrases with a single sign.

Watchmen and Stentors

The first mention of a permanent system of signaling using fires or beacons can be found in a work that has been ascribed to the school of Aristotle (384–322 B.C.). In *Peri Kosmon* (The World Around Us), Book 6, either Aristotle or one of his students writes about a system that was used in the

500 B.C. Persian empire around 500 B.C.:[71]

> The organization, however, was so good, especially that of the fire-watches that passed on fire signals along rows, from the border of the kingdom to Susa and Ekbatana, so that the king would know within one day everything that took place in Asia Minor.

The city of Susa, which is today called Shûsh in southwestern Iran, was the ancient Persian capital where King Darius I had his palace during his reign from 521 to 486 B.C. The city was at the eastern endpoint of the Persian Royal Road that ran west about 2,600 km (1,600 miles), to Sardis in modern-day Turkey. Herodotus reported that there were no less than 111 relay stations along this road.[72] He, however, also indicated that the Persians preferred the reliability of well-trained couriers to fire signals.[73]

Elsewhere, Xenophon (431–355 B.C.) referred to a curious variant of a relay system.[74]

> It was at night that the Paralus arrived at Athens. As the news of the disaster was told, one man passed it on to another, and a sound of wailing arose and extended first from Piraeus, then along the Long Walls until it reached the city. That night no one slept.

This may be a first reference to a system of human stentors, or shouters, that passed news across roads or fields, from one person to the next. A more explicit description of such a system was given by Diodorus Siculus, in the first century B.C., describing events that took place in Persia,

315 B.C. roughly two centuries earlier.[75]

> Although some of the Persians were distant a thirty days' journey, they all received the order on that very day, thanks to the skillful arrangement of the posts of the guard, a matter that it is not well to pass over in silence. Persia is cut by many narrow valleys and has many lookout posts that are high and close together, on which those of the inhabitants who had the loudest voices had been stationed. Since these posts were separated from each other by the distance at which a man's voice can be heard, those who received the order passed it on in the same way to the next, and then these in turn to others until the message had been delivered at the border of the satrapy [province].

A little later, in the same book, Diodorus Siculus also refers to other organized systems for long-distance communications, also in use around this time.[76]

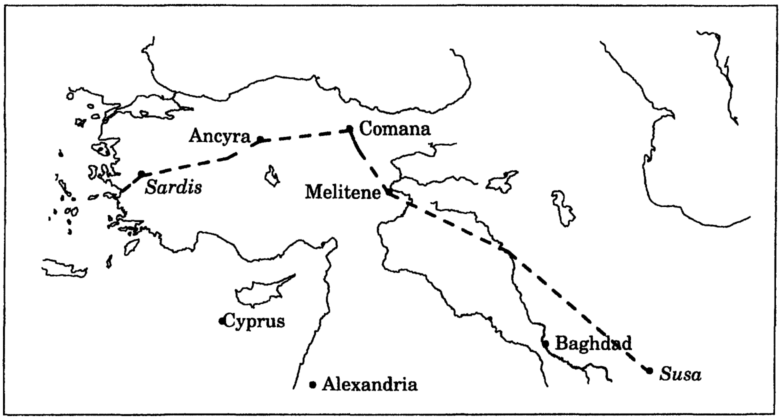

Figure 1.5 The Persian Royal Road from Sardis to Susa.

> He [Antigonus] himself established at intervals throughout all that part of Asia of which he was master a system of fire signals and dispatch carriers, by means of which he expected to have quick service in all his business.

The clear suggestion here is that at least three systems were in use at the same time: calling posts, fire signals, and couriers. Presumably these could have dealt with three different types of messages. Short, high-priority messages could be sent during the day by calling post, and by night with fire signals. Other messages could travel by mounted courier.

The Romans later also used all three systems for long-distance communications. We have already discussed the Roman courier system. Julius Caesar (100–44 B.C.) referred to the other two systems in his *Bellum Gallicum*. First, he described the use of calling posts:[77] 52 B.C.

> Quickly the news reaches all parts of Gaul, because whenever something important happens, they announce it by loud calls across fields and plains. These calls are heard by others, that have been positioned in rows and these pass them on to the next, and so on. Then, what happens at sunrise at Genabum [Orleans], is heard before sunset near Arverner, at a distance of 160,000 double-steps [approx. 240km (150 miles)].

Caesar also mentioned the systematic use of fire signals:[78]

> . . . the alarm was quickly given by fire signals, in accordance with orders issued beforehand, and troops hastened up from the nearest redoubts.

Plinius the Elder (A.D. 23–79) stated that the Carthaginian general Hannibal, who lived 247–183 B.C., made elaborate use of fire signals and watch towers during his campaigns. He wrote:[79]

> Even today, in Spain one can still see Hannibal's watch towers, and the earthen towers erected at mountain ridges.

Plutarch (A.D. 46–120), one of the most important Greek writers from the early Roman period, seems to indicate that the use of fire signs was common in the Roman army, not even worthy of much elaboration. In *The Lives of The Noble Grecians and Romans*, he describes how the Roman
73 B.C. general Sertorius trained his army:[80]

> . . . and [he] brought them to make use of the Roman armour, taught them to keep their ranks, and observe signals and watchwords; and out of a confused number of thieves and robbers he constituted a regular, well-disciplined army.

In his description, Woods goes even further. He wrote:[81]

> During most of the Greek and Roman wars there were special corps of signalists or telegraphers within their armies, known as πυρδευται (*pyrdeitai*). The word frequently has been translated as "fire-bearers." More literally it is "fire-movers," "fire-shakers," or perhaps . . . "fire-swingers" from πυρ, the word for "fire" and δευω, the verb "to move" or "to shake." Marcellinus [third century A.D.] mentions "speculatores" and "vexillarii" who observed and reported signals in the Roman navy.

According to Shaffner and Hennig, Vegetius states in *De Re Militari* that the Roman generals were accustomed to communicating by telegraph.[82] Aschoff is more guarded in his interpretation.[83] The assumption is based on the following intriguing quote from Vegetius:[84]

> When troops are separated, they announce to their colleagues, with fires during the night, and with smoke during the day, anything that cannot be otherwise communicated. Many also mount wooden beams at the towers of fortifications or cities, sometimes pointing upwards sometimes downward, to indicate what takes place. [Latin: *Aliquanti in castellorum aut urbium turribus adpendunt trabes, quibus aliquando erectis aliquando depositis indicant quae geruntur.*]

It is tempting to recognize a semaphore system in this description, but, as Aschoff points out, other explanations are also possible. Several authors point to illustrations on the Victory Columns erected by the Roman emperors Trajan (A.D. 53–117) and Marcus Aurelius (A.D. 121–180) in Rome.[85] The clearest illustration appears at the base of Trajan's Column,
A.D. 113 dating from A.D. 113 (Figure 1.6). It shows what appears to be a series of six guard houses. Three of the houses have a Roman soldier posted in front, and a large torch mounted through an opening near the roof.[86] The illustration lead Dvornik to a far-reaching conclusion:[87]

> On the famous columns of the Emperors Trajan and Marcus Aurelius, on which their victories are depicted, we see soldiers signaling with flaming torches from the towers of the limes as a warning of the approach of the barbarians. This can be considered sufficient evidence that fire signals were introduced at last on a large scale in the Roman army during the imperial period.

Although the sequence could well depict a communication chain, more conservative explanations are equally plausible. There is little else to be found in Roman art and literature that could substantiate the claim that a

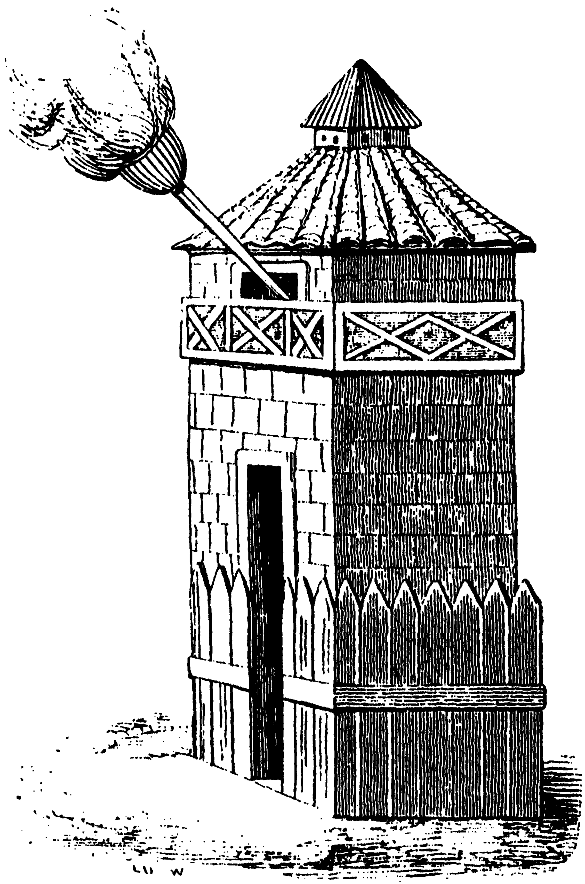

Figure 1.6 Guard House on Trajan's Column.
(Source: [Hennig 1908], p. 15)

telegraph system existed in early Rome.

Is there, then, any reliable indication that telegraphic systems existed? This question brings us to the first explicit descriptions of telegraphs in antiquity: devices that allowed for true long-distance communications.

The First Telegraphs

Many problems have to be solved before a telegraphic device can be built that can be used for two-way communications. Messages have to be encoded, and some type of protocol has to be established between sender and receiver to deal minimally with the basic problems of synchronization ("after you?", "no, after you!"), visibility ("repeat please"), and transmission speed ("not so fast!"). When did people first build such devices?

The first person who we reliably know developed a telegraph was Aeneas (not the Aeneas from Vergil's *Aeneid*). Aeneas was a well-known author in
350 B.C. ancient Greece, who lived around 350 B.C. and wrote works on military strategy. Only part of his main work, *The Art of War*, still exists, and unfortunately it does not contain the description of his telegraph.

We do have a clear description of Aeneas's design by the historian Polybius (ca. 200–118 B.C.). In *The Histories* Polybius first described, in crystal-clear prose, the limitations of plain beacon fires.[88]

> I think that as regards the system of signaling by fire, which is now of the greatest possible service in war but was formerly underdeveloped, it will be of use not to pass it over but to give it a proper discussion. It is evident to all that in every matter, and especially in warfare, the power of acting at the right time contributes very much to the success of enterprises, and fire signals are the most efficient of all the devices which aid us to do this. For they show what has recently occurred and what is still in the course of being done, and by means of them anyone who cares to do so even if he is at a distance of three, four, or even more days' journey can be informed. So that it is always surprising how help can be brought by means of fire messages when the situation requires it. Now in former times, as fire signals were simple beacons, they were for the most part of little use to those who used them. For the service should have been performed by signals previously determined upon, and as facts are indefinite, most of them defied communication by fire signals. To take the case I just mentioned, it was possible for those who had agreed on this to convey information that a fleet had arrived at Oreus, Peparethus, or Chalcis, but when it came to some of the citizens having changed sides or having been guilty of treachery or a massacre having taken place in the town, or anything of the kind, things that often happen, but cannot all be foreseen—and it is chiefly unexpected occurrences which require instant consideration and help—all such matters defied communication by fire signal. For it was quite impossible to have a preconcerted code for things which there was no means of foretelling.

In the next section, Polybius describes Aeneas's solution to this problem, dating back to around 350 B.C. This is how he described it, over 2,100 years ago.[89]

> Aeneas, the author of the work on strategy, wishing to find a remedy for the difficulty, advanced matters a little, but his device still fell far short of our requirements, as can be seen from his description of it. He says that those who are about to communicate urgent news to each other by fire signal should procure two earthenware vessels of exactly the same width and depth, the depth being some three cubits[90] and the width one. Then they should have corks made a little narrower than the mouths of the vessels and through the middle of each cork should pass a rod graduated in equal sections of three fingerbreadths, each clearly marked off from the next. In each section should be written the most evident and ordinary events that occur in war, e.g., on the

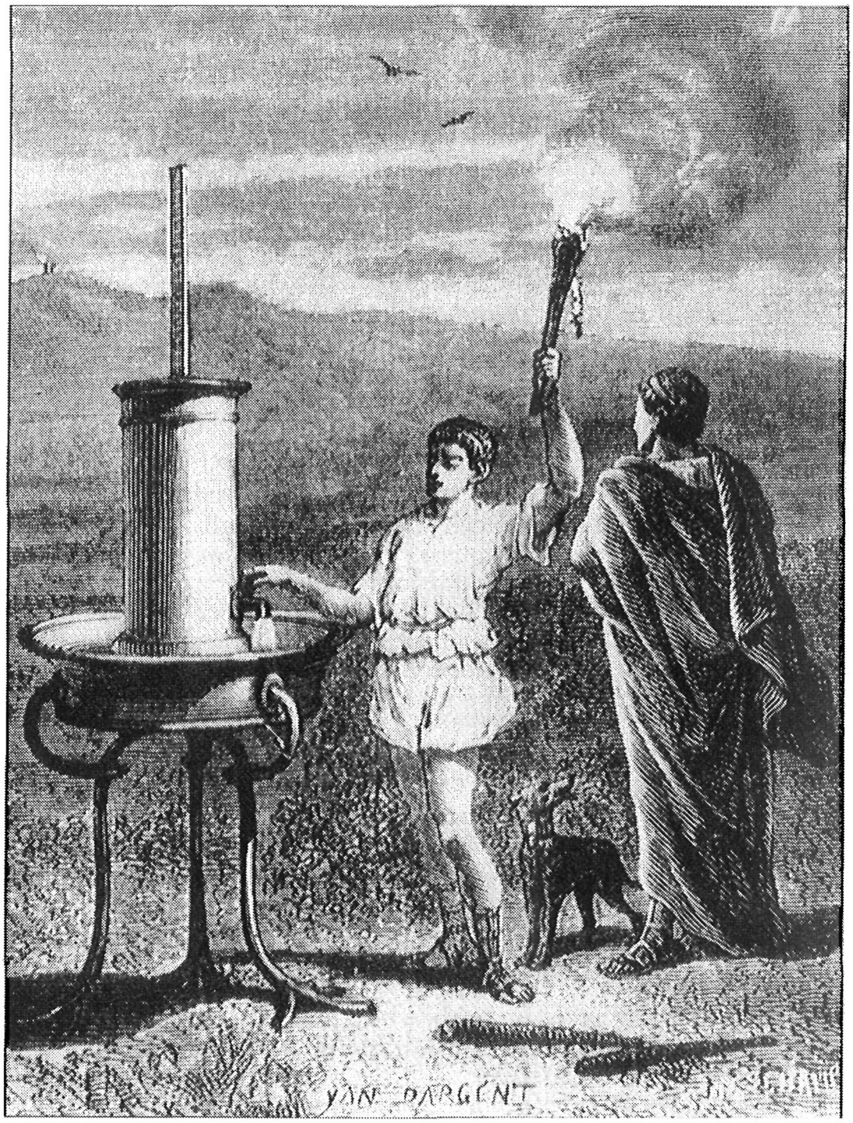

Figure 1.7 Synchronous Telegraph, ca. 350 B.C.
(Coll. Musée de la Poste, Paris)

first "Cavalry arrived in the country," on the second "Heavy infantry," on the third "Light-armed infantry," next "Infantry and cavalry," next "Ships," next "Corn," and so on until we have entered in all the sections the chief contingencies of which, at the present time, there is a reasonable probability in wartime. Next he tells us to bore holes in both vessels of exactly the same size, so that they allow exactly the same escape. Then we are to fill the vessels with water and put on the corks with the rods in them and allow the water to flow through the two apertures. When this is done it is evident that, the conditions being

> precisely similar, in proportion as the water escapes the two corks will sink and the rods will disappear into the vessels. When by experiment it is seen that the rapidity of escape is in both cases the same, the vessels are to be conveyed to the places in which both parties are to look after the signals and deposited there. Now whenever any of the contingencies written on the rods occurs he tells us to raise a torch and to wait until the corresponding party raise another. When both the torches are clearly visible the signaler is to lower his torch and at once allow the water to escape through the aperture. Whenever, as the corks sink, the contingency you wish to communicate reaches the mouth of the vessel he tells the signaler to raise his torch and the receivers of the signal are to stop the aperture at once and to note which of the messages written on the rods is at the mouth of the vessel. This will be the message delivered, if the apparatus works at the same pace in both cases.

