Title: DEVICE FOR DETECTING ELECTRICALLY CONDUCTIVE FEATURE

Abstract: A device for detecting a conductive feature in a sheet of non-conductive material, comprising a signal transmitter producing a high frequency time-varying signal, at least one sensor electrode arrangement including two pairs of sensor electrodes and a ground electrode, wherein each pair of sensor electrodes comprises a transmitting electrode and a receiving electrode, and the device further comprises a signal receiver, and a signal processing unit. The device is characterized in that the two pairs of sensor electrodes are arranged in the same plane, so that two receiving electrodes are electrically connected together and placed between the two transmitting electrodes, and the pairs of electrodes are aligned in parallel, the transmitting electrodes are feed with opposite phases of the high frequency signal of the signal transmitter, and the signal receiver is connected to the receiving electrodes to measure the signal of the receiving electrodes, and the signal processing unit is connected to the receiver and adapted to compare the output signal of the receiver with a predetermined signal to detect the presence of a conductive feature in the sheet of non-conductive material by detecting deviation of the measured signal.
DEVICE FOR DETECTING ELECTRICALLY CONDUCTIVE FEATURE

The present invention relates to devices for detecting of electrically conductive features provided in a sheet of nonconductive material. The device may be applicable in a system for validating authenticity of documents, e.g. banknotes. Further, the device may be applicable in other systems for processing sheets of nonconductive material.

It is known to incorporate electrically conductive features in a sheet of nonconductive material such as security means like threads, signatures and other signs provided in banknotes and capital issues. These electrically conductive features can be detected using sensing devices producing an output signal which reflects capacitance change due to the presence of electrically conductive feature proximate to the sensor arrangement.

Typical sensing device of this type comprises an electrode connected with frequency generator and transmitting a high frequency signal, and a receiving electrode connected with some measuring or signal processing arrangement. Stability in detection of an electrically conductive feature is affected by a number of factors such as stray capacitance between sensor electrodes which value depends on changing environment conditions, e.g. temperature and humidity, capacitance variation due to changes in separation distance from the sensor caused by wobbling of a document or another sample of thin material and the presence of internal receiver noise specific for every measuring arrangement.

A device comprising a high frequency generator must comply with requirements to electromagnetic interference (EMI) such as limits for radio disturbance characteristics specified by EN 55022 standard. One of objectives when designing devices of this type is providing acceptable level of radiated EMI. U.S. 6,019,208 discloses a device for validating the authenticity of a document which resolves a part of listed problems. The device uses changes in capacitance due to the presence of an electrically conductive security thread. A frequency generator produces a high frequency time varying signal and provides the signal to an elongate oscillator electrode extending across the path of movement. Two elongate measuring electrodes are positioned on both sides of the oscillator electrode at a predetermined distance from this oscillator electrode. Signals from the measuring electrode and the oscillator electrode are provided to a signal processing arrangement. The signal processing arrangement includes a synchronous detector which compares a signal derived from the measuring electrode to the reference signal from the oscillator electrode and detects a change in phase caused by conductive security thread passing by electrodes. In one embodiment of U.S. 6,019,208 the stray capacitance reduction is provided due to the arrangement where signals of two measuring electrodes provided to a differential input of a synchronous detector. An arrangement of two functionally identical sensors in another embodiment U.S. 6,019,208 is useful for resolving the problem of banknote wobbling, as the cumulative capacitance signal from the two sensors reduces variation in the signal caused by wobble. The method of stray capacitance compensation proposed in this patent is insensitive to varying environment conditions, as stray capacitances between the oscillator electrode and two measuring electrodes vary in the same manner according to changes in the environment conditions. Contributions of these stray capacitances to the measured signal are mutually compensated as signals of two measuring electrodes are provided to differential input of a synchronous detector.
However this solution has significant drawbacks. First, the device comprises a generator providing a high frequency signal to the oscillator electrode. This high frequency signal causes electromagnetic interference affecting functionality of surrounding devices, therefore additional shielding arrangements are required to reduce the level of radiated EMI. Second, both measuring electrodes are equally spaced from the oscillatory electrode, and both measuring electrodes are similar in shape and size. Such configuration of electrodes provides perfect stray capacitance compensation. However, any type of signal receiving arrangement connected to measuring electrodes has a finite sensitivity limited by its internal noise. In case of perfect compensation of stray capacitance variations of received signal can appear below the sensitivity threshold. Thus, it can be found that a small signal variation due to presence of security thread is undetectable. Third, the device is suitable for detecting security threads provided across a document, like a banknote, along the direction orthogonal to the path of the document moving. It allows detecting a position of an electrically conductive thread in a document along the direction of the document moving. However, it does not allow detecting a position of electrically conductive feature in a document along the direction orthogonal to the document moving, in case an electrically conductive feature has an arbitrary shape, and does not extend across the document.

An objective of the present invention is providing an easy-to-work device for stable detecting a conductive feature in a sheet of nonconductive material, the device being applicable, e.g. in systems for validating authenticity of documents.

This is attained owing to the fact that, according to the present invention, there is provided a device for detecting a conductive feature in a sheet of nonconductive material. The device may be applicable in a system for validating authenticity of documents, e.g. banknotes. Further, the device may be applicable in other systems for processing sheets of nonconductive material. The device comprises a signal transmitter producing a high frequency time varying signal, at least one sensor electrode arrangement comprising two pairs of sensor electrodes and a ground electrode, wherein each pair of sensor electrodes comprises a transmitting electrode and a receiving electrode. The device further comprises a signal receiver and a signal processing unit.

The two pairs of sensor electrodes are arranged in the same plane and aligned in parallel into a symmetrical "common-centroid" configuration, so that said two receiving electrodes are electrically connected together and placed between said two transmitting electrodes. The transmitting electrodes are fed with opposite phases of said high frequency signal of the transmitter, whereby stray capacitances of two pairs of electrodes are mutually compensated.

The signal receiver is connected to the receiving electrodes to measure the signal of the receiving electrodes. The signal processing unit is connected to the receiver and adapted to compare the output signal of the receiver with a predetermined signal to detect the presence of a conductive feature in the sheet of non-conductive material by detecting deviation of the measured signal.

For simplicity, in the description of the present invention the output signal of the receiver is called a sensor signal.

Preferably, the signal processing unit is comparing the sensor signal with a predetermined or expected signal to detect the presence of a conductive feature in the sheet of non-conductive material by observing the measured signal deviation caused by said conductive feature.
This symmetric electrode configuration provides stable compensation for temperature variations in the electrodes, not only in cases where both electrodes are evenly heated or cooled, but also in cases where a temperature gradient occurs over the electrodes surface. An increase in the received signal caused by a conductive feature can be expressed by the ratio of the coupling capacitance between the electrically conductive feature and electrodes to the stray capacitance between electrodes. Therefore, compensation of stray capacitance facilitates detecting the change in the received signal due to the presence of a conductive feature.

Furthermore, unlike the known device, in the present invention two transmitting electrodes fed with opposite phases of oscillator signal produce two components of EMI with similar amplitudes and opposite phases, whereby EMI of two transmitting electrodes are mutually compensated. This makes possible to provide less shielding arrangements and facilitates embedding the device of the present invention into a system for validating authenticity of documents.

Preferably, transmitting and receiving electrodes are implemented in a metal layer on a surface of a printed circuit board.

The ground electrode is preferably implemented as a ground plane surrounding transmitting and receiving electrodes on a surface of a printed circuit board.

In one embodiment of the invention transmitting electrodes are placed at opposite sides of electrically connected together receiving electrodes and the transmitting electrodes are equally spaced from the receiving electrodes, whereby the device is able to provide perfect mutual compensation of stray capacitance.

In another embodiment of the invention transmitting electrodes are placed at opposite sides of electrically connected together receiving electrodes and the transmitting electrodes are unequally spaced from the receiving electrodes, whereby the device is able to provide deliberate partial mutual compensation of stray capacitance.

In yet another embodiment the transmitting electrodes differ in linear sizes from each other, whereby the device is able to provide deliberate partial mutual compensation of stray capacitance.

The present invention is not limited to the shape or size of electrodes or predefined distances separating the electrodes.

The present invention is not limited to the type of transmitted high frequency signal, therefore the invention is not limited to a particular transmitter and receiver, or a particular signal processing unit.

Preferably, said signal transmitter comprises at least one high frequency oscillator.

In one embodiment transmitter produces a dual sideband (DSB) signal with suppressed carrier. For a person skilled in the art it is obvious that if a DSB signal is transmitted, then the received signal strength indicator (RSSI) depends on both received signal amplitude and phase. This is useful for detecting high-impedance conductive features.

In one embodiment a signal processing unit detects a received signal deviation in comparison with the signal received in the absence of a conductive feature, in particular this is a short peak increase of a sensor signal, caused by an electrically conductive feature passing proximate to electrodes.

In another embodiment the signal processing unit is implemented so that to compare the received signal with the signal response to the presence of a particular feature obtained beforehand. Thus, the present
invention allows simultaneously detecting the presence of a conductive feature and discerning particular features by their specific signal responses.

In one embodiment a plurality of sensor electrode arrangements is installed to monitor a banknote surface wherein the sensors electrode arrangements are positioned in the same plane in multiple rows manner. This allows recognition of security features size and shape at expense of lower signal to noise ratio due to smaller area monitored by each row sensor.

In another embodiment two sensor electrode arrangements are positioned on opposite sides of the nonconductive sheet under test, and the signal processing unit measures an average value of two sensor signals, whereby variation of a distance to sensor electrodes, caused by document wobbling, is compensated.

Preferably, a device of the present invention comprises a transport means for moving a sheet of nonconductive material along a predetermined path proximate to said sensor electrode arrangement, so that said material overlaps at least one pair of electrodes while moving. The transport means is adapted for moving a sheet of nonconductive material with constant speed.

Preferably transmitting and receiving electrodes are of rectangle shape extended in the direction orthogonal to the path of banknote moving.

Furthermore, transport means in the preferable embodiment of the invention comprises at least one position sensor to trace the sheet position and its orientation inside the transportation mechanism at every moment with good accuracy. In the preferable embodiment two position sensors are used for more precise position detection. The structure of these sensors does not comprise subject matter of the present invention. A person skilled in the art can select any appropriate sensor basing on the particular embodiment specification. Information of exact position and orientation of the sheet at every moment in combination with a predetermined constant speed allow determining a position of a conductive feature in the sheet in the direction of moving.

The present invention can either be used as a separate device or within a system for validating authenticity of documents, in combination with other devices for examining objects.

An embodiment of the present invention is described below, by way of example, with reference to the accompanying drawings. The embodiment is illustrative only, and the present invention is not limited to the described embodiment.

Fig. 1 shows capacitive coupling between electrodes and a conductive security thread.

Fig. 2 is an equivalent circuit of capacitive coupling used for simulation.

Fig. 3 is a block diagram of a prior art device.

Fig. 4 is a block diagram of the device of the present invention.

Fig. 5 shows a sensor electrode arrangement with symmetrical "common-centroid" electrode configuration.

Fig. 6 shows the sