

Carries Stripped to the Bone: Episodes in the History of Coaxial Modular Digital Counters

Denis Roegel
University of Lorraine

Mechanical counters have been ubiquitous, and they had become so commonplace that little thought now is given to them. We could find such counters in many cars, where they served as odometer displays. They could and still can be found on other vehicles, such as bikes, on various machines, and so forth. The most common construction for such counters is made of rotating disks, which are all similar and located on the same axis. Such counters also were components of cash registers and of various calculating machines. Although they look simple in appearance, and perhaps standardized, they have a history of their own. Many such counters have been built for a variety of purposes until the current counters became widespread and before their replacement by electronic displays.

Alas, although much has been written on the history of calculating machines, very little attention has been paid to these components and their evolution.

In this article, we analyze three of the earliest known models of counters, which can be viewed as ancestors of the modern mechanical.

A Brief History of Counters

Analog Counters

The first counters were odometers (properly hodometers). This word is from the Greek *hodomētron* (way measurer, from *hodós*, path, and *mētron*, measure) and refers to a device for measuring a distance. Usually, what actually is measured is the number of steps of a person (we then speak of pedometers) or the number of revolutions of a wheel.

Odometers usually were made of various gears, especially wormgears, to slow down the motion and their display was by hands on dials. Such a display inherently was analogical. Actual pedometers are more specialized, and count the number of times a small weight has moved due to walking. Therefore, they can count steps and be used to estimate distances. In this article, we will focus on devices for measuring rotations and will not go into the details of pedometers.

The earliest (distance) odometers seem to go back at least to Vitruvius (1st century BC). Leonardo da Vinci (1452–1519) designed an odometer, probably inspired by Vitruvius. In the 16th century, some of the odometers were used for surveying and measuring distances in a territory. Beckmann^{1,pp.2–19} mentions the odometers made by John Fernel around 1550, by Paul Pfinzing at the end of the 16th century, and others, although some of these odometers were not counting anything. Fernel's "odometer" seems to have merely struck a bell after each turn of a wheel, and one then had to count the number of such strikes.

Improvements in odometers were mainly about ensuring that they were automatic, that they counted properly, and that they could count large numbers of revolutions. Some constructions made use of differential gears; that is, they used two wheels moving at slightly different speeds, and the position of one wheel would be used on a dial placed on the other. This was the case, for instance, of Vaussin-Chardanne's "célérimètre" patented in 1835.^{2,3}

Most of these counters would never stop, but after a certain number of turns, they would repeat themselves.

Some of the odometers were not reversible. That was the case of the odometer invented by Meynier in 1724. Since it did not work backwards, an excess of distance would have to be subtracted from the distance given by such a counter, if at some point the carriage went backwards and again forwards (the same distance being then counted twice). Outhier's improvement of Meynier's odometer in 1742 overcame this problem.^{4–6}

Other odometers were very much operating like chronometers, sometimes triggered by impulsions.⁷

During the 19th century, counters found new uses, for instance with the development of gas meters. The most widespread solution in the 1840s was the Samuel Clegg (1781–1861) counter, as improved by Crosley. A detailed description is given in a treatise by Clegg.^{8,pp.319,320} Another interesting construction is the one patented by Thomas Edge in 1842.⁹

Analog odometers are, of course, related to flowmeters, used to measure the speed of water in rivers.

Mention should be made of the “anti-fraud” counter invented by Viard in 1823.¹⁰ This counter is made of a number of gears, but in such a way that its display is cryptic. Basically, the counter will show the remainders of the number of rotations of a machine, but the remainders use various integers, some of them prime numbers, so that eventually the actual number of rotations can be found only by a computation and is unlikely to be falsified by workers.

Other specialized counters, for instance, were made for counting passengers in a streetcar (Dumont in 1843, French patent 15783), but they still were analog in nature, moving nuts along screws.

The First Digital Counters

Almost every analog counter works with gears, and each part moves with a constant speed, provided that the input does.

On the other hand, digital devices are machines that have a number of clearly defined states from which the transitions occur quickly. Most importantly, digital devices have parts that are still during certain periods, even if the input changes. This naturally is convenient for reading numerical values. If we restrict ourselves to measuring/counting devices, the first digital devices probably were the calculating machines, such as Pascal’s adding machine developed in the 1640s.¹¹ Whereas analog counters usually are kept in motion for some time, the first digital machines were operated only quickly and intermittently. They were not used to measure distances, revolutions, or other continuously changing amounts. In other words, the digital part came without being associated with counting. It came with calculation. Of course, a calculating machine, such as Pascal’s, also could have been used to count something, for instance the number of rabbits coming out of a magician’s hat, by adding 1 whenever necessary, but that was not its first aim.

Things changed little by little in the middle of the 19th century, when the need more and more was felt to measure not only distances or volumes, which are inherently continuous, but operations of steam engines, trains, and other machines, which were more discrete in nature. These measures were used to evaluate work during a certain time, and also may have been used for factory wages. Large discrete values, such as several thousands or tens of thousands, had to be counted. This made it desirable to attach counters to machines.

The notion of a counter then certainly took a life of its own. A counter now more than ever conveyed the idea of counting 1 by 1, that is of counting things when they occur, and not afterwards when they have occurred. There is an

underlying idea of an event, which usually is absent from analog odometers, for which miles are no milestones.

Counters little by little became adapted to cars, trains, coin counters, and so forth.

Counters, of course, must be distinguished from adding machines: a general adding machine must be able to add any two numbers and not all counters can do that, since with some counters, only units can be added.

It should be noted that digital counters often contain an analog input. An old car odometer, for instance, has its rightmost wheel turning slowly, and certainly not skipping instantly from one digit to the next. Still, the next transitions occur quickly and all digits except the first one are still most of the time. In that sense, such counters are considered to be digital ones.

