METHOD AND APPARATUS FOR DETECTING AN ELECTRIC CODE

This publication discloses an apparatus and method for reading an electronic code. The apparatus comprises means for generating an alternating-electricity signal (2), electrodes (4, 5) connected to the alternating-electricity signal generating means (2) for bringing the alternating-electricity signal to the code (1) being read, and means for measuring the current travelling through the electrodes (4, 5) or the voltage between them. According to the invention, the electrodes (4, 5) are open, without an insulator layer, and the means for generating an alternating-electricity signal (2) are such that they generate an alternating-electricity signal of at least 1 MHz.
Method and Apparatus for Detecting an Electronic Code

The present invention relates to an apparatus, according to the preamble of Claim 1, for detecting an electronic code.

The invention also relates to a method for detecting a code.

According to the prior art, in freight transport, both optically readable barcodes and remotely readable RFID identifiers are used.

Barcodes have the advantage of a standardized technology, but this technology requires a visible mark and also a reading technique that takes place at least within the range of vision, which limits the use of the application. The visible mark makes the technology susceptible to abuse.

RFID technology has many advantages over the aforementioned barcode technology, among other things, remote readability and the possibility to hide the code entirely in a product, which can prevent the counterfeiting of codes. However, the identifiers used in the technology are clearly more expensive than barcode technology.

US patent 5 818 019 discloses a solution, in which a reader is used to measure capacitively control-resistance marks in lottery tickets. The machine permits measurement to take place contactlessly at close distance, hi the measurement, the order of magnitude of several (for example, 8) resistances is determined by simultaneous measurement, in such a way that the resistance value of each resistance should be within specific predefined limits. This is thus a question of evaluating the electrical correctness of a lottery ticket using a 'digital technique'. If all the resistances are within the predefined limits, the ticket is accepted, and even a single deviance results in rejection.

The invention is intended to eliminate the defects of the state of the art disclosed above and for this purpose create an entirely new type of method and apparatus for reading an electronic code.
The invention is based on using a sufficiently high measurement frequency and using, as an electrode, an electrode or electrode group, in which there is no insulated tip.

According to one preferred embodiment of the invention, an electrode matrix are used, by means of which a higher resolution is achieved.

According to a second preferred embodiment of the invention, multiplexing is used in connection with an electrode matrix, in order to implement measurement by time or frequency interval.

More specifically, the apparatus according to the invention is characterized by what is stated in the characterizing portion of Claim 1.

For its part, the method according to the invention is characterized by what is stated in the characterizing portion of Claim 22.

Considerable advantages are gained with the aid of the invention.

With the aid of the invention, it is possible to avoid the difficult, and thus expensive electrical insulation of the electrodes. The electrodes can be permitted to wear, so that their properties do not change in use, because there is no wearing, precisely dimensioned insulator layer.

By means of matrix electrodes, measurement accuracy and reliability can be increased.

The other embodiments of the invention offer a clear advantage over a barcode, thanks to their invisibility. By means of an invisible code, counterfeit products, for instance, can be detected easily and cost-effectively.

In practice, the applications of the invention are similar to those of RFID technology and barcode technology. The code according to the invention can be either visible, or hidden under an opaque protective membrane. The code according to the invention can be used, for example, in access-surveillance applications, for coding product information, for
authentication, and for determining the origin of a product.

Compared to electrically readable RFID marks, the invention, for its part, offers a considerable cost advantage, because the code can be manufactured using printing technology.

Thanks to the optimization of the electrical properties of the mark, the measurement electronics can be manufactured from cheaper components.

In the following, the invention is examined with the aid of examples and with reference to the accompanying drawings.

Figure 1 shows one measuring device according to the invention.

Figure 2 shows a measurement subject according to the invention.

Figure 3a shows the equivalent circuit between the electrodes of a measuring device according to the invention, when there is no code to be read between the electrodes.

Figure 3b shows the equivalent circuit between the electrodes of a measuring device according to the invention, when there is a code to be read between the electrodes.

Figure 4 shows graphically, from the point of view of a measuring device according to the invention, the behaviour of the real part and imaginary part of a mark being read, as the code resistance increases.

Figure 5 shows graphically the first measurement results of a measuring device according to the invention after angle correction, in which the real part is the lower curve and the imaginary part the upper curve.

Figure 6 shows the real part of the admittance after angle correction.

Figure 7 shows the measurement results of a poor-quality code read by a measuring
device according to the invention.

Figure 8 shows the measurement results of a code read by a measuring device according to the invention, divided into an imaginary and a real part.

Figure 9a shows a top view of one circuit solution according to the invention.

Figure 9b shows a front view of the solution of Figure 9a.

Figure 9c shows a top view of an alternative circuit solution.

Figure 9d shows a front view of the circuit solution according to Figure 9c.

Figures 10a - 10d show alternative electrode structures according to the invention.

Figures 11a and lib show two alternative electronic circuits for the electrodes according to Figures 10a - 10d.

Figures 12a - 12d shows four ways according to the invention of using the electrode structures according, for example, to Figures 10a - 10d.