Not many would have trouble reproducing the device from this description. It appears that precisely this system was used for the communications of the Roman troops at Carthage, on the Tunesian coast of North Africa, and Sicily in the second century A.D., long after Polybius. This is how Polyaenus described it in his work *Strategematon* from this period:[91]

> They [the Carthaginians] must watch and when they see a fire signal in Sicily, they should let the water flow from the water-clock in Carthage. When they see another fire signal, they should stop the flowing of water and see which circle it had reached. When they had read the inscription they should send in the quickest way the things they had been asked for by these signals.

A set of nine specific inscriptions used for this purpose was also given by Polyaenus: "We need warships, cargo boats, money, machines for besieging, food, cattle, arms, infantry, cavalry." The shortest distance between Sicily and Carthage, however, is close to 150 km, which makes it hard to interpret correctly what type of signal could have been used to bridge such a large gap. It almost certainly could not have been a simple torch signal, not even if shot up into the air with arrows or slings.[92]

Polybius continues his account with what may be the first technical critique of a telegraphic device in recorded history. He wrote:[93]

> This is a slight advance on beacons with a preconcerted code, but it is still quite indefinite. For it is evident that it is neither possible to foresee all contingencies or, even if one did, to write them on the rod. So that when circumstances produce some unexpected event, it is evident that it cannot be conveyed by this plan. Again none of the things written on the rod are defined statements, for it is impossible to indicate how many infantry are coming and to what part of the country, or how many ships or how much corn. For it is impossible to agree beforehand about things of which one cannot be aware before they happen. And this is the vital matter; for how can anyone consider how to render assistance if he does not know how many of the enemy have arrived, or where? And how can anyone be of good cheer or the reverse, or in fact think of anything at all, if he does not understand how many ships or how much corn has arrived from the allies?

Polybius hints here at a method for encoding the alphabet into signals, so that arbitrary messages can be spelled out. From other sources we know that such a device had been developed by Cleoxenus and Democleitus.[94] Polybius proceeds by describing this design, with some important alterations.[95] 150 B.C.

> The most recent method, devised by Cleoxenus and Democleitus and perfected by myself, is quite definite and capable of dispatching with accuracy every kind of urgent message, but in practice it requires care and exact attention. It is as follows: We take the alphabet and divide it into five parts, each consisting of five letters. There is one letter less in the last division, but it makes no practical difference. Each of the two parties who are about to signal to each other must now get ready five tablets and write one division of the alphabet on each tablet, and then come to an agreement that the man who is going to signal is in the first place to raise two torches and wait until the other replies by doing the same. This is for the purpose of conveying to each other that they are both at attention. These torches having been lowered, the dispatcher of the message will now raise the first set of torches on the left side indicating which tablet is to be consulted, i.e., one torch if it is the first, two if it is the second, and so on. Next he will raise the second set on the right on the same principle to indicate what letter of the tablet the receiver should write down.

Note that there were no spaces or punctuation characters (none were used in written Greek at the time) and that the Greek alphabet contained only 24 letters. Polybius chose not to use the 25th spare letter code, but instead designed an out-of-band code for synchronization: one torch in each group raised simultaneously. It would be a long time before anyone else paid this much attention again to the design of a signaling code!

There is still a question as to how much of this design was due to Polybius, and how much had already been present in the descriptions of Cleoxenus and Democleitus. There is, fortunately, an independent description of this telegraph, written between A.D. 200 and 250 by Sextus Julius Africanus. From the differences we can reasonably deduce what the additions of Polybius were.

In the system described by Sextus Julius Africanus in his book *Kestoi*, the alphabet was divided into three groups of eight letters each.[96] The sender used three different torches, one for each group. By raising a torch between one and eight times, the corresponding letter from that group would be signaled.[97] There was also an alternative way of transmitting the signals by using more torches or fires, as was illustrated in 1796 by Edelcrantz in his treatise:[98]

> Polybius and Julius Africanus record its use by the Greeks and Romans, using kettles with burning twigs or straw in oil, indicating letters in such a way that 1 to 8 fires in the first series encoded the first 8 letters of the alphabet, and similarly, fires in the next two series were used to encode the remaining 16 letters. One, two, or three separate fires lit at a distance were used to indicate the number of the series intended.

The improvements to this system that were due to Polybius were in all likelihood the more systematic usage of a smaller number of torches, and,

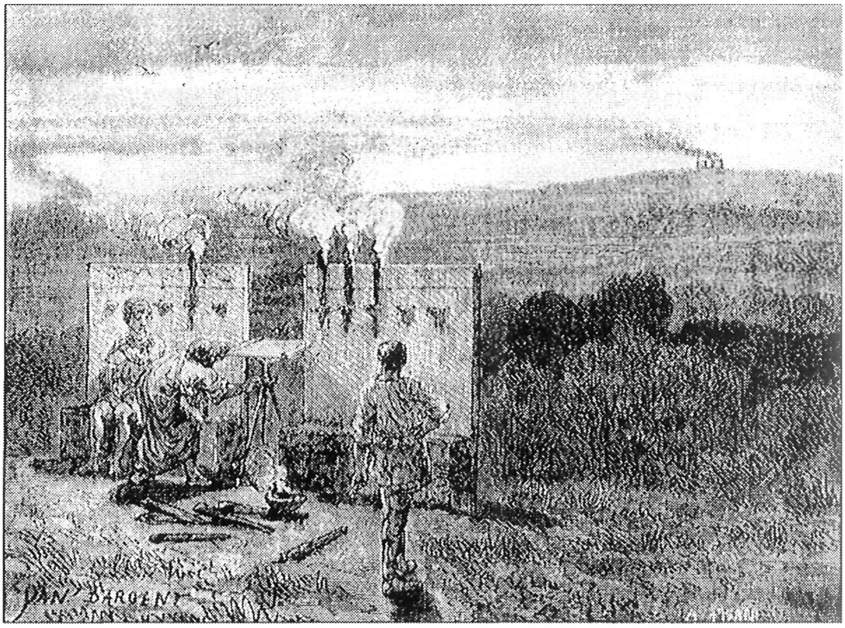

Figure 1.8 Polybius's Torch Telegraph, ca. 150 B.C.
(Coll. Musée de la Poste, Paris)

as described in the next section, the use of special screens and viewing tubes to block out peripheral light.[99] Polybius continued:[100]

> Upon their separating after coming to this understanding each of them must first have on the spot a "viewing tube" with two cylinders, so that with the one he can observe the space on the right of the man who is going to signal back and with the other that on the left. The tablets must be set straight up in order next the tubes, and there must be a screen before both spaces, as well the right as the left, ten feet in length and of the height of a man so that by this means the torches may be seen distinctly when raised and disappear when lowered. When all has been thus got ready on both sides, if the signaler wants to convey, for instance, that a hundred of the soldiers have deserted to the enemy, he must first of all choose words which will convey what he means in the smallest number of letters, e.g., instead of the above "Cretans a hundred deserted us," for thus the letters are less than one half in number, but the same sense is conveyed. Having jotted this down on a writing-tablet he will communicate it by the torches as follows: The first letter is kappa. This being in the second division is on tablet number two, and, therefore, he must raise two torches on the left, so that the receiver may know that he has to consult the second tablet. He will now raise five torches on the right, to indicate that it is kappa, this being the fifth letter in the second division, and the receiver of the signal will note this down on his writing tablet. The dispatcher will then raise four torches on the left as rho belongs to the fourth division, and then two on the right, rho being the second letter in this division. The receiver writes down rho and so forth. This device enables any news to be definitely conveyed.

The "viewing tubes," referred to here, although sometimes translated as "telescopes," did not magnify, but merely limited the field of vision.[101]

How hard would it be to use a telegraph like this? Polybius had a few words to say about this as well.[102]

> Many torches, of course, are required as the signal for each letter is a double one. But if all is properly prepared for the purpose, what is required can be done whichever system we follow. Those engaged in the work must have had proper practice, so that when it comes to putting it in action they may communicate with each other without the possibility of a mistake.

Volker Aschoff reported that students from the Technical University of Aachen in Germany successfully reproduced Polybius's torch telegraph.[103] They achieved a quite reasonable signaling rate of up to eight letters per minute on short messages, without using modern telescopes.

Well aware of the importance of his description, Polybius concluded with the following observation.[104]

> In offering these observations I am acting up to the promise I originally made at the outset of this work. For I stated that in our time all arts and sciences have so much advanced that knowledge of most of them may be said to have been reduced to a system. This is, then, one of the most useful parts of a history properly written.

According to the Roman historian Titus Livius (64 B.C.–A.D. 17), torch telegraphs as described by Polybius and his predecessors were used by Philip of Macedonia (238–179 B.C.) in his war against the Romans in 207 B.C. 207 B.C.
Livius wrote:[105]

> From there, in order that he [Philip of Macedonia] might meet every movement of his enemies, he sent men into Phocis, Euboea and to Peparethus, to select heights from which signal fires might be visible. For himself he placed a watch-tower on Mountain Tisäon, whose peak rises to a great height, so that by fires on distant heights he might in an instant receive a message as to where his enemies were active.

Implicit in this description is the realization that letter telegraphs, just like beacon fires, can be used to cover very long distances by using stations as relays in chains. That principle was already recognized by Julius Sextus Africanus when he wrote in *Kestoi*:[106]

> . . . then they signal what they have received to those who operate the next fire signals post, and these in the same manner pass it further, towards those who operate the last signal post.

Many of the principles laid out so clearly in the third and second century B.C. would not be rediscovered until the seventeenth century A.D.

The 2000-Year Gap

It is hard to believe that for almost two millennia people were any less curious about the construction of practical methods for long-distance communication than they were at the time of the Egyptians, Babylonians, Greeks, and Romans, but the sobering fact is that throughout this period only occasional references were made to simple beacon fires or messenger systems. All progress that had been made was forgotten.

We find a first new reference to a telegraphic system in the ninth century A.D. It was developed by Leo the Mathematician in Byzantium, during the
A.D. 842 reign of Theophilus (A.D. 829–842). Francis Dvornik described this system as follows:[107]

> He [Leo] constructed two identical clocks which kept exactly the same time. One was placed at the last station of the fire signals near the frontier [in Loulon], and the other near the imperial palace [in Constantinople]. Twelve incidents likely to occur, and which would have to be communicated through seven relays to headquarters at the imperial palace, were assigned to each of the twelve hours and written on the faces of both clocks. Upon receiving intelligence that the enemy was about to cross the frontier, the commander of the frontier post lit his fire signal when the clock showed the hour of one, and thus the watches in the palace knew at what time [day?] the invasion had begun.

Reportedly, this system was used until well into the tenth century A.D. To make a system like this work at all, there must have been a method to compensate for the 22-minute time difference between Loulon and Constantinople, and the shortening of the time available for nighttime signaling during the summers. Even with those problems solved, it must have been hard to construct clocks that could be kept in sufficient synchrony, and hard to cope with the average half-day delay before an urgent message could be sent. Considering also the limited code space, it is hard to see this as an improvement over Polybius's system.

Three hundred years later we find the following passage in *Usatges*, a
A.D. 1176 book written by Berengars I in 1176:[108]

> When the sovereign is attacked, or when he discovers that a king or monarch advances to fight him, he will inform his constituents either by proclamation, or by messengers, or in the usual way, by fire signals.

The use of the phrase "in the usual way" (German: *auf die gewohnte Weise*) seems to indicate that the use of fire beacons was still the standard way of communicating signs of alarm, victory or attack.

Another three hundred years later there still hadn't been much progress.
A.D. 1455 The text of an enactment of the Scottish Parliament from the year 1455, for instance, reads:[109]

> One bale of faggot shall be the notice of the approach of the English in any manner; two bales that they are "coming indeed;" and four bales blazing beside each other, to say that they are "coming in earnest."

The first sign of improvement came in the early sixteenth century. In this period, the French, Spanish and Venetian navies started using simple flag signaling methods for ship-to-ship and for ship-to-shore communications. Precious little is known about the devices or codes that were used,[110] but

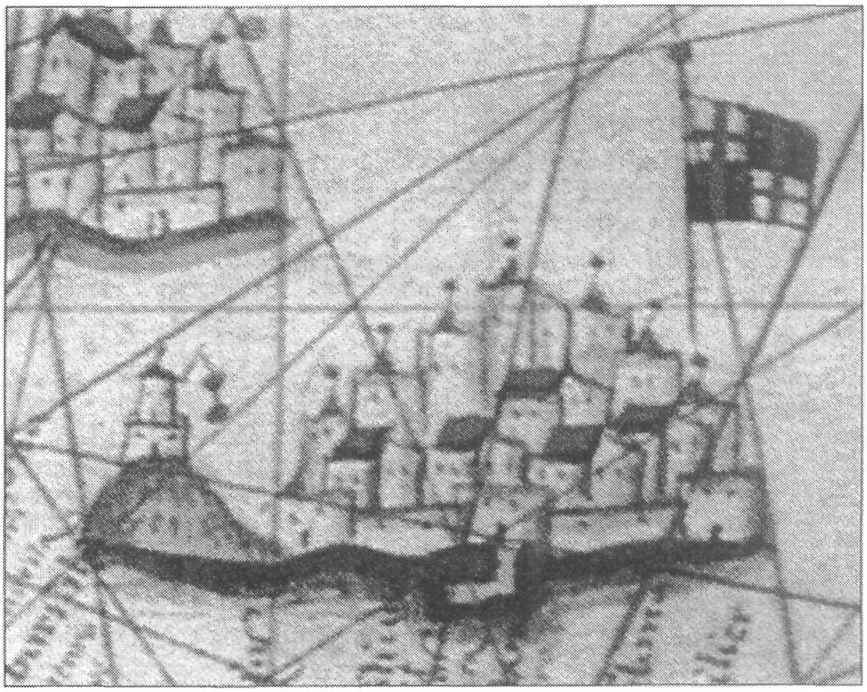

Figure 1.9 Sixteenth Century Spanish Map (Detail).
(Source: [Sider 1992], Fig. 24)

on old maps from this period peculiar disc-shaped devices suspended from towers can be seen that in all likelihood served signaling purposes (Figure 1.9). Almost identical signaling devices were used in Holland until well into the nineteenth century.[111]

The improvements in signaling apparently did not spread very rapidly through Europe. In 1569, for instance, the British erected a signal house A.D. 1569 on a platform battery in Portsmouth, as the endpoint of a classic line of beacons that stretched from Portsmouth to London. It was this line of beacons that notified London of the approach of the Spanish Armada in 1588.[112] If the Spanish did indeed have better signaling methods, it does not seem to have helped them in this instance.

At the start of the seventeenth century a discovery was made that would change the art of signaling decisively.

TELESCOPES

In 1608 Dutch spectacle-maker Hans Lippershey accidentally aligned two A.D. 1608 lenses of opposite curvature and of different focal lengths in his workshop in Middelburg. He discovered that this combination of lenses distorts the image in a wonderfully useful way: the telescope was born. Galileo was able to reproduce the effect, based on a description he had received from

A.D. 1609 Holland. By the end of 1609, he had succeeded in building a 30-power telescope, allowing him to discover, for instance, the moons of Jupiter. In 1610 he published his findings in *Siderius Nuncius* (The Starry Messenger).

The invention of the telescope made a considerable difference in the development of telegraphs. Since large objects could now be spotted from 15 to 30 km (10 to 20 miles) away, it didn't take much imagination for the inventors of those days to consider all kinds of new telegraphic schemes. Some of these systems are referred to in Edelcrantz's treatise, as follows:[113]

> Also notable is an idea from an unknown person that is contained in a letter to Schottus. He proposes to establish communication between Mainz and Rome by erecting 5 poles on a hill at such a distance from each other that they can easily be distinguished from 5 to 6 [German] miles away with a telescope. A pulley is attached to the top of each pole to hoist a stick, a sheaf of straw, or other objects to the top. If the alphabet is divided into 5 groups of letters, an object is first raised to indicate the group number. After the first object is lowered, another one is raised to indicate the number of the letter within the group. The art is the same as that of the Greeks but adapted to daytime use. The inventor, however, seems to be the first to have suggested the use of telescopes.

Edelcrantz refers to Gaspard Schottus, who lived from 1608 to 1666. The
A.D. 1664 letter that Schottus quoted in 1664 was written by Philipp Ernst Vegelin von Claerberg, an official at the court of the Prince of Nassau.

Edelcrantz continues with a more interesting reference to a method that even predates the one described by Schottus.

> Someone named Kessler, who lived at the beginning of the last century [i.e., the seventeenth century], suggested using letters cut from the bottom of barrels, using them to spell out words that would be readable at great distances.

Someone named Franz Kessler (ca. 1580–1650) did in fact write a book called *Unterschiedliche bisshero mehrern Theils Secreta oder Verborgene, Geheime Kunste* (Various until now mostly hidden, secret arts), which was
A.D. 1616 published in Oppenheim in September 1616. The description of Kessler's method given by Edelcrantz is not quite accurate, though. Kessler was one of the first authors to describe a working system based on the use of a telescope and a light signaling device.

In the preface to Kessler's book written by Hans Dietrich von Bry, a bookseller from Oppenheim, the method is introduced as follows:[114]

> Then it is not a small matter that two good friends in case of emergency, or otherwise at their pleasure, can communicate their wishes to each other, without meeting or go-between, and also at one or two miles distance can have their discourse or conversation, which in case of a siege or in other emergencies can be used to advantage to save an entire city or fortress, as will also be learned in more detail from the [following] description.

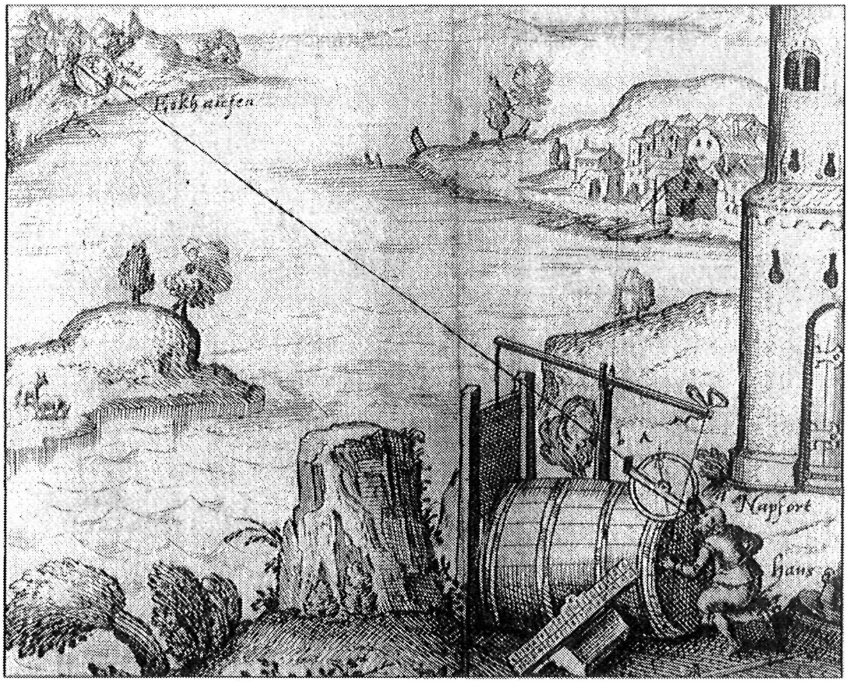

Figure 1.10 Kessler's Device.
(Coll. New York Public Library, New York)

Kessler himself then refers to the telescope as a useful novelty from Holland. Apparently the word *telescope* had not been adopted yet.[115]

> With the help of a long perspective, and in recent years in Holland newly discovered Tubular Spectacles [German: *Rohren Brillens*], used outside in the field, with which one can see best in time of peace, and the most secure at times of war.

Kessler then describes how the alphabet can be compressed into fifteen essential characters, each of which can be associated with a number between one and fifteen in a pre-arranged random order, to make it harder for others to detect what is being signaled. Kessler stresses that the code can and should be changed frequently if secrecy is required.

To use this code, in addition to "tubular spectacles," one needs:[116]

> At night a burning light or a torch suffices; by day a mere stick with a white piece of cloth or paper.

Kessler then details the nighttime signaling method. For this one needs:

> . . . two square boxes, or common round barrels. They must, however, also on the inside, be covered with lead. In the middle of the barrel one must place a long hook. The bottom of the barrel must have a square door, about a quarter

> ell [15 cm] long and wide, so that, through this door, one can hang from the hook several pitch-crowns of appropriate size.

The barrel is placed on its side, with the bottom facing the signaler, as illustrated by Kessler in Figure 1.10. The other side is open, but equipped with a shutter that can be lifted or lowered to produce the light signals: one flash for the letter "d," two flashes for an "i," and so on.

Kessler realized well that the same encoding would work for waving a flag, or for giving sound signals with bells, or hammers, or by knocking on walls.[117]

He gives much attention to a related problem, which seems to indicate that, unlike many other inventors from this period, he really did use the signaling method he describes. The question is how one could locate a remote receiver or sender in the middle of the night, before the signaling begins. To solve that problem Kessler built a large disc, marked in degrees from 0 to 360, with a compass on it, and with a pointing device attached to the center. The pointing device was a simple stick with two flat pieces of metal at the ends, each with a small slit in it. The idea was that at daylight one would accurately locate the remote correspondent, mark the angle on the disc, using the compass for an absolute reference of orientation. Then, at night, at a predetermined hour, the barrel and the disc would be lined up with the remote location, and signaling could begin. Curiously, Kessler states that the receiver only really needed the disc, not the barrel, which implied that he had not thought of things like message acknowledgement or error control. The method is reminiscent of signal-lights flashing Morse codes, as they are used in the Navy even today.

Several less sophisticated methods from the same period seem to have been popular; sufficiently so for the Dutch writer Wynant van Westen to remark in his booklet, *Mathematische Vermakelyckheden* (Mathematical
A.D. 1636 Amusements), published in Arnhem in 1636, that these signaling devices were of most use to spies, since they made it so much easier to intercept the supposedly secret communications of an adversary.

Mentioned in many sources is a description from the Marquis of Worces-
A.D. 1663 ter, in his book *Century of Inventions*, which was published in 1663. He claimed:[118]

> . . . a method by which, at a window, as far as [the] eye can discover black from white, a man may hold discourse with his correspondent, without noise made or notice taken; being according to occasion given, or means afforded, *ex re nata*, and no need of provision beforehand; though much better if foreseen, and course taken by mutual consent of parties.

There is again no mention that a large-scale use of this method was ever contemplated.

Another telegraphic device mentioned by Edelcrantz is a letter telegraph developed by the Englishman Robert Hooke (1635–1703).[119] Hooke's device would prove to be a seminal step in the development of telegraphy.

Nonetheless, it appears to have been only of passing interest to Hooke himself.

The Art of Conveying Intelligence

The only record of Hooke's invention is the text of a lecture he gave on 21 May 1684 to the Royal Society with the title *On Showing A Way How To Communicate One's Mind At Great Distances.* The design he describes there has some unique features that had not been described before. Even though the device itself appears never to have been applied in practice, it provided a rich inspiration for many others. The text of Hooke's speech gives a unique view of the communication problem as it was seen by this seventeenth century scholar:[120] A.D. 1684

> That which I now propound, is what I have some years since discoursed of; but being then laid by, the great siege of Vienna, the last year, by the Turks, did again revive in my memory; and that was a method of discoursing at a distance, not by sound, but by sight. I say, therefore, 't is possible to convey intelligence from any one high and eminent place, to any other that lies in sight of it, though 30 or 40 [English] miles distant in as short a time almost as a man can write what he would have sent, and as suddenly to receive an answer as he that receives it hath a mind to return it, or can write it down in paper. Nay, by the help of three, four, or more of such eminent places, visible to each other, lying next it in a straight line, 't is possible to convey intelligence, almost in a moment, to twice, thrice, or more times that distance, with as great certainty as by writing.

In the next paragraph Hooke refers to telescopes, still as a recent invention. The term "tubular spectacles" had now been abandoned.