Some adding machines have the appearance of digital machines, but are still analog. This is, for instance, the case of Chebyshev’s machine (1876), which uses a row of epicyclic gears to achieve continuous motion (and consequently totally dispenses of carries) and at the same time maintains the readability of the result.¹²⁻¹⁵

Clocks come close to counters, in that they contain the stepwise motion of the hands, whose source is the escapement and oscillation of the pendulum. However, clocks count time, and usually nothing else. It is not that easy with a clock to find out how many seconds it has been working since it was rewound. This information may be inferred from the time given by the clock and other informations, but it is not directly readable on the clock. Some clockmakers have adapted clocks so that they could count something else. Wagner,^{16,17,pp.207,208} for instance, constructed a “pendulum counter,” which uses a ratchet connected to a pendulum moving with the oscillating mechanical piece.¹⁸

Modern Mechanical Digital Odometers

Many patents have been filed for counters in the 19th and 20th centuries. Some early digital counters had gears, but not really meshing gears. Each wheel had some kind of pin that could move the next one. Examples are Hart’s odometer (1867),¹⁹ where the counting mechanism was not considered an odometer, but an “odometer register.” or La Fountain’s counter for printing presses (1894, US patent 521,318). Some of these counters also were part of calculating machines, for instance the 3-place counter within Bouchet’s adding machine (1882, US patent 251,823).

If we fast forward to the 20th century, we can see that modern digital counters usually use auxiliary wheels for carries. These wheels sometimes are located within the digit wheels, as in Powell’s patent (1967; US patent 3,333,768).

Probably the most common type of counter uses a wheel with a slit, and an auxiliary pinion with two pairs of four teeth. This construction seems to go back at least to Alphonse Darras's 1896 patent^{20,21} (Figure 1²²) but a related construction was invented by Balzer in 1893 (US patent 489,703) and almost a copy of Darras's construction by Bassett, also in 1896 (US patent 567,288). A somewhat related but more complex scheme was invented by Wolfe in 1894 (US patent 526,884). Bouchet's patent (1882), mentioned above, also contains a primitive version of such a construction. Among the many other constructions that appeared at that time, mention should be made of Gould's counter (US patent 458,897 from 1891), which takes the unusual approach of having a mobile blade traverse all of the Figure wheels for the purpose of transmitting carries.

Darras's construction became standard and appears in a number of later patents (for instance Helgeby, US patent 1,798,941 from 1928, or Kleinbohl, US patent 3,935,996 from 1976) and it may have been rediscovered independently by Karl Meer in Germany in the 1930s. Meer obtained a US patent for his construction in 1941²³ (Figure 2), and does not appear to cite Darras.

The Darras and Meer constructions include a number of coaxial Figure wheels, each of which has 20 teeth on the right side (these teeth are not shown in Meer's Figure), and two teeth on the left side. The pinions have 8 teeth, but four of them are short and the other four are long. Such pinions sometimes are called "mutilated pinions."²⁴ In Figure 2,²⁵ the left rim of the digit wheel passes between two long pinion teeth and keeps the pinion still. When the digit wheel moves from 9 to 10, the first of the two isolated teeth then meets a short tooth of the pinion and forces it to turn.²⁶ This is possible because the next long tooth can enter the notch between the two isolated teeth and the pinion then completes its quarter turn. At the same time, the teeth on the left side of the pinion mesh with those on the right side of the next digit wheel, thereby forcing it to move by two teeth, hence a tenth of a turn, or one unit. This construction ensures that a wheel can be incremented only by one unit, and moreover it is reversible.³⁰

Coaxial Counters

Almost every digital counter contains wheels with the digits 0 to 9, sometimes repeated several times. These wheels often are laid out on parallel axes, so that with an adequate lid, only one digit from each wheel is visible. Such a construction entails rather spaced values, except if the values are written on concentric rings.

A much better layout is that using coaxial digit wheels, as in the modern counters by Darras and Meer. Such constructions may contain gears, but need not. Darras's counter has some gears, as had all ancient analog odometers.

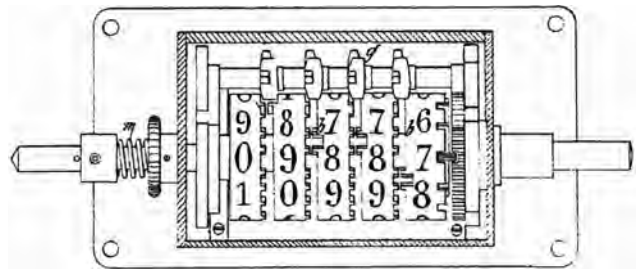


FIGURE 1. Excerpt of Darras' patent (1896).²²

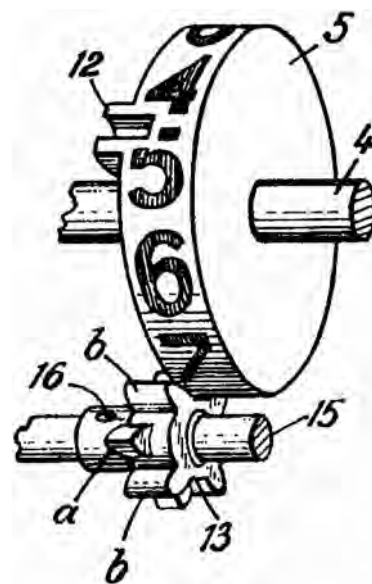


FIGURE 2. Figure of Meer's patent (1941).²⁵

Coaxial systems have advantages and drawbacks. The main drawback is that these systems are thicker, which may be a problem in some devices, such as watches. A major advantage is that in coaxial systems the digits can be laid out very near to each other. Another important advantage is the modularity. Given a common arbor, adding one digit does not require additional fixtures, and parts can be replaced easily. A 4-digit coaxial counter usually could be transformed easily in a 5-digit counter.

Coaxial systems usually are systems with intermittent motion. Not all parts turn at the same time. If this is the case, these systems usually had no (complete) gears, and they sometimes were advertised as "gearless."

In this article, we are focusing on the first gearless coaxial digital counters. We also are limiting ourselves to constructions without auxiliary wheels, where each unit is self-contained in a wheel, and little more. In other words,

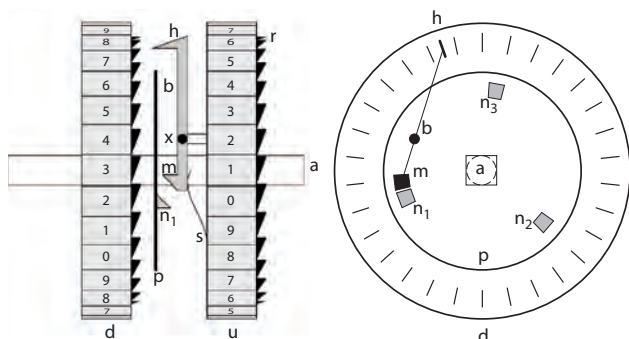


FIGURE 3. Péreire's carry mechanism, as reconstituted by the author. On the right, we see the wheel d seen from the right. The disk p also is shown, with three catches n_1 , n_2 , and n_3 . The bascule b is part of wheel u. h is a hook and m is an inclined plane. b rocks around the axis x, which is parallel to the side of u. This is just one construction, and different ones are possible following Péreire's description. We have omitted the Figures for subtraction, the openings for reading the Figures, and the notches for the stylus.

we are interested in the simplest possible counters, yet modular ones, and in these counters, we could say that carries are stripped to the bone. The wheels then both store the values and are ensuring that the carries are transferred. Some of the oldest calculating machines with some coaxial wheels were Stanhope's machines built in the 1770s, but these machines were not counters, and they had gears and auxiliary wheels.

The first machine of interest to us is Péreire's counter, described in 1751. In the 19th century, among many patents, for specific applications, we will consider the Schwilgué (1844) and Évrard (1846) patents as the first successors of Péreire's machine.³¹ These two counters are, in fact, currently the oldest known extant coaxial digital counters.

Of course, calculating machines with coaxial wheels, and often with auxiliary wheels, became widespread at the end of the 19th century, with the inventions of Baldwin (1873), Odhner (1878), and others. In these constructions, the display (total) is distinct from the engine (value to be added). In purely coaxial systems, the two functions (storing a value, and incrementing it) are merged together.

Péreire's Machine (1751)

Péreire's machine was described in 1751 in the *Journal des Sçavans*.^{32,pp.507-511} Jacob Rodrigues Péreire (1715-1780) was a French scientist who was a pioneer in the education of deafmutes.³³⁻³⁷ To help them to learn to calculate, he invented a simple machine, which also could be of use to the blind if some changes were made.³⁸ Contrary to later 19th century counters, Péreire's counter was

not meant to be operated by another machine, but it shared a number of features with later machines.

Péreire's machine actually is an ingenious device that takes care of carries. It is not a totally new machine in that it borrows ideas from Perrault's machine (*abaque rabdologique*) (ca. 1660),^{39,40,p.89} which had only rods side by side.⁴¹ Péreire's machine can be viewed as a circular version of Perrault's machine. It possibly is the first counter with coaxial wheels, something that already had been observed by Mehmke.^{42,p.959} Although the original machine has not survived, a reconstruction was attempted in 1877.⁴³ A more recent reconstruction was published in 2008 by Stephan Weiss,⁴⁴ and our Figure 3 shows another interpretation to the textual description published in 1751, restricted to the way the carries are transferred.

According to the description published in 1751⁴⁵ as well as its translation by Wolf,^{46,pp.655-657} Péreire's instrument consisted of several wooden wheels thread on an axle a. These wheels could turn independently, and their circumferences were divided into 30 parts, three times the Figures 0 to 9. Péreire actually also had written the Figures in opposite order, so that the machine could be used to decrement the values. Figure 3 shows two such wheels, u and d, but only with the positive numbering. Péreire had assigned two wheels to monetary units (*sols* and *deniers*), one to simple fractions ($1/2$, $1/3$, $1/4$, and so forth)⁴⁷ and then seven wheels to units, tens, hundreds, etc. Therefore, his machine had 10 wheels. The entire mechanism was enclosed in a small box approximately three inches long, and there were grooves over each wheel so that it could be turned with a needle. Moreover, over each wheel there were two apertures indicating the value of the wheel, either for additions or subtractions. As soon as one of the wheels had gone through 10 of its units, the next wheel was advanced by one unit. This was achieved by adding 30 teeth r on the circumference of the right side of each wheel, and on the other side he added a bascule b, or diametral lever, pivoting about its center x, having at one end a hook h, and at the other, an inclined plane m. Whenever the circumference of this wheel advanced by 10 units, the inclined plane m of the bascule met a catch n_i fixed to the plate p located between each pair of wheels; this catch forced that end into a hole in the thickness of the wheel; the hook h at the other end, thus, was made to project. It passed through an opening in the tin plate (in our reconstruction, we have made the plate shorter and h, therefore, extends beyond the plate, but it is possible to use a plate with openings, since the carries occur at fixed positions), took one of the teeth r on the next wheel and moved it forward by one unit. However, before it could move the wheel any further, the inclined plane m escaped from the catch n_i and the hook h withdrew to its normal place under the action of a spring,

leaving the neighboring wheel undisturbed until another 10 divisions had been traversed.

Thus, Péreire's machine was made of coaxial wheels and it was built in a very modular way, with no auxiliary wheels and no gears. It assumed, however, that the central axis a was carrying a number of fixed plates p . We do not know how many of these machines were built, but probably only a handful of them and only for the use of Péreire's institution.

One important problem in Péreire's construction is that the effort required for transmitting carries increases if there are several simultaneous carries, such as when going from 1999 to 2000. This, thus, makes it impossible to have too many wheels, and to use such a carrying mechanism for additions on numbers having more than a few digits. A more efficient construction for transmitting carries was devised by Roth in 1840, although his counters did not have coaxial wheels.⁴⁹ However, Péreire's machine also has some advantages, for instance that it can be used as an adding machine, since any wheel can be incremented, not only the first (as in modern counters).

Nevertheless, Péreire's mechanism is very simple, and what is particularly interesting is that almost the same construction reappeared a century later, in the patents of Schwilgué and Évrard.

Schwilgué's Counter (1844)

Schwilgué (1776–1856) above all is known for building the third astronomical clock (1838–1843) of the Strasbourg cathedral, but he was, in fact, a clockmaker and engineer.⁵¹ He began as a clockmaker's apprentice, then worked his way to weights and measures controller, and to professor of mathematics. In the 1820s, he worked on improving scales and moved to Strasbourg in 1827. He was interested particularly in tower clocks and he constructed approximately 500 of them, many still in existence.

The region surrounding Strasbourg, Alsace, was a very industrial one and there already had been other counters for machines, for instance that of Saladin.⁵² So, it is not surprising that on Christmas eve 1844, Schwilgué and his son, Charles, requested a 15-year patent for a mechanical counter.^{55,56} On the same day they also submitted a patent for a key-driven machine,⁵⁹ which was described in an earlier article,⁶⁰ and which turns out to be the currently oldest known key driven adding machine.

Schwilgué's counter is housed in a small box, which can be closed with a key, and has a glass opening at the top (Figure 4). The similarity to Péreire's machine is striking, but this certainly is only a coincidence. In Schwilgué's counter, there usually are four or five 10-faced digit wheels, which are, in fact, similar to the digit wheels used in Schwilgué's

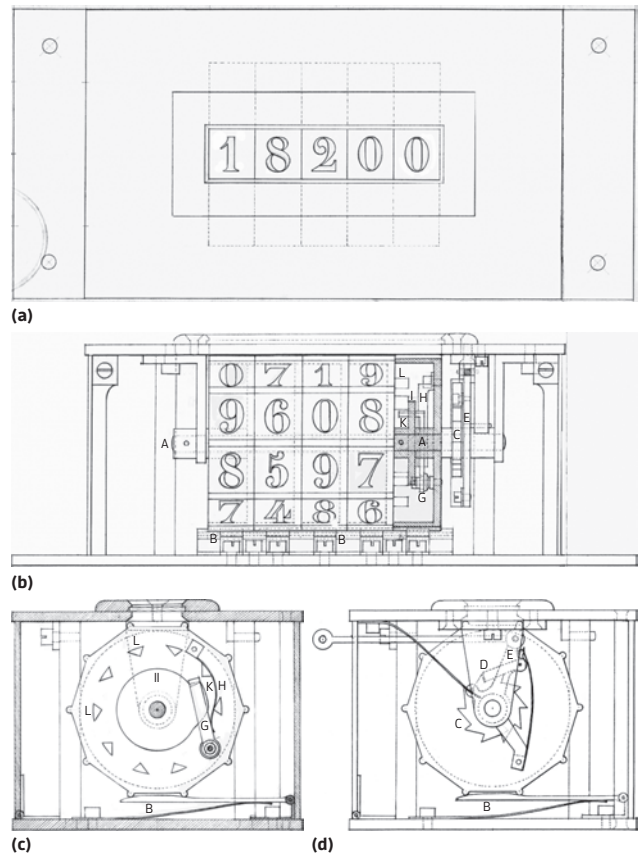


FIGURE 4. (a) Schwilgué's counter from the outside. (b) Front view. (c) Side view immediately after carrying. (d) Detail of the ratchet wheel and the lever operating the counter. (patent Figures, Institut National de la Propriété Industrielle)

specialized adding machine.⁶¹ These wheels can turn freely on a fixed arbor, but they are kept in place by flat springs. Between two adjacent wheels there is a fixed cam, which has the same function as Péreire's plate, p .

Each wheel contains on its left side a lever, and that lever is raised when meeting the fixed cam. That, in turn, forces the lever to advance the next wheel. The wheels are kept in place by springs, and this is sufficient to prevent them from overtripping.

The cams are fixed to the arbor by pins, so that they are maintained in precise positions, and the arbor itself is fixed to its support by pins, so that the entire arbor cannot rotate.

The input motion is a back-and-forth motion acting on a lever, itself acting on a ratchet wheel attached to the first digit wheel. This assumes that a rotary motion or another back-and-forth motion of a machine, for instance a piston, be transformed into an input adequate for the counter, but this is not difficult to achieve. The counter does not

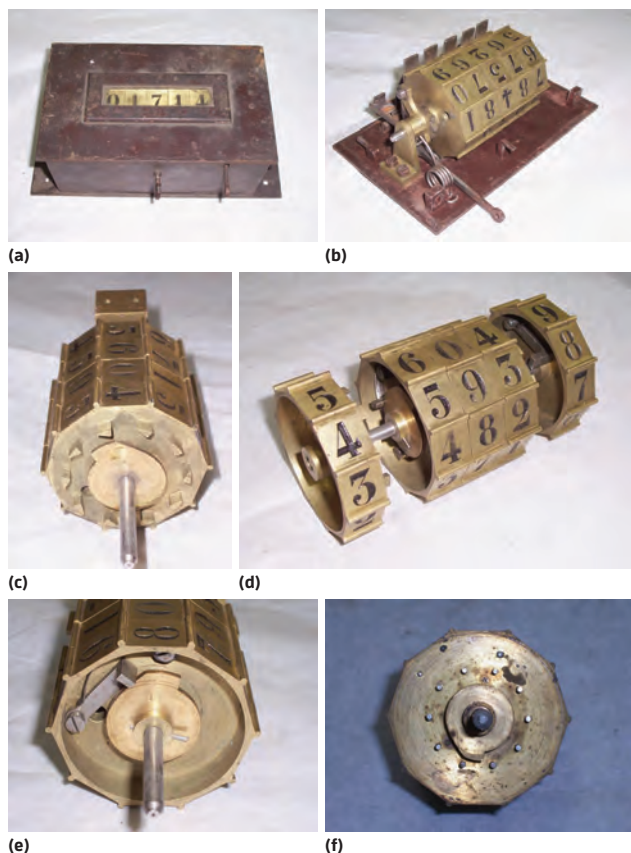


FIGURE 5. Schwilgué's counter: (a) outside view, (b) inside. (c) The cam and the 10 catches, as depicted in the patent. (d) The modular assembly of five wheels. (e) The carry lever and its cam. (f) An alternative construction with pins. (Photographs by the author, courtesy of the Strasbourg museums.)

overtrip, provided that the friction is sufficient. In a 2-page brochure describing his counter,⁶² Schwilgué states that his counter can count up to 250 strokes per minute, hence 4 per second. Schwilgué's counter also could, if needed, have any of its digit wheels incremented, not only the first.