Figure 1 shows a measuring device 1, in which two energized input electrodes 4, fed by an oscillator 2, activate a current, which travels through the surface being measured and a conductive structure possibly in it. In the arrangement according to the figure, the central measurement electrode 5 is used to measure the signal. The capacitance (CMOS or JFET) of the wiring and amplifier 6 are generally large enough for the impedance of the reading electrode 5 to represent a capacitive short circuit. If this is not so, current feedback can be arranged in the amplifier 6, which will make the amplifier's input very low impedance. The signal is detected by using phase-sensitive detection 7, which is based on the signal being mixed down in phase with the alternating electricity connected to the subject and with the 90-degree phase-shifted signal. If the measurement is not differential, the capacitive connection between the conductors is cancelled with an antiphase signal, in order to balance the bridge. The circuit according to the arrangement
of the figure measures the imaginary 9 and real 8 part of the surface's admittance.

Figure 2 illustrates a situation, in which conductive (opaque) codes 11 are formed on top of a substrate 10. The substrate 10 can be paper, cardboard, plastic, or some other corresponding, typically non-conductive, surface. In the figure, coding is performed in such a way that the width of the code 11 is constant, but the distance between the codes is modulated. Thus, in the code there are short gaps 12 and long gaps 13 between the conductive structures 11. Coding can also be arranged by varying the length or conductivity of the conductive gap, or by combinations of these alternatives. In some situations, there is a thin plastic film or other insulating layer (e.g., ink) on top of the code 11, which reduces the capacitive connection with the subject.

If the code according to Figure 2 is wiped with an arrangement according to Figure 1, the admittance varies in principle between two values. The electrical circuit of Figure 3a depicts a situation, in which the subject being measured is pure paper, and Figure 3b depicts a corresponding situation, in which there is an electrically conductive layer on top of the substrate 10. Because the field is divided, in a precise model we must depict the situation using several capacitors and resistors. If there are several conductive structures in the surface, which are wiped over, we create admittance modulation. In this case, when measuring using a single frequency, the impedance measurement produces an imaginary and a real part of the subject's admittance. In terms of the measurement, the essential factor is what the fluctuation of the imaginary and real parts of the admittance is, compared to a situation, in which the code alters both the real and the imaginary part. The central idea of the present invention is how to make the measurement, in such a way that we can maximize the signal-noise ratio of the measurement.

If we assume that the noise of the electrical resistance of the subject is not substantial, in terms of the electronics we seek to maximize the current of the real or imaginary part. This is achieved by maximizing the capacitive connection to the subject, by making wide electrodes and a wide code, as well as by minimizing the distance of the code from the measuring electrodes. However, at high frequencies, it is often the subject's noise and not the noise of the electronics that determines the signal-noise ratio. Noise often
arises from the 'hunting' and tilting of the reading device, as well as from the roughness of the paper (subject). Because most substrates are not conductive, the problems mainly cause noise only in the imaginary part of the admittance. Though the surface is to some extent lossy, the noise of the real part will always remain less than the noise of the imaginary part. Noise can also arise on top of the code. If the code is highly conductive, but the ink remains 'porridgy' due to, for instance, the roughness of the paper, the problem will arise that on top of the code both the imaginary part and the real part are noisy. The real part can also remain very small, because the electric current travels from the input electrode to the measuring electrode only over highly conductive bridges.

Let us first examine the matter somewhat mathematically. Let us also assume a simple equivalent circuit for the subject, in which the series connection of the capacitor and the resistor depict the impedance in a situation with the reading head on top of the code. Outside the code, the subject is nearly completely lossless, so that it can be depicted using only a capacitor. The current received by the electronics can be given by the equation

\[ I = U \omega C \frac{r + i}{r^2 + 1}, \text{ in which } r = \omega CR \]  

First, it will be noted that the current can be maximized by using the highest possible frequency and seeking to measure the conductive code from as close as possible - by creating a large capacitance.

Figure 4 shows graphically with the aid of a curve 40 the behaviour of the real part and imaginary part of the admittance when the resistance increases. The figure is a standardized presentation, in which the measurement distance is constant, i.e. the magnitude of the capacitance is constant. In addition, an ellipse 43 is drawn in the image, which depicts the admittance without a code. It will be noted that the modulation of the real part maximizes when \( r = 1 \) at point 44, at which the imaginary part and real part of the measured admittance are equal in magnitude, whereby the real and imaginary parts of the measured impedance will naturally also be equal in magnitude. An imagined
situation (the black ellipse 42) is also drawn in the figure, in which a high-quality conductive surface is measured. The circle 41 depicts a situation, in which a 'holey' code is measured, whereby the variations of both the real part and the imaginary part are of equal magnitude. When using an insulating substrate material, the value of the real part and its fluctuations will be small, whereby the distance and conductivity of the ink are best selected in such a way that \( r = 1 \) and thus we maximize the signal-noise ratio of the real part of the admittance. If the resistance increases to infinity, the curve approaches the ellipse 43.