> For the performance of this, we must be beholden to a late invention, which we do not find any of the ancients knew; that is, the eye must be assisted with telescopes, of lengths appropriated to the respective distances, that whatever characters are exposed at one station, may be made plain and distinguishable at the other that respect it.
>
> First. For the stations; if they be far distant, it will be necessary that they should be high, and lie exposed to the sky, that there be no higher hill, or part of the earth beyond them, that may hinder the distinctness of the characters which are to appear dark, the sky beyond them appearing white: by which means also, the thick and vaporous air, near the ground will be passed over and avoided; for it many times happens that the tops of hills are very clear and conspicuous to each other, when as the whole interjacent vale, or country, lies drowned in a fog. Next, because a much greater distance and space of ground becomes visible, insomuch that I have been informed by such, who have been at the top of some very high mountains, as particularly at the top of the pike of Teneriff, that island of the Grand Canaries, which lies above 60 [English] miles distant, appears so clear, as if it were hard by; and I myself have often taken notice of the great difference there is between the appearing distance of objects seen from the tops and bottoms of pretty high hills, the same objects from the top appearing nearer and clearer by half, and more than they do when viewed from lower stations of the hills; and this not only when the space between them was land, but where it was nothing but sea. I have taken notice also of the

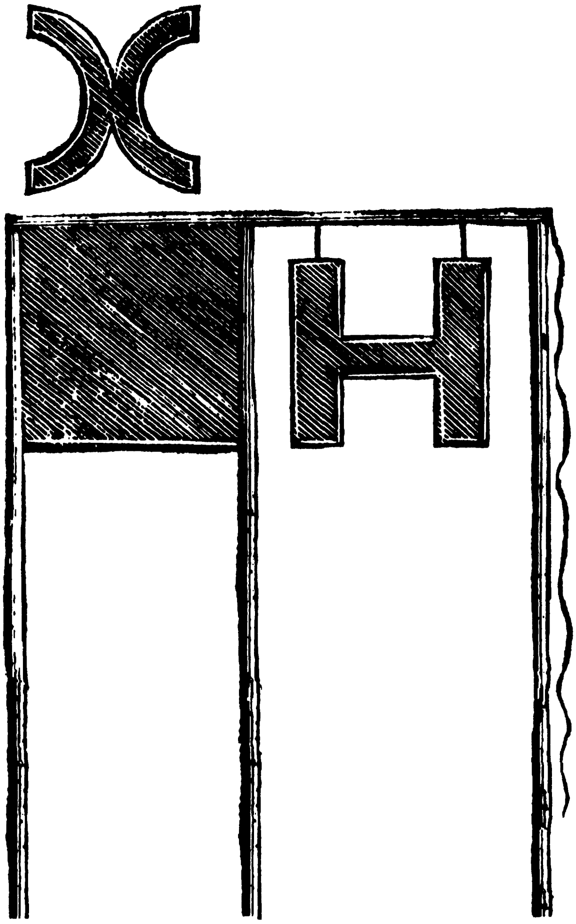

Figure 1.11 Hooke's Device.
(Source: [Hooke 1726])

same difference from the prospect of places from the top of the column at Fish-street Hill, where the eye is, in good part, raised above the smoky air below.

After more on air quality, and the type of telescopes that would be required, Hooke continued:

Next, there must be certain times agreed on, when the correspondents are to expect; or else there must be set at the top of the pole [the first mention of the word "pole" in the description], in the morning, the hour appointed by either of the correspondents, for acting that day; if the hour be appointed, pendulum

> clocks may adjust the moment of expectation and observing. And the same may serve for all other intermediate correspondents.

Other than Kessler or the Marquis of Worcester before him, Hooke had a clear view of how his system could be used to set up a longer chain of signaling stations.

Hooke then describes his encoding method in detail.

> Next, there must be a convenient apparatus of characters, whereby to communicate any thing with great ease, distinctness, and secrecy. There must be therefore, at least, as many distinct characters as there are necessary letters in the alphabet that is made use of . . . and those must be either day characters or night characters: if they are to be made use of in the day-time, they may all be made of three slit deals [boards or planks], moving in the manner I here shew, and of bigness convenient for the several distances of the stations for which they are made, that they may be visible through the telescope of the next station. Any one of which characters may signify any one letter of the alphabet, and the whole alphabet may be varied 10,000 ways; so that none but the two extreme correspondents shall be able to discover the information conveyed, which I shall not now insist on, because it does more properly belong to Cruptography [Hooke's spelling].

Hooke's encoding by arbitrarily mapping letters of the alphabet to symbols is similar to Kessler's. It is not certain, however, that Hooke knew about Kessler's book. Also interesting is the detailed attention that even the earliest developers of signaling systems seem to have given to cryptography. To Hooke's credit, though, he was one of the few who realized that it was a separate topic, and need not be confused with the design of the basic signaling method.

Hooke next explains how the night characters can be made, but here he is not very explicit.

> If the characters are for the night, then they may be made with links [Oxford dictionary: torches formerly used for lighting/guiding people along streets], or other lights, disposed in a certain order, which may be veiled, or discovered, according to the method of the character agreed on; by which, all sorts of letters may be discovered clearly, and without ambiguity.

Next, Hooke comes to the actual apparatus that he is proposing for displaying the day characters.

> There may be various contrivances to facilitate and expedite the way of displaying and exposing these characters to view, and of withdrawing, or hiding them from the sight; but this I here shew, I conceive, will be as easy and simple as any: all which may be exposed at the top of a high pole, and by two small lines moved at the bottom, so as to represent any character.
>
> By these contrivances, the characters may be shifted almost as fast, as the same may be written; so that a great quantity of intelligence may be, in a very short time, communicated.

The characters are suspended from a frame, where they can be obscured behind a screen when moved to the left, or displayed when moved to the right, with the help of lines attached to each character, each line going down to an operator standing at the bottom of the frame.

In the next paragraph, Hooke explicitly describes the use of control codes that can be used in true two-way communication, for instance, to signal acknowledgements or error conditions. As far as we know, Hooke was the first person who realized that such codes were necessary for effective communication.[121]

> There will also requisite several other characters, which may, for expedition, express a whole sentence, to be continually made use of, whilst the correspondents are attentive and communicating. The sentences to be expressed by one character [symbol] may be such as these . . . I am ready to communicate [synchronization]. I am ready to observe [idem]. I shall be ready presently [delay]. I see plainly what you shew [acknowledgement]. Shew the last again [an error code]. Not too fast [rate control]. Shew faster [idem]. Answer me presently. *Dixi*. Make haste to communicate this to the next correspondent [priority]. I stay for an answer; and the like. All which may be expressed by several single characters, to be exposed on the top of the poles [instead of suspended below them, like the other characters], by themselves, in the following manner, so as no confusion may be created thereby.

The meaning of the word *Dixi* is not clear. It was set in a different font, and may not have represented a separate code. It could, however, also be Latin for "I have said," meaning "end of message." From the other ten code words, at least eight are control codes that can be found in most modern data communication protocols, and some of these (i.e., the rate control codes) only in the most recent designs. For the first design that included control codes at all, it was not a bad choice indeed.

Hooke summed up his lecture as follows, anticipating his critics:

> There may be many objections brought against this way of communication; and so many the more, because the thing has not yet been put in practice. But, I think, there can hardly be any so great, as may not easily be answered and obviated.
>
> There may be many uses of this contrivance, wherein it will exceed any thing of this kind yet practiced, but I shall not now spend time to enumerate them; only in two cases, it may be of inestimable use. The first is for cities or towns besieged, and the second is for ships upon the sea; in both which cases, it may be practiced with great certainty, security, and expedition.

The telegraph design of Hooke would never be put to practice, but it
A.D. 1690 inspired many of his successors.[122] In 1690, a curious variant of Hooke's method, developed by the Frenchman Guillaume Amontons was described in a letter written by Abbé Fénelons, the Archbishop of Cambrai, to the secretary of the Polish king Johann Sobieski:[123]

> Monseigneur has told me that he was in Meudon and from there sent a secret message via windmills to Belleville and from there to Paris. The answer was given to him similarly by signals, that were attached to the wings of the

> windmill and read in Meudon with a telescope. The signals were letters from the alphabet, displayed one after the other, at the rate of the slowly turning mill. As soon as each letter appeared, it was recorded in a table by the observer at the observatory in Meudon. The inventor [Amontons] stated that by increasing the distances, with signals and fire signs one could quickly and cheaply send messages from Paris to Rome; but, I believe, he agreed with me, that this invention is more a curiosity than a practical form of traffic.

A method attributed to Amontons is also described in the *Encyclopaedia Britannica* of 1797, but this time much more systematically, and without the mention of windmills.[124]

> His method was this: let there be people placed in several stations, at such a distance from one another, that by the help of a telescope a man in one station may see a signal made in the next before him; he must immediately make the same signal, that it may be seen by persons in the station next after him, who are to communicate it to those in the following station, and so on.
>
> These signals may be as letters of the alphabet, or as a cipher, understood only by the two persons who are in the distant places, and not by those who make the signals. . . .
>
> Amontons tried this method in a small tract of land before several persons of the highest rank at the court in France.

The signaling methods of Hooke and of Amontons were apparently quite well-known in the eighteenth century. They are referred to in letters to *Gentleman's Magazine* from 1794, discussing Claude Chappe's telegraph designs.[125] They are also mentioned in Edelcrantz's treatise.[126] In footnote 29, for instance, Edelcrantz remarked:[127]

> Apart from Linguet, one usually credits the invention to both Amontons and to Hooke, but there is no real evidence to support this.