Schwilgué's counters, of course, were sold primarily to factories. They have been declined in several variants. First, the counters did not always have the same number of digits. The known counters had 4 or 5 digits. However, when we opened some of the counters, we realized that there also were variant constructions. Some of the counters followed the patent exactly (Figure 5). It seems that Schwilgué also provided an iron version, cheaper than the brass version, but whether any were sold is not known.⁶³

We currently know of only five such counters. Four of them are stored at the Strasbourg historical museum and are undated. These counters were rediscovered in 2009,

after having been in a cellar for many years. We were able to examine them shortly after their rediscovery.⁶⁷ Other Schwilgué counters must have existed, but many of them probably have been scrapped with the machines to which they were attached. Some of these counters probably did not carry the name Schwilgué. We also do not know whether the counters sold by Ungerer (Schwilgué's successors after 1858) carried an Ungerer plate.

One of Schwilgué's counters is attached to a clock, so that it became possible to measure the time taken for counting a number of revolutions. This clock-counter is undated, but may have been made around 1844. It is interesting to compare Schwilgué's counter to the one invented by Paul Garnier (French patent 15915, 1843), who also was a clock-maker⁶⁹ (see also ref. 70). Garnier's counter probably is slightly older than Schwilgué's counter. It has six (non-coaxial) digit wheels, as well as a clockwork mechanism. Schwilgué's and Garnier's clocks are spring driven and use a balance wheel. Garnier's clockwork is intermittent and will work only when the counter is advancing. This is done in a very subtle way in that the clockwork stops only after a number of seconds after the counter comes to rest, and this delay can be tuned. If, before the end of this delay, there again is a counter incrementation, the clock goes on as if it were not about to stop. Therefore, the clock does, indeed, measure the time the machine has been working. In Schwilgué's clock-counter, the clockwork is never stopped, but it is linked to a second dial. The connection between the two dials depends on the incrementation of the counter. When it is incremented, the gears of the second dial are advanced by the main clockwork, so that it is possible to see how long a machine has been working. This clock was described by Alfred Ungerer in 1932⁷¹ (who mistakenly dated it to 1835), but unfortunately the clock-counter is now missing the second gear-work and dial. Schwilgué's construction is much simpler than Garnier's construction, but works too.

Of course, Schwilgué's counter exhibits the same problem as Péreire's, namely that it cannot work with too many digits, since the carries may occur simultaneously. It should be observed that Schwilgué used sequenced carries in his large adding machine,⁷² which was developed at approximately the same time as this counter.

Évrard's Counter (1846)

Maximilien Évrard (1821–1905) was a French engineer from the St-Étienne mining school. He worked in several mines, in particular in Algeria, made various improvements to the processing of coal, and directed the mines of Chazotte, near St-Étienne, from 1852 until 1872.^{73–75}

In 1846, Évrard patented a counter,^{76,77} which bears many similarities with those of Péreire and Schwilgué,⁷⁸

although this counter certainly also was developed independently. Évrard's patent was for a *compteur perpétuel décimal sans engrenages*, that is a *gearless perpetual digital counter*. Évrard named his counter perpetual, because with more digits it could be left operating for years.

Évrard actually provided two different constructions. In the first version of his counter, each wheel was surrounded by ten special teeth, and one of them would be used to transfer a carry to the next wheel, using an external lever.⁸⁰ In Évrard's second version, these teeth have been put inside the wheels and a cam was added (Figure 6), resulting in a mechanism very similar to that of Schwilgué. Évrard's counter also could be used as an adding machine, like those of Péreire and Schwilgué.

In fact, in 1848, Évrard observed that there were many counters in Alsace,⁸¹ and he may have had Schwilgué's counter or other counters in mind. His idea then was to replace the measure of time worked, by a precise measure of rotations, not only the time it took to construct something, but the actual production.

The *Musée des arts et métiers* in Paris holds one of Évrard's counters (inv. 3422), but we were not able to obtain photographs for publication. This copy corresponds to Évrard's second type.

The comparison of three early counters by Péreire, Schwilgué, and Évrard revealed their close relationship, and they can be viewed as the legacy of Perrault's *abaque*. These counters represent one strand of coaxial counters in which the wheels could turn independently, and are gearless, modular, and, of course, digital.

None of these counters can go backwards, but there was no need for it. Often, only the difference between two values was of interest, but if really needed, any value can be reached by moving the counters forwards. For instance, to reach 0, one merely has to advance the units to 0, then the tens to 0, and so on. This, of course, will introduce carries, but each carry will only modify the digits to its left.

Coaxial displays quickly became ubiquitous. However, with some minor exceptions,⁸² they did not keep the initial features designed by Péreire, Schwilgué, or others. These counters all had their own problems: Péreire's *bascules* and springs exposed it to problems. Schwilgué's counter had springs inside, which also might have failed. Évrard's first mechanism was even more complex, but his second one was similar to Schwilgué's. Of course, none of these counters was reversible. You could not turn them backwards without hitting limits and damaging the counters.

In contrast, modern counters had no springs at all, only auxiliary wheels. Although a modern counter cannot

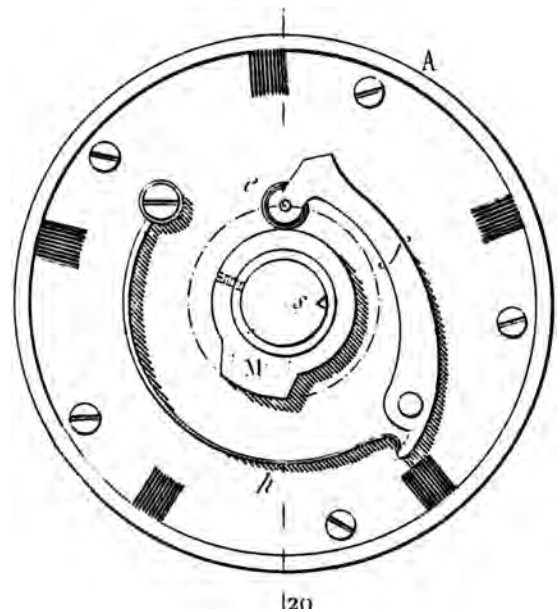


FIGURE 6. Detail of Évrard counter (compare with Figure 5e).⁵⁴

be set to a random value, it can be turned backwards. Some counters (such as the one patented by Darras) have a means to unmesh the pinions, thereby allowing for random values, or for resetting the counter.

No original copy of Péreire's machine is known. This seems to make Schwilgué's counter (1844) the currently oldest known gearless coaxial digital counter, invented slightly before Évrard's counter (1846), which also survives. ♪

Acknowledgments

It is a pleasure to thank Valéry Monnier and Cyrille Foasso for information on the counters invented by Darras and Évrard.

References and Notes

1. J. Beckmann, *A History of Inventions and Discoveries*, vol. 1, London, 1817 [translated from the German edition 1782–1805 by W. Johnston].
2. A.J.M. de Label de Lambel, "Rapport fait par M. le comte Lambel, au nom du Comité des arts mécaniques, sur un instrument nommé célérimètre, inventé par M. Vaussin-Chardanne, à Villeneuve-St-Georges," *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, vol. 38, pp. 9–11, plate 751, 1839.
3. A.J.M. de Label de Lambel. Bericht des Hrn. Vaussin-Chardanne in Villeneuve St. Georges erfundenen Celerimeter," *Polytechnisches J.*, vol. 72, pp. 429–431, plate 7, 1839.

4. "Odomètre," *Histoire de l'Académie royale des sciences*, année 1742, pp. 143–146, 1745.
5. "Odomètre inventé par M. l'abbé Outhier," *Machines et inventions approuvées par l'Académie royale des sciences, etc.*, vol. 7, pp. 175–182, plate, Antoine Boudet, 1777 [description originally published in 1742].
6. J.A. Borgnis, *Traité complet de mécanique appliquée aux arts*, Bachelier, 1820.
7. An example is the counter invented by Bally in 1870 (French patent 88550).
8. S. Clegg, *A Practical Treatise on the Manufacture and Distribution of Coal-Gas*, 5th ed., D. Van Nostrand, 1868.
9. T. Edge, "Patent for Certain Improvements in Apparatus for Measuring Gas, Water, and Other Fluids," *London J. Arts, Sciences, and Manufactures, and Repertory of Patent Inventions*, vol. 23, pp. 237–247, plate X, 1843.
10. "Compteur," *Dictionnaire technologique, ou nouveau dictionnaire universel des arts et métiers, etc.*, vol. 5, pp. 473–485, Thomine et Fortic, 1824.
11. M.R. Williams, *A History of Computing Technology*, IEEE Computer Society Press, 1997.
12. M. d'Ocagne, *Vue d'ensemble sur les machines à calculer*, Gauthier-Villars et Cie, 1922.
13. E. Martin, *The Calculating Machines (Die Rechenmaschinen): Their History and Development*, MIT Press, 1992 [translation of the original 1925 German edition].
14. A. Guyot, *La machine à calculer continue de Tchebychev et le reporteur différentiel*, 2014.
15. D. Roegel, *Chebyshev's Continuous Adding Machine*, tech. report, INRIA (Nancy), 2015; <https://hal.inria.fr/hal-01198445>.
16. A. Morin, *Conservatoire impérial des arts et métiers: Catalogue des collections*, 3rd ed., Neuilly, 1859.
17. A. Morin, *Leçons de mécanique pratique, Ire partie*, L. Mathias, 1846.
18. A. Morin, *Notions géométriques sur les mouvements et leurs transformations ou éléments de cinématique*, L. Hachette et Cie, 1857.
19. H.F. Hart, *Register of Odometers*, 1867 [US patent 72033].
20. A. Darras, *Système de compteur perfectionné pour la mesure des mouvements relatifs ou alternatifs*, 1896 [French patent 251,219].
21. Darras filed several patents for counters, in particular one (non-coaxial) for a loom in 1894.
22. Darras, *Système de compteur perfectionné pour la mesure des mouvements relatifs ou alternatifs*.
23. K. Meer, *Counter Mechanism*, 1941 [US patent 2,253,721].
24. J.H. Bickford, *Mechanisms for Intermittent Motion*, Industrial Press, 1972.
25. Meer, *Counter Mechanism*.
26. This intermittent motion is similar to that of Geneva wheels.^{27,28} In addition, there are counters that replace the first pinion by a genuine Geneva wheel to reduce impacts,^{29,p.132} or even counters that use a Geneva wheel at every level (for instance, Winn & Spalding's US patent 662,899 from 1900 or Grip's US patent 2,503,332 from 1950).
27. Bickford, *Mechanisms for Intermittent Motion*.
28. J. Martin, *Mécanismes à mouvements intermittents*, Dunod, 1974.
29. Bickford, *Mechanisms for Intermittent Motion*.
30. Interestingly, the same construction can be made flat, with parallel axes, and it already may have been used in some early (non-coaxial) counters.
31. It, of course, is possible that earlier machines were built according the same scheme. Perhaps the gearless counter shown by Laignel at the Société d'Encouragement in 1840 (*Bulletin*, 1840, p. 493) is one of these, but unfortunately, we lack details.
32. "Description de la machine arithmétique de Péreire," *Le journal des sçavans*, pp. 507–511, 1751 [contains Jean-Jacques Dortous de Mairan and Antoine Deparcieux's report on the machine].
33. E. Seguin, *Jacob-Rodrigues Pereire, etc.: Notice sur sa vie et ses travaux, et analyse raisonnée de sa méthode*, J.-B. Baillière, 1847.
34. A. Hlawatsch, "Jakob Rodrigo Pereire," *Sippurim, eine Sammlung jüdischer Volkssagen, Erzählungen, Mythen, Chroniken, Denkwürdigkeiten und Biographien berühmter Juden aller Jahrhunderte, insbesondere des Mittelalters*, W. Pascheles, ed., vol. 2, pp. 162–164, Wolf Pascheles, 1853.
35. E. Carmoly, "Jacob-Rodrigues Péreire," *Archives israélites*, vol. 23, no. 6, pp. 332–342, 1862.
36. E. La Rochelle, *Jacob Rodrigues Péreire, premier instituteur des sourds-muets en France: sa vie et ses travaux*, Paul Dupont, 1882.
37. J.-L. Séverin Foisset, "Pereire (Jacob-Rodrigue)," *Biographie universelle, ancienne et moderne*, L.G. Michaud, ed., vol. 33, pp. 348–350, L.G. Michaud, 1823.
38. J.R. Pereire, "Lettre A l'Auteur du Mercure," *Mercure de France*, pp. 157–161, 1751.
39. J.P. Bischoff, *Versuch einer Geschichte der Rechenmaschine, Ansbach 1804*, S. Weiss, ed., Systema Verlag, 1990.
40. J. Marguin, *Histoire des instruments et machines à calculer— Trois siècles de mécanique pensante*, 1642–1942, Hermann, 1994.
41. There also have been later simplifications of Perrault's machine, for instance by Billiard (French patent 6703, 1847).

42. R. Mehmke, "Numerisches Rechnen," *Enzyklopädie der mathematischen Wissenschaften mit Einschluss ihrer Anwendungen*, vol. 1–2, pp. 938–1079, B.G. Teubner, 1900–1904. (Mehmke's chapter was published in 1902. A French translation by Maurice d'Ocagne was published in the *Encyclopédie des sciences mathématiques pures et appliquées*, tome 1, vol. 4, 1906–1911, fascicules 2 (1908) and 3 (1909), pp. 196–452, under the title "Calculs numériques.")
43. "Note on a Reconstruction of Péreire's Machine," *Mémoires et compte rendu des travaux de la Société des ingénieurs civils*, vol. 30, p. 388, 1877.
44. S. Weiss, *Notizen zur Rekonstruktion der Arithmetischen Maschine von Pereire 1751*, 2008.
45. "Description de la machine arithmétique de Péreire," *Le journal des sçavans*.
46. A. Wolf, *A History of Science, Technology, and Philosophy in the Eighteenth Century*, 2nd ed., George Allen & Unwin Ltd, 1952.
47. If the wheel devoted to fractions had 30 teeth, it is not clear how Péreire managed to manipulate fractions such as $1/4$. Perhaps that wheel had, in fact, only 24 teeth, or rather $3 \times 24 = 72$ teeth. This then would work with the examples given in the *Journal des Sçavans*. For the monetary units, we also assume that one wheel had 36 teeth and the other 60. Some of these observations had been made before by Weiss.⁴⁸
48. Weiss, *Notizen zur Rekonstruktion der Arithmetischen Maschine von Pereire 1751*.
49. In Roth's construction,⁵⁰ the rotation of a wheel adds to the tension of a spring, so that the last incrementation does not require more effort than the previous ones. Moreover, the carries are slightly offset, so that they are cascaded, and do not exactly occur simultaneously. Such an idea also was used on some coaxial calculating machines, for instance that of Fossa-Mancini (British patent 4489 from 1899).
50. D. Roth, *Brevet 11492 pour une machine à calculer*, Institut National de la Propriété Industrielle, 1842.
51. C. Schwilgué, *Notice sur la vie, les travaux et les ouvrages de mon père J. B. Schwilgué, etc.*, G. Silbermann, 1857.
52. Eugène Saladin invented several interesting counters, using a variety of unusual gears, see Dollfus's report⁵³ (and also ref. 54).
53. É. Dollfus, "Rapport sur un compteur à cadran, présenté à la Société, par M. B.-E. Saladin," *Bulletin de la Société industrielle de Mulhouse*, vol. 14, no. 70, pp. 501–514, plate 130, 1841.
54. M. Évrard, "Compteur décimal sans engrenages, pour enregistrer le nombre de révolutions des machines, et appelé compteur perpétuel," *Publication industrielle des machines, outils et appareils les plus perfectionnés et les plus récents employés dans les différentes branches de l'industrie française et étrangère*, J. Armengaud, ed., vol. 6, pp. 262–269, plate 20, 1848 [followed on pp. 269–272 by descriptions of the Garnier and Saladin counters; 2nd ed. in 1856].
55. J.-B. Schwilgué and C. Schwilgué, *Brevet 624 pour un compteur mécanique*, Institut National de la Propriété Industrielle, 1844.
56. A summary of the patent also was published in 1850⁵⁷ (p. 131) and 1851.⁵⁸ A more detailed description of Schwilgué's counter, with numerous pictures, Figures, and the identification of all known copies, is given in a separate report.
57. *Description des machines et procédés pour lesquels des brevets d'invention ont été pris sous le régime de la loi du 5 juillet 1844*, vol. 2, Imprimerie nationale, 1850.
58. J.-B. Schwilgué and C. Schwilgué, "Instrument servant à constater le nombre de révolutions des moteurs et machines," *Le génie industriel*, vol. 1, pp. 191–192, plate 12, 1851.
59. J.-B. Schwilgué and C. Schwilgué, *Brevet 623 pour un additionneur mécanique*, Institut National de la Propriété Industrielle, 1844.
60. D. Roegel, "An Early (1844) Key-Driven Adding Machine," *IEEE Annals of the History of Computing*, vol. 30, no. 1, pp. 59–65, 2008. (An update was published in vol. 30, no. 3, p. 3.)
61. D. Roegel, "A Mechanical Calculator for Arithmetic Sequences (1844–1852): Part 1, Historical Context and Structure," *IEEE Annals of the History of Computing*, vol. 37, no. 4, pp. 90–96, 2015; D. Roegel, "A Mechanical Calculator for Arithmetic Sequences (1844–1852): Part 2, Working Details," *IEEE Annals of the History of Computing*, vol. 38, no. 1, pp. 80–88, 2016.
62. Archives Schwilgué, Archives départementales du Bas-Rhin, Strasbourg
63. In the 1846 guide of Schwilgué's clocks,⁶⁴ the counters are sold at 45 or 60 Francs, depending on the version. This should be compared to the price of the large adding machine offered for 300 to 400 Francs and to the small adding machine, sold at 75 or 85 Francs. The counters still were sold at the same price in 1847,⁶⁵ and at least until 1878. In the 1846 German guide,⁶⁶ they were priced at 22 fl or 30 fl (florentine Gulden, in use in South Germany), and in 1882 at 36 and 48 Marks.
64. J.-B. Schwilgué and C. Schwilgué, *Des horloges du système Schwilgué, pour églises, chemins de fer, établissements publics et particuliers*, Dannbach, 1846,