The method is based centrally on separating the real part and imaginary part of the admittance from each other. At high frequencies and particularly when using a square wave, there is no accurate information on the so-called angle error. With a square wave, which contains high harmonics, the whole concept of a real part and an imaginary part is, in a way, incorrect. According to one embodiment of the invention, what is essential is that the following angle-correction equations are used on the measured real and imaginary parts

\[
\begin{align*}
\text{Re} \{ Y_u \} &= \text{Re} \{ F \} \cos \alpha + \text{Im} \{ y \} \sin \alpha \\
\text{Im} \{ Y_M \} &= -\text{Re} \{ F \} \sin \alpha + \text{Im} \{ y \} \cos \alpha
\end{align*}
\]

The subindex \( u \) relates to the angle-corrected admittance. The correction angle is marked with \( \alpha \). The basic idea of the method is that the correction angle is selected in such a way that the variation of the real part is minimized, when the measuring device wipes the surface of the paper (plastic) at a point at which there is no code. Calibration can be improved by intentionally making depressions in the surface of the paper, or swinging the measuring tip (pen) in such a way that the distance from the surface of the paper varies. It is preferable to perform calibration on the surface used in the application. Another alternative is to make the calibration for the angle when wiping the code in an area in which there is no code. When the measuring tip is wiped over such a code-free, lossless surface, in principle only the component measuring non-loss will change. This means that the angle can be found in such a way that the change in the real part of the admittance is minimized. If the angle is chosen in such a way that placing of the tip on the paper does not affect the real part of the angle, the noise of the real part will also be
minimized. In practice, calibration of the angle need only be made once, if the reading
depends on the manufacturing variations in the electronics.

Thus, the aim of angle correction is to eliminate variation in the measuring signal arising
from the changes in the paper's properties and the attitude of the tip, and to make it
depend only on the properties of the code. Background noise is eliminated.

In angle correction, the rotation angle alpha of the set of co-ordinates is selected in such
a way that a change in the lossless dielectric material does not appear in the angle-
corrected Re signal.

This aim is achieved by producing a change of only lossless permittivity in the
measuring tip, for example by lowering the tip onto the paper. After this, the angle-
corrected signals Re and Im are examined. The angle alpha is adjusted until the change
cauised by the change appears only in the Im signal, or the minimum of the Re signal is
reached. After correction, the Re signal is measured, in which the change appears only at
the location of the code.

Figure 5 shows one test, in which an admittance tip operating at 50 MHz wipes a code
through thin plastic. It will be noted that, though the imaginary part 50 is clearly stronger
than the real part 51, the noise of the imaginary part 50 is very great. This is caused by
the roughness of the paper. Prior to wiping the code, the measured real part 51 and
imaginary part 50 were corrected using an angle correction of about 28 degrees. Without
the angle correction, both components would have been mainly determined by
capacitance modulation.

Figure 6 shows only the real part 60 of the admittance. Even though, in the case in
question, the conductivity of the code is not optimized, the real part's signal-noise ratio
is very good. In fact, the noise on top of paper is determined from the digitalization used
in the measurement. The low noise means that we can set the trigger level very close to
the zero point of the real part and thus even a poor code can be read.
Figure 7 shows a special case, in which the code is read from very close, but due to the roughness of the paper the code has "porridged". Because the ratio of the real 71 and imaginary 70 parts is not optimal in this special case, the real part 71 remains considerably smaller than the imaginary part 70. On the other hand, because the code has 'porridged', both are noisy on top of the code. In such a situation, it is best to include the imaginary part too in the measurement. This situation is shown in Figure 4, in which it is assumed that both noise levels will be high on top of the code.

It should be noted that in these measurements the conductivity of the code has been high and for this reason the signal obtained from the imaginary part has been dominant.

For its part, Figure 8 represents a typical measurement situation, in which the broken line depicts the imaginary part of the measured impedance and the solid line the real part. As can be seen from the figure, the signal-noise ratio of the real part is clearly better that the signal-noise ratio of the imaginary part.

One central idea of the method is to calibrate the pen acting as the measuring head in such a way that it distinguishes the imaginary part and the real part from each other. This can be done by adjusting the correction angle in such a way that the pen produces no change in the real part when it is placed on a lossless dielectric surface. Another way is to scratch the dielectric surface and ensure that fluctuations do not take place in the real part when wiping over the surface. In a practical measurement situation, the real part is reset on the surface of the paper and the trigger level is set beforehand, or an algorithm seeks a suitable trigger level based on the strength of the signal. Because the noise of the real part is low, the trigger level can be set very close to zero. Only in situations, in which the dimensioning of the conductivity of the code is wrong, or the code has 'porridged', is it worth using longitudinal modulation of the vector instead of modulation of the real part. In principle, taken generally, the code can be detected by emphasizing in a suitable ratio the lengths of the real part and the imaginary part, thus optimizing the signal-noise ratio.

In principle, we can measure the correct conductivity of the code from the real and imaginary parts of the admittance. Depiction is mathematically very difficult, because...
the field is divided. The depiction depends on the mean distance of the pen, the width of
the code relative to the width of the pen's electrodes, etc. However, if we calibrate the
pen for a specific application, we can experimentally (or numerically using FEM
computation) seek the depiction

\[ r = f[Rc(Y)M(Y)] \]  \hspace{1cm} (3)

in such a way that the change in the variable \( r \) on top of the code and outside it are
independent of small variations in distance. This is due simply to the fact that both terms
are proportional to the distance, so that we can use both variables to eliminate changes in
the distance. It should be noted that the method in question does not measure the
absolute resistivity of the code, but is proportional to the difference between resistivities
of the code and the paper. This more precise measurement of conductivity is important,
if we are measuring sensor data. However, we can return the measurement of sensor data
to become the measurement of the real part, if, in addition to the measurement lines of
the code, we place reference lines, which have a known conductivity, or the value of the
conductivity is given in connection with the code information. In this case, we can
calculate the resistance value of the resistivity \( r \) of the sensor from an equation of the
real and imaginary parts of the admittance \( Y \)

\[ r = \frac{\text{Re}_\alpha(7) \cdot \text{Re}_\text{ref}(Y)^2 + \text{Im}_\text{ref}(Y)^2}{\text{Re}_\text{ref}(7) \cdot \text{Re}_\alpha(y)^2 + \text{Im}_\alpha(7)^2} \]  \hspace{1cm} (4)

In the equation, the subindex \text{ref} refers to the measurement of the reference code and the
subindex \( a \) refers to the measurement of the sensor. Of course, the equation can be used
reliably only if the geometry of the reference is the same as that of the sensor. If either
the real part or the imaginary part dominates the admittance, the equation becomes, of
course, simpler. On the other hand, it often happens that the imaginary part is nearly the
same on top of both the reference and the sensor, and therefore the approximate
conductivity of the sensor can often be obtained by simple mathematics. It should be
noted that in equation 4 the admittance \( Y \) depicts the angle-corrected admittance.
In addition to angle correction, it is possible to correct automatically the amplitude and zero level of the signal (see Figures 6 and 7), as well as the equilibrium of the bridge circuit, in such a way that the dynamics of the amplifier and the AD converter can be exploited optimally. It is also worth to correct the individual amplification and zero-level variations of the reader devices using an automatic calibration method. At its simplest, this takes place in such a way that the signal is measured from on top of the substrate or the code with at least two amplification values and two equilibrium-adjustment values, and on the basis of these to mathematically calculate the magnitude of the amplification and the equilibrium point of the bridge. In addition, the zero level of the signal can be set to the desired point by measuring the magnitude of the signal and correcting the values of the measured real and imaginary parts by summing them with such DC voltages that the signal can be moved to the desired point, in order to maximize the dynamic range. In order to prevent saturation of the amplifiers, the amplification can also be adjusted automatically or manually, in such a way that the amplitudes of the real and imaginary parts of the signal do not exceed a specific saturation value when reading the code.

The code can be made in several different ways. One possibility is to 'copy' the method used in barcodes. However, a way is presented here, which permits a natural way of eliminating speed variations taking place in wiping by a pen or mouse. In addition, the way described is based on setting the trigger level close to the paper's impedance so that the code is not used as a 'zero reference'. In the code of Figure 2, the information is recorded in the width modulation between the lines and the width of the conductive line is constant. If we divide the number of samples, which accumulate during the code (non-conductive material) and divide this by a number, which is either the maximum number of samples from the nearby conductive codes, or the mean value of the number of samples accumulated from the nearby conductive areas, we will obtain a standardized code datum, which depicts the distance of two lines from each other compared to the width of adjacent lines. This number is independent of speed. On the other hand, for a known code and a fixed trigger level, the ratio between a long code and a short code is constant, thus permitting the detection of erroneous readings. The advantage of this type of coding is also that, if the width of the line is minimized, there will be more pure paper than there is code in the entire surface to be read and we can regard the code as being less visible. Over a long period, with good material we can possibly go as far as a line
even 40-µm wide, in which case the visibility of the code will be reduced even further. A suitable width for a short code is in the same order as the width of the conductive area and correspondingly a wide gap could be 1.5 - 3-times wider, depending on the signal-noise ratio of the reading and the chosen error-correction algorithm. If the coefficient is only 1.5, we will obtain an information density of 1/2.25 bits per unit of travel. For example, a 40-µm line would lead to 1/90 bit/µm, i.e. a 96-bit EPC code would require a code about 9-mm long. In practice, a comfortable wiping length with a pen-like tip is 3 - 5 cm, so that an EPC code would require a code width of at least 250 µm. Using a pen, it is possible to wipe even longer distances and especially if we use a mouse-type interface the distance can easily be 5 - 10 cm. This means that even large numbers of bits can be coded electrically. In addition, if a 2D code is made with a corresponding method, the amount of information can be many times greater.

According to one embodiment, the reading of the code is thus optimized as follows: once the structure of the electrodes, the distance from the code, and the reading frequency have been agreed, the conductivity of the ink is optimized, in such a way as to make the reactance of the capacitance the same order as the resistance of the conductive ink. The real and imaginary parts of the admittance, measured with the aid of the measurement electronics, is corrected using angle correction, in such a way that the real part measures only losses. This can be easily seen by bringing the tip close to the non-conductive dielectric surface. The correction can be in connection with the analog capacitive bridge, or after mixing. Correction can also be made after digital AD conversion. After the angle correction, the code is interpreted mainly from the real part. For example, if, on account of checking the origin of the ink, we need better information on the conductivity, we can calculate the real part of the admittance with the aid of the admittances and decide the conductivity of the code from this.

One embodiment of the invention can also be described as follows. The permittivity of the dielectric material being measured (paper, cardboard, plastic) is complex, containing a lossy and a lossless part. The reader according to the invention measures both of these. The lossless part is formed by polarization. The lossy part is formed of either losses relating to polarization, or conductivity losses. The permittivity of clean paper is almost entirely lossless.
When moving the tip of the reader, which is represented, for example, by the electrodes 5 and 4 in Figures 3a and 3b, in a place on the surface (paper, cardboard, plastic) of the subject being measured where there is no code, the signal proportional to the lossless permittivity measured by the tip of the reader will change for the following reasons:

1. The permittivity arising from the fibrousness of the paper varies at different locations.

2. The moisture absorbed by the paper alters the permittivity in different ways in different locations.

3. When the tip tilts, the connection from the tip to the paper changes and affects the signal.

There is no signal at all proportional to the lossy permittivity.