NEW LENS DESIGNS

The telescopes of the seventeenth century could produce superb images, even at high magnification levels. The restriction to single-element lenses, however, meant that the telescopes had to be made quite long to achieve optimal image quality.[128] Christiaan Huygens, for example, showed in 1656 that Saturn's "ears," as they were called by Galileo, were actually rings. He used a telescope of almost six meters long.

This problem was not solved until 1747, when Leonhard Euler A.D. 1747
(1707–1783) discovered that one could use the flaws of one lens to correct those of another, by using multiple lens elements in a compact design. Euler's goal was primarily to improve the quality of the microscope, by reducing flaws such as chromatic and spherical aberration, but the principles applied equally to the telescope. Shortly afterwards, in 1750, the Swede Samuel Klingenstjerna (1698–1765) made an extensive study of the color separation properties of different types of glass. And in 1757 all A.D. 1757
this new knowledge was combined in the construction of the so-called "Dollond telescope," by John Dollond (1706–1761) in England, with much

improved image quality and resolution. It became the standard for many years to come, and was used in the optical telegraphic systems that followed within a matter of years.

The Non-Inventions

Before the attempts to build a better telegraph were successful, quite a few non-designs would be pursued. Most of these non-designs were efforts to exploit the simple observation that two magnetized objects will align themselves when held close together. The idea was that if two small magnets can do this at a few centimeters distance, two stronger magnets should be able to do this a few decimeters apart, and with some further study, special magnets might be able to allow communication from one city to the next. Figuring out who would be talking to whom, with a number of such magnets in use in different cities, was another one of the details to iron out in field studies. The important thing was that one knew quite definitely in which direction to search.

A.D. 1553 In 1553 a young Giambattista della Porta (1535–1615) published his *Magia Naturalis* which, for better or worse, became a standard reference for later scholars. Porta described several telegraphic instruments, one resembling a heliograph, another an acoustical device where people would shout messages through so-called "speaking tubes."[129] They are duly referred to by Edelcrantz in his treatise.[130] The book also contains brief mention of cryptographic systems of substitution ciphers. This, and his more encompassing *De Furtivis Literarum Notis*, published in 1563, gained Porta recognition as one of the founders of modern cryptography.[131] Especially in *Magia Naturalis*, however, Porta frequently allows his pen to be guided by his enthusiasm. The 1589 edition of *Magia Naturalis*, for instance, contains the following statement that inspired many of Porta's contemporaries and successors:[132]

> And to a friend that is at a far distance from us, and fast shut up in prison, we may relate our minds; which I doubt not may be done with two Mariner's Compasses, having the Alphabet writ about them.

Porta did not have such a method; he only thought there had to be one. To illustrate on what shaky grounds Porta's claim stood, the sentence that immediately follows the one about Mariner's Compasses, but rarely included in the quote, is:

> Upon this [also] depends the principle of perpetual motion, and more admirable things, which I shall here let pass.

A flurry of "inventions" soon followed. The first victim seems to have been
A.D. 1600 Daniel Schwenter. In 1600 he published a book, titled *Steganologia et Steganographia*, under the assumed name of Johannes Hercules de Sunde, in which he describes a communication system based on the deflection of two magnetized compass needles.[133] Schwenter divided the alphabet into groups of four letters, each group assigned to a section of the compass. By moving a needle between one and four times into one of its sections, the

sender could indicate a specific letter within the corresponding group.

In 1617 the Italian Famianus Strada published the first edition of his *Prolusiones Academicae* which also became a standard reference work. He described the new invention in elaborate detail:[134] A.D. 1617

> Therefore try the experiment, if you desire a friend who is at a distance to know anything to whom no letter could get, take a flat smooth disc, describe round the outside edges of the disc stops, and the first letters of the alphabet, in the order in which boys learn them, and place in the centre, lying horizontally, a dial-pin that has touched the magnet, so that, turned easily from thence, it can touch each separate letter that you desire.
>
> After the pattern of this one, construct another disc, described with a similar margin, and furnished with a pointer of iron—of iron that has received a motion from the same magnet. Let your friend about to depart carry this disc with him, and let it be agreed beforehand at what time, or on what days, he shall observe whether the dial-pin trembles, or what it marks with the indicator. These things being thus arranged, if you desire to address your friend secretly, whom a part of the earth separates far from you, bring your hand to the disc, take hold of the movable iron, here you observe the letters arranged round the whole margin, with stops of which there is need for words, hither direct the iron, and touch with the point the separate letters, now this one, and now the other, whilst, by turning the iron round again and again throughout these, you may distinctly express all the sentiments of your mind.
>
> Strange, but true! The friend who is far distant sees the movable iron tremble without the touch of any one, and to traverse, now in one, now in another direction; he stands attentive, and observes the leading of the iron, and follows, by collecting the letters from each direction, with which, being formed into words, he perceives what may be intended, and learns from the iron as his interpreter.

It wasn't just a one-way system. Strada continued:

> Moreover, when he sees the dial-pin stop, he, in his turn, if he thinks of any things to answer, in the same manner by the letters being touched separately writes back to his friend.
>
> Oh, I wish this mode of writing may become in use, a letter would travel safer and quicker, fearing no plots of robbers and retarding rivers. The prince, with his own hands, might despatch business for himself. We, the race of scribes, escaped from an inky sea, would dedicate the pen to the Shores of Magnet.

Each new inventor guarded the secret mechanism of his device with his life and more often than not refused to demonstrate it to anyone other than the king of whatever country he happened to live in. Needless to say, these kings quickly got wary of all the non-devices, and they soon learned to reject such requests, which in turn made it harder for those who were studying more realistic solutions.

In 1632 Galileo referred to the popularity of these non-inventions in his *Dialogus de Systemate Mundi*. In it, he has Sagredo say:[135] A.D. 1632

> You remind me of a man who wanted to sell me a secret art that would allow me to speak to someone at a distance of 2–3 thousand miles, by means of the attraction of magnetized needles. When I told him that I would be delighted to

> purchase the device, if only I was allowed to try it first, and that I would be satisfied if I could do so from one corner of the room to another, he answered that at such a short distance the effect would barely be visible. At that point I said farewell to the man and I told him I had no interest to travel to Egypt or Moscow before I could try the device, but if he wanted to move there I would be happy to remain in Venice and give the signals from here.

There were also more serious attempts, some of which contained concepts that would be rediscovered only hundreds of years later. Telegraph design became a popular pastime in the late eighteenth century.

A.D. 1782 On 8 June 1782, for instance, Dom Gauthey submitted two proposals to the Academy of Sciences in Paris. One was said to be an improvement of an early system used by Dupuis (about which more shortly). The other was a variation of an acoustical method that had been described earlier by Giambattista della Porta. Gauthey's variation of Porta's method was to replace the shouting of messages through metal tubes with the blowing of air puffs,[136] or the tapping of a code on the outside of the tubes with a hammer.[137] The tapping comes remarkably close to a Morse code, but no specific method of encoding is mentioned by Gauthey.

Gauthey called his machine a *télélogue*. Ignace Chappe wrote in 1824 that Gauthey had stipulated that his methods could not be disclosed unless they were adopted.[138] His original plans were kept sealed at the Academy of Sciences in Paris for almost half a century. The seals were broken on 6 February 1826, perhaps prompted by Ignace Chappe's publication, but Gauthey was long dead by then, and the plans received no further attention.[139]

A.D. 1784 A new device of a charming simplicity was proposed in 1784 by the Swiss watchmaker Christin. His invention was to connect the stations that wished to communicate with a system of shafts and gears.[140] The parties could signal each other by rotating a letter wheel. This device would probably have worked, although not over very large distances.

A.D. 1786 In 1786 the German professor Johann Bergstrasser (1732–1798) (sometimes also spelled as "Bergstraesser") constructed an optical telegraph line between Feldberg, Homberg and Phillippsruhe. Not much is known about the precise type of telegraph he used. Bergstrasser did, however, publish an influential study of communication methods in 1785, titled *Synthematographik*, referenced respectfully by Edelcrantz.[141] If the telegraph built by Bergstrasser was one of those he described in his book, it was no real competition for either Chappe's or Edelcrantz's later designs. There are indications that it was based on light flares. An eyewitness of an experiment performed by Bergstrasser in 1786 said:[142]

> I have seen your experiment of the fourth [4 April 1786] near Bergen, at a distance of roughly three hours, and saw both signals, the first consisting of two, and the second of three flares [German: *Raketen*].