65. J.-B. Schwilgué and C. Schwilgué. *Des horloges du système Schwilgué, pour églises, chemins de fer, établissements publics et particuliers*, Dannbach, 1847.
66. J.-B. Schwilgué and C. Schwilgué. *Übersicht der Schwilgue'schen Thurmuhren auf Kirchen, Eisenbahnen und Fabriken, etc.*, L. Dannbach, 1846.
67. Three of the counters (C_1^5 , C_2^5 , C_3^5) are to 5 places, and the fourth (C_4^4) is to 4 places. Two of these counters have pins instead of the wedges shown in the patent Figures. Other than that, there are only minor differences. One of the counters (C_3^5) is attached to a clock. The Strasbourg historical museum also keeps a brief note about a counter that was sent to a customer in 1857. A fifth counter, also to 5 places, and dated 1847, is located in a private collection. Older pictures of several of these counters are found in the Schwilgué archives, and also in the archives of the *Musée des arts et métiers* in Paris, probably originating from the 1920 exhibition.⁶⁸
68. E. Lemaire, "Exposition publique de machines à calculer anciennes et modernes," *Bulletin de la Société d'encouragement pour l'industrie nationale*, vol. 132, pp. 608–644, 1920.
69. C. Combes, "Rapport fait par M. Combes, au nom du comité des arts mécaniques, sur un compteur à horloge présenté par M. Paul Garnier, horloger du roi, rue Taitbout, 6 et 8," *Bulletin de la société d'encouragement pour l'industrie nationale*, pp. 306–311, plate 930, 1844.
70. Évrard, "Compteur décimal sans engrenages, pour enregistrer le nombre de révolutions des machines, et appelé compteur perpétuel."
71. A. Ungerer, "J.-B. Schwilgué, sa vie, ses travaux, son œuvre," *La France horlogère*, pp. 28–29, 1932.
72. Roegel, "A Mechanical Calculator for Arithmetic Sequences (1844–1852): Part 1, Historical Context and Structure."
73. J. Biron, "Maximilien Évrard," *Annales de la société d'agriculture, industrie, sciences, arts et belles-lettres du département de la Loire*, vol. 25 (2nd series), pp. 64–71, 1905.
74. St. Le Tourneur, "Évrard, Maximilien," *Dictionnaire de biographie française*, Roman d'Amat, ed., vol. 13, p. 306, Letouzey et Ané, 1975.
75. G.-M. Thermeau and R. Estier, *Les patrons du Second Empire: Loire Saint-Étienne*. Cénomane, 2010.
76. M. Évrard, *Brevet 2968 pour un compteur perpétuel décimal sans engrenage*, Institut National de la Propriété Industrielle, 1846.
77. Évrard, "Compteur décimal sans engrenages, pour enregistrer le nombre de révolutions des machines, et appelé compteur perpétuel."
78. The description of Schwilgué's counter in 1851, by the same publisher, mentions Évrard's counter.⁷⁹
79. Schwilgué and Schwilgué, "Instrument servant à constater le nombre de révolutions des moteurs et machines."
80. A somewhat similar construction was used by Hawkins in 1880 (US patent 227,975).
81. Évrard, "Compteur décimal sans engrenages, pour enregistrer le nombre de révolutions des machines, et appelé compteur perpétuel."
82. Some of the exceptions are Castle's "calculator" (US patent 21941 from 1858), which is a key-driven adding machine with a counter register operating like those described here, Coffin's counter patented in 1890 (US patent 423,374), Miehle's one patented in 1897 (US patent 593,773) and Rinsche's one patented in 1903 (US patent 744,407).

Denis Roegel is associate professor of computer science at the University of Lorraine, Nancy, France, as well as a member of the LORIA research laboratory. He is co-author of the LATEX Graphics Companion (2007) and the creator and maintainer of the LOCOMAT site on mathematical and astronomical tables (locomat.loria.fr). From 2006 to 2012, he was part of the scientific committee supervising Schwilgué's astronomical clock. He can be reached at the following address: Denis Roegel, LORIA, BP 239, 54506 Vandœuvre-lès-Nancy cedex, France, roegel@loria.fr.

myCS

Read your subscriptions through
the myCS publications portal at
<http://mycs.computer.org>