This signal proportional to the lossless permittivity appears in both angle-corrected signals (Re_orig and Im_orig), which is due to the phase difference between the modulation and the demodulation. By altering the correction angle alpha, this phase difference can be altered (reference can also be made to a rotation of the co-ordinates).

By altering the angle, new signals Re and Im are formed. At a suitable angle, the signal caused by variations in the lossless permittivity appears only in the Im part. At the same time, it disappears entirely from the Re signal.

In practice, the angle correction is thus made by moving the reader on clean paper and adjusting the angle alpha, until the change caused by the movement appears only in the imaginary part, or, if changes appear in the real part, they are minimal and very minor. Thus, the real part is measured only from the lossy, resistive component of the impedance.

Thus, because there is lossy permittivity only at the location of the code, the Re signal changes only at the location of the code.
The angle-correction operation described above is typically one-off and need only be performed once, or repeated at relatively long intervals (one a month - once a year).

The invention can be implemented using voltage or current input, in which case voltage input is used to measure the current between the measuring electrodes and current input is used to measure the voltage between the measuring electrodes. The measurement variables (current or voltage) can also be referred to more generally as measurement signals.

One aspect of the invention is to create economic measurement electronics, which can be mass produced. In this solution, the measurement electronics are formed, together with the electrodes, on a circuit board (PCB, Printed Circuit Board), which is shaped suitably so that an end product requiring only casing is obtained directly from it. The circuit board thus comprises both the electronics and the electrodes. In this case, the radio-frequency input and the electrodes are located either inside, or on the surface of the circuit board. The electrodes are made as metallic conductors of a suitable thickness, by means of standard circuit-board manufacturing technologies. The sensitive radio-frequency amplifier can thus be located close to the reading electrode, in order to minimize stray capacitances. In addition, by using a sufficiently high measurement frequency, the measurement signal will be sensitive neither to static electricity, nor to random galvanic contacts with the measurement subject, making it possible to avoid the difficult and expensive coating of the electrodes.

When it is sought to determine capacitively small changes in impedance at a scale of less than a millimetre on top, or in the vicinity of the material being investigated, the key problem is how to connect electrically to the subject material being measured. A coding procedure that is being strongly developed is the replacement of optical barcodes with corresponding electrically conductive barcodes. These lines can be narrow and close to each other, the distance between them being in the order of 0.1 mm. Therefore the measurement electrodes must be brought very close to the lines, typically to about 0.01 mm from the lines. Another problem in this technique is the wear of the electrodes, if the measuring device is wiped over the surface on which the codes are. The surface is typically paper containing rock material and thus acting as an abrasive, which wears the
electrodes. A third problem is how to manufacture the electrodes and electronics cost-effectively in mass production.

A solution to all these problems is presented here. In addition, the system according to the invention is immune to noise and permits easy improvements in capacity and measurement precision, in order to improve reading precision.

The sensor operation according to Figure 9a can be integrated on the same circuit board as a durable construction, which is easy and cheap to manufacture.

In the top view shown in Figure 9a, the measuring device 1 is formed on a single circuit board 102, in which are located a connector or radio link 107, if necessary a battery 105 as a power source, analog and digital electronics 106, a clock 103, a low-noise amplifier 101, and a measuring head 100. For its part, the measuring head 100 is formed of an input electrode 4 and a measurement electrode 5. As can be seen from Figure 9b, in this solution, the input 4 and measurement 5 electrodes are located between the different layers of a multi-layer circuit board 102. By means of this technique, the distance between the electrodes is thus the thickness of a circuit-board layer, which in present-day technology is in the order of 50 - 500 µm. The thicknesses of the electrodes 4 and 5 are in the order of 10 - 100 µm, and the widths are in the order of 50 - 500 µm. For their part, Figures 9c and 9d show a solution, in which the electrodes 4 and 5 are implemented as via solutions, in which case the measuring head is created on the under surface of the circuit board. Alternatively, the circuit board 102 can be machined at the location of the vias, in order to form an electrode pair. In this case, the electrode pair 4, 5 is made vertical and each electrode 4, 5 is orthogonal to the plane of the circuit board 102.

In earlier, non-public solutions, a separate circuit-board substrate was used for the measurement electronics. Expensive LTCC was typically used then as the circuit board material. The electrodes were then embedded in insulation, in order to avoid galvanic contact. Because the distance between the electrode and the measurement subject should be minimized, very precise manufacturing tolerances were required when manufacturing the insulation. The precision needed to be in the order of 10 µm and, in addition, the
insulation had to be highly wear-resistant. In the method according to the invention, the insulation layer is not required and, in addition, both the electronics and the electrodes can be integrated in a low-cost circuit board and the measurement information processed using a separate apparatus, which is connected by cabling or over a wireless telecommunications link.

In one embodiment of the invention, the invention is used by wiping a measurement tip 100 over a one-dimensional electrical, weakly conductive barcode. In such an embodiment, it is important to use a sufficiently high measurement frequency of more than 1 MHz, preferably of 5 - 100 MHz, in order to ensure a sufficient capacitive connection between the measurement tip 100 and the subject 11 being measured. The high frequency and the phase detection permit low-frequency noise and interference caused by static electricity to be damped or even eliminated. The optimal square resistance is determined from the capacitive coupling reactance, and the measurement can be further optimized by means of the measurement frequency and the geometry of the reading electrodes.

The invention also permits multi-electrode structures, in other words the electrode matrices according to Figures 10a - 10d. In the figures, the electrodes 4 and 5 are located on different layers of a multi-layer circuit-board structure. The manufacturing technology permits electrodes, the maximum dimensions of which are in the order of 100 µm, depending on the circuit-board processes available. Typically, the manufacturing technology permits the following manufacturing tolerances: 10 - 100 µm and 100 - 200 µm.

Figure 10a shows a multi-electrode structure, in which both the input 4 and measurement electrodes 5 are divided. For its part, Figure 10b shows a solution, in which the input electrode 4 is unified, but the measurement electrodes 5 are divided. Figure 10c shows a structure, in which the structures of Figure 10a are placed on top of each other, in other words the divided input 4 and measurement 5 electrodes alternate as layers in horizontal directions. In addition, in this solution, the electrode layers overlap each other, in order to increase positional resolution. For its part, Figure 10d shows a layered structure, in which the structures of Figure 10b are set on top of each other as alternating layers, in
such a way that the unified input electrodes 4 alternate with the divided measurement electrodes 5. In addition to the solutions shown in the figure, it is possible to place the input 4 and measurement 5 electrodes on the same circuit-board layer.

According to Figures 11a and 11b, the electrodes according to Figures 10a - 10d can be run overlapped (multiplexed) on either the time or frequency plane. In time-plane multiplexing, the electrodes are run alternately, and in frequency multiplexing different frequencies are used for different electrodes. According to Figure 11a an rf output stage 111 is used to feed a demultiplexer 112, which in turn, controlled by control electronics 110, feeds the rf signal alternately to each of the input electrodes 4. By means of this procedure, a multi-electrode structure can be run using a single rf output stage 111, and the signal coming to the measurement electrodes can be amplified using a single low-noise amplifier 101.

Figure 11b shows a solution, in which, in addition to the elements of Figure 11a, a multiplexer 113 is used in connection with the measurement electrodes, before the amplifier 101. By means of this method, it is possible, for example, to obtain information from the electrode structures of Figure 10a or 10c on the code under each measurement electrode pair separately, because the desired measurement electrode 5 can be distinguished from the other measurement electrodes. Both Figures 11a and 11b show an optional isolation capacitor 114 integrated in the circuit board, the purpose of which is to protect the low-noise amplifier and other sensitive electronics.

Figures 12a - 12d show various forms of operation for the electrode structures according to the invention. Figure 12a shows the use of a two-electrode reading head 100 with a wiping method in connection with a one-dimensional code 11. Figure 12b, on the other hand, shows the use of a reading head 100 based on a multi-electrode structure, using a touch-mode procedure. In that case, each electrode pair 4, 5 measures the code or its absence independently. For its part, Figure 12c shows a reading head 100 based on a multi-electrode structure, which is used with a wiping method for detecting a fingerprint or two-dimensional code. Figure 12d, on the other hand, shows the use of a reading head 100 based on a multi-electrode structure with a touch-mode procedure for a two-dimensional mark 11.
According to the invention, the electrical amplification of the various electrodes can be varied, in which case the reading device can adapt automatically to different kinds of codes, which have square resistances differing from each other.
Claims:

1. Apparatus for reading an electronic code, which apparatus comprises

- means for generating (2) an alternating-electricity signal,
- electrodes (4, 5) connected to the alternating-electricity signal creation means (2) for bringing the alternating-electricity signal to the code (11) being measured, and
- means for measuring the current travelling through the electrodes (4, 5) or the voltage between them,

**characterized** in that

- the electrodes (4, 5) are open without an insulator layer, and
- the means for generating (2) an alternating-electricity signal are such that they generate at least a 1-MHZ alternating-electricity signal.

2. Apparatus according to Claim 1, **characterized** in that the means for generating (2) an alternating-electricity signal are such that they generate an alternating-electricity signal with a frequency range of 5 - 100 MHz.

3. Apparatus according to Claim 1 or 2, **characterized** in that a matrix-electrode structure (4, 5) is used in it.

4. Apparatus according to Claim 3, **characterized** in that it comprises means for demultiplexing (110, 112) the input signal.

5. Apparatus according to Claim 4, **characterized** in that it comprises means for multiplexing (110, 113) the measurement signal.

6. Apparatus according to any of the above Claims, **characterized** in that it is manufactured with the aid of multi-layer circuit-board technology.
7. Apparatus according to any of the above Claims, characterized in that its electrode structure (4, 5) is manufactured with the aid of multi-layer circuit-board technology.

8. Apparatus according to any of the above Claims, characterized in that the distance between the electrodes of the electrode structure (4, 5) is 50 - 500 µm.