The Czech musical director Jóseph Chudy developed a more interesting
A.D. 1787 optical telegraph in 1787. His design consisted of a row of five lights that

Table 1.2 Long-Distance Communication Methods.

Method	First Recorded Use		Last Recorded Use	
Pigeons	Egypt	2900 B.C.	California	A.D. 1981
Runners/Couriers	Egypt	1928 B.C.	Pony Express	A.D. 1860
Beacons/Torches	Troy	1184 B.C.	England	A.D. 1588
Calling posts	Persia	400 B.C.	Germany[143]	A.D. 1796
Heliographs	Greece	400 B.C.	Arizona	A.D. 1886
Flags	Greece	400 B.C.	Maritime use	today

could individually be turned on or off, giving 2^5 possible code combinations. With a telescope, the code could be read from a distance and passed on from station to station.

Chudy's design would not get much attention. When Chappe's telegraph did, Chudy decided to publicize his contribution in the best way he could: by writing an opera. The premiere of this opera, *Der Telegraph oder die Fernschreibmaschine* (The Telegraph or the Telewriter), took place on 3 January 1796 in the city of Buda, today part of Budapest.

The most interesting part of Chudy's design is the use of the five-bit binary code, some hundred years before a similar five-bit code by the French telegraph operator Emile Baudot was adopted as International Telegraph Alphabet No. 2. Chudy was, however, not the first to develop such a five-bit binary code, even if we discard the torch telegraph of Polybius (see the Bibliographic Notes below).

In 1788, finally, the Frenchman Charles Francois Dupuis constructed a A.D. 1788
private telegraph line between Ménil-Montant and Bagneux, a few kilometers apart. The line was used until 1792 for a correspondence between Mr. Dupuis and a Mr. Fortin (sometimes spelled "Fortui"). No precise description of the telegraph itself has been preserved, other than a terse observation that it was an improvement of the design of Guillaume Amontons from 1690.[144] According to Chappe, Dupuis abandoned his design when the Chappes submitted their proposal to the Legislative Assembly in 1792.[145] Dupuis was a member of that body.

The success of Chappe's telegraph unmistakably started a new era in the history of long-distance communications.

Summary

There are many ways to transmit information over long distances, also without the help of electricity. Most of them have not only been tried, they have been applied throughout history on a remarkably large scale.

Table 1.2 summarizes the methods that have been applied, and gives the approximate dates of the earliest and the latest recorded use. Each type of system was initially used as a point-to-point communication method, e.g., a single messenger running a distance. In due time, though, most systems developed into sophisticated relay systems, with permanent posts at fixed distances, covering a fairly wide area. It should perhaps not be surprising that almost all methods have remained in use virtually up to the present day, give or take a few hundred years.[146]

There is just one class of systems that did not fully develop until the late eighteenth century A.D., but then dominated the landscape for nearly half a century: the optical semaphores. The remainder of this book is devoted to the people who first built them.

Bibliographic Notes

Most of the writings of historians such as Herodotus, Plutarch, Polybius, Thucydides, or Xenophon are available in modern translations, for example, in the Penguin Classics or Viking Library series. Nothing, of course, can equal the reading of these original texts. The bibliography on p. 210 of this book contain the details on the translations that we have used.

Systems of messengers and couriers on horseback are said to have existed also in China as early as the Chou Dynasty (1122–256 B.C.). Very few documents describing these systems have survived though. For a discussion see, for instance, [Dvornik 1974, p. 277], or [Olbricht 1954]. The relay systems that were used by the Mongol ruler Kublai Khan (sometimes spelled Kubilai Khan) were described in Marco Polo's *Travels*. Excerpts can also be found in [Dvornik 1974, p. 290–291].

Fire, smoke, and drum signals are also known to have been used until quite recently by African and Australian tribes, and by native Americans. It seems likely that the history of the usage of these methods dates back much further than we could ever hope to find written records. Good descriptions can be found in [Mallery 1879] and [Hodge 1910].

Outstanding surveys of early communication methods can also be found in [Bergstrasser 1785], [Bockmann 1794], [Chappe 1824], [Shaffner 1859], [Hennig 1908], [Appleyard 1930], [Hennig 1936], [Still 1946], [Michaelis 1965], [Woods 1965], [Herbarth 1978], [Aschoff 1984], and of course also in [Edelcrantz 1796]. The most thorough studies among these, roughly in order of importance, are [Aschoff 1984], [Hennig 1908], [Bergstrasser 1785], and [Woods 1965].

More details on naval flag signaling systems and their use at the battle of Trafalgar is contained in [Keegan 1988], and can also be found, in Swedish, in [Cyrus 1912].

Many of the fifteenth and sixteenth century maps that appear to show ball- or disc-semaphores in Spain were published in [Sider 1992]. Several of the maps show a semaphore tower on mount *Montjuich*, near the city of Barcelona. City records from Barcelona indicate that towers at this location have been used for signaling since at least A.D. 1073, when construction on a new stone signaling tower was begun. The first mention of the word *pomo*, which could refer to a ball or disc, in relation to this signaling post dates from 1534, see [Voltesbou 1940, Chapter 7]. The description from 1534, which is by far the oldest known reference to this type of semaphore, includes mention of a signaling code that details how the balls or discs are

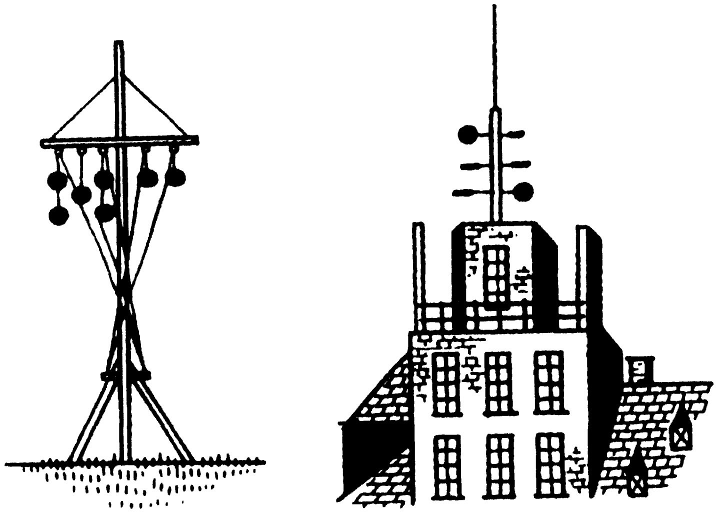

Figure 1.12 Dutch Semaphores—Nineteenth Century.
(Source: [Ringnalda 1902], p. 1)

to be displayed from a mast at different heights. In [Ringnalda 1902] and also in [Michaelis 1965] similar looking semaphores are reproduced, which were used for telegraphy around 1831 in Holland (cf. Figure 1.12). A variant of the naval telegraph that was used by the British in the early nineteenth century also appears to match this design. See, for instance, Plate II-1 in [Woods 1965] for a telegraph that was deployed between 1808 and 1814. It also uses series of discs or balls suspended from masts. More details on the use of disc telegraphs in the Netherlands and in Curacao in the nineteenth century can be found in Chapter Five of this book.

More about the early non-devices for communication based on magnetized needles can be found in [Fahie 1884]. Fahie lists over twenty works of sixteenth and seventeenth century authors, describing variations of telegraphs that were supposedly based on the use of magnets.

The principle of encoding up to 32 items with five symbols of two types only was described in 1641 by John Wilkins (1614–1672). In a summary he referred to his description as follows:[147]

> It is more convenient, indeed, that these Differences should be of as great Variety as the Letters of the Alphabet; but it is sufficient if they be but twofold, because Two alone may, with somewhat more Labour and Time, be well enough contrived to express all the rest. Thus any two Letters or Numbers, suppose A B being transposed through five Places, will yield Thirty two Differences, and so consequently will superabundantly serve for the Four and twenty Letters, as was before more largely explained in the Ninth Chapter.

Wilkins based himself on Sir Francis Bacon (1561–1626), who in 1623 described a binary encoding of the alphabet, also using the letters A and B.[148] The earliest reference to binary encoding is said to appear in a work from around 1605 by the English mathematician Thomas Harriot (1560–1621).[149] The credit for inventing a binary arithmetic based on this encoding, finally, was claimed in 1697, and first published in 1703, by the German mathematician Gottfried Wilhelm Leibniz (1646–1716).

Robert Hooke's lecture from 1684, finally, is included in [Hooke 1726], which was published after his death.