9. Apparatus according to any of the above Claims, characterized in that it comprises means (2, 4, 5, 3, 6, 7) for determining the real (8) and the imaginary (9) parts of the current or voltage, and means for making an angle correction to the real (8) and imaginary (9) parts of the current or voltage when the electrodes (4, 5) are on an essentially lossless surface, in such a way that substantial changes in the current or voltage take place only in the imaginary part (9) of the current or voltage.

10. Apparatus according to Claim 9, characterized in that it comprises means for selecting the measurement frequency of the measuring device (1), the reading distance of the measurement head from the code (11), and the resistivity of the code (11), in such a way that the reactance of the capacitance seen by the measuring device (1) is of the same order of magnitude as the resistance of the conductive ink seen by the measuring device (1).

11. Apparatus according to Claim 9 or 10, characterized in that it comprises means for implementing a measurement as a wiping measurement at touch distance.

12. Apparatus according to Claim 9, 10, or 11, characterized in that it comprises means for reading a code by defining the non-conductive areas between the conductive code lines (11).

13. Apparatus according to Claim 9, 10, 11, or 12, characterized in that it comprises means to take into account variation in the speed of the wiping, in manually performed wiping.

14. Apparatus according to any of the above Claims, characterized in that when the current received by measuring device (1) is depicted by the equation
\[ I = U \omega C \frac{(r + j)}{r^2 + 1}, \quad \text{in which} \quad r = \omega CR \] (1)

in which,
R and C depict the resistive and capacitive parts of the impedance of the mark being read, the apparatus comprises means for selecting the reading distance of the measuring system, the electrical properties of the code, and the measurement frequency, in such a way that the condition \( r = 1 \) is met as accurately as possible.

15. Apparatus according to any of the above Claims, characterized in that the measuring device includes calibration means, by which the correction angle can be adjusted, in such a way that the reading pen (4, 5) of the measuring device (1) will not produce changes in the real part when it is placed on a lossless dielectric surface.

16. Apparatus according to any of Claims 9 - 14, characterized in that it comprises means, by which the measuring device can be calibrated by scratching a dielectric surface, measuring it, and adjusting the measuring device in such a way that fluctuation do not occur in the real part of the measurement result when the scratched surface is wiped over.

17. Apparatus according to any of the above Claims, characterized in that it comprises means, in which, in the measurement situation, the real part (8) of the measurement result can be reset on the surface of uncoded material (8) and the trigger level initiating the measurement by the electronics (1) can be preset on the basis of the reset real part (8).

18. Apparatus according to any of the above Claims, characterized in that it comprises means, by which, in the measurement situation, a suitable trigger level initiating the measurement can be sought with the aid of an algorithm, on the basis of the strength of the signal.

19. Apparatus according to any of the above Claims, characterized in that it comprises
means, by which the amplitude and zero level (Figures 6 and 7) of the signal, as well as the equilibrium of the bridge circuit can be corrected, in such a way that the dynamics of the amplifier and the AD converter can be optimized, in such a way that at least two amplification values and two equilibrium adjustment values are measured from the base of the signal or on top of the code, and on the basis of these the magnitude of the amplification and the equilibrium point of the bridge are calculated mathematically.

20. Apparatus according to any of the above Claims characterized in that it comprises means, by which the zero level of the signal is adjusted to the desired point by measuring the magnitude of the signal and correcting the values of the measured real and imaginary parts by summing them with such DC voltages that the signal can be moved to the desired point, in order to maximize the dynamic range.

21. Apparatus according to any of the above Claims, characterized in that it comprises means, by which the amplification is adjusted, in such a way that, in order to prevent saturation of the amplifiers, the amplitudes of the real and imaginary parts of the signal do not exceed a specific saturation value when a code is read.

22. Method for reading an electronic code, in which method

- an alternating-electricity signal (2) is generated,
- the alternating-electricity signal is lead to the code (11) to be measured, with the aid of electrodes (4, 5), and
- the current travelling through the electrodes (4, 5), or the voltage between them is measured,

characterized in that

- the alternating-electricity signal is lead to the code (11) to be measured through uncoated electrodes (4, 5), and
- an alternating-electricity signal, with a frequency of 1 MHz, is used.

23. Method according to Claim 22, characterized in that an alternating-electricity signal
with a frequency range of 5 - 100 MHz is used.

24. Method according to Claim 22 or 23, characterized in that a matrix-electrode structure (4, 5) is used in it.

25. Method according to Claim 24, characterized in that the input signal is demultiplexed (110, 112).

26. Method according to Claim 25, characterized in that the measurement signal is multiplexed (110, 113).

27. Method according to any of the above Claims, characterized in that the measuring device is manufactured with the aid of multi-layer circuit-board technology.

28. Method according to any of the above Claims, characterized in that the electrode structure (4, 5) is manufactured with the aid of multi-layer circuit-board technology.

29. Method according to any of the above Claims, characterized in that the distance between the electrodes of the electrode structure (4, 5) is 50 - 500 µm.

30. Method according to any of the above Claims, characterized in that the real (8) and the imaginary (9) parts of the current, or correspondingly the voltage are determined, and when the electrodes (4, 5) are on an essentially lossless surface, an angle correction is made to the real (8) and imaginary (9) parts of the current, or correspondingly the voltage, in such a way that substantial changes in the current or voltage take place only in the imaginary part (9) of the current or voltage.

31. Method according to Claim 30, characterized in that the measurement frequency of the measuring device (1), the reading distance of the measurement head from the code (11), and the resistivity of the code (11), are selected in such a way that the reactance of the capacitance seen by the measuring device (1) is of the same order of magnitude as the resistance of the conductive ink seen by the measuring device.
32. Method according to Claim 30 or 31, characterized in that the measurement is implemented as a wiping measurement at touch distance.

33. Method according to Claim 30, 31, or 32, characterized in that the code is formed by varying the non-conductive areas between the conductive code lines.

34. Method according to Claim 30, 31, 32, or 33, characterized in that, in manually performed wiping, variation in the speed of the wiping is taken into account.

35. Method according to any of the above Claims, characterized in that, when the current received by the measuring device (1) is depicted by the equation

\[ I = UaC \frac{(r+i)}{\sqrt{r^2+1}}, \text{ in which } r = \omega CR \]  

(1)

in which,

R and C depict the resistive and capacitive parts of the impedance of the mark being read, the reading distance of the measuring system, the electrical properties of the code, and the measurement frequency are selected in such a way that the condition \( r = 1 \) is met as accurately as possible.

36. Method according to any of the above Claims, characterized in that the measuring device is calibrated by adjusting the correction angle, in such a way that the pen does not produce changes in the real part when it is placed on a lossless dielectric surface.

37. Method according to any of Claims 30 - 36, characterized in that the measuring device is calibrated by scratching a dielectric surface, measuring the scratched surface, and adjusting the measuring device in such a way that fluctuation do not occur in the real part of the measurement result when the scratched surface is wiped over.

38. Method according to any of the above Claims, characterized in that, in the measurement situation, the real part (8) of the measurement result is reset on the surface of uncoded material (8) and the trigger level initiating the measurement by the
electronics (1) is preset on the basis of the reset real part (8).

39. Method according to any of the above Claims, characterized in that, in the measurement situation, an algorithm seeks a suitable trigger level initiating the measurement, based on the strength of the signal.

40. Method according to any of the above Claims, characterized in that the amplitude and zero level of the signal are corrected (Figures 6 and 7), as is the equilibrium of the bridge circuit, in such a way that the dynamics of the amplifier and the AD converter can be optimized, in such way that at least two amplification values and two equilibrium adjustment values are measured from the base of the signal or on top of the code, and on the basis of these the magnitude of the amplification and the equilibrium point of the bridge are calculated mathematically.

41. Method according to any of the above Claims characterized in that the zero level of the signal is adjusted to the desired point by measuring the magnitude of the signal and correcting the values of the measured real and imaginary parts by summing them with such DC voltages that the signal can be moved to the desired point, in order to maximize the dynamic range.

42. Method according to any of the above Claims, characterized in that the amplification is adjusted, in such a way that, in order to prevent saturation of the amplifiers, the amplitudes of the real and imaginary parts of the signal do not exceed a specific saturation value when a code is read.
Fig. 1

Oscillator
Bridge balancing
Current amplifier

Real part
Imaginary part
Phase-sensitive detector
Mixer

Fig. 2

Conductive code

Fig. 3a
Without code

Fig. 3b
With code
Fig. 4
1. Connector or radio link
2. Battery (optional)
3. Clock (optional)
4. Analog and digital electronics
5. PCB
6. LNA
7. Low noise amplifier

Fig. 9a

Fig. 9b

Fig. 9c

Fig. 9d

a) Metallization at the PCB edge as integrated sensor electrodes
b) Vias through the PCB as integrated sensor electrodes

Fig. 10a

Fig. 10b

Fig. 10c

Fig. 10d

a) Vias through the PCB as integrated sensor electrodes
b) Metallization at the PCB edge as integrated sensor electrodes

Fig. 10c

Fig. 10d
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>WO 2006108913 A1 (M REAL OYJ et al.) 19 October 2006 (19.10.2006) abstract; page 20, lines 28-33; page 21, lines 1-23; figures 7, 8 and 9</td>
<td>1-8, 22-29</td>
</tr>
<tr>
<td>A</td>
<td>WO 2005008574 A1 (AVANTONE OY et al.) 27 January 2005 (27.01.2005) abstract; page 3, lines 1-4; figure 4</td>
<td>1-42</td>
</tr>
<tr>
<td>A</td>
<td>GB 2436634 A (AVANTONE OY) 03 October 2007 (03.10.2007) abstract; page 2, lines 2-7</td>
<td>1-42</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

See patent family annex.

Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search

06 August 2010 (06.08.2010)

Date of mailing of the international search report

10 August 2010 (10.08.2010)

Name and mailing address of the ISA/FI

National Board of Patents and Registration of Finland

P O Box 1160, FI-00101 HELSINKI, Finland

Facsimile No. +358 9 6939 5328

Authorized officer

Pasi Suvikunnas

Telephone No. +358 9 6939 500

Form PCT/ISA/210 (second sheet) (July 2009)
<table>
<thead>
<tr>
<th>Patent family</th>
<th>Publication date</th>
<th>Patent family members(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>Code</td>
<td>Description</td>
<td>Year</td>
</tr>
<tr>
<td>----------------</td>
<td>--------</td>
<td>----------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Int.CI.</td>
<td>G06K 7/08</td>
<td>(2006.01)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G06K 19/067</td>
<td>(2006.01)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G06K 7/10</td>
<td>(2006.01)</td>
<td></td>
</tr>
</tbody>
</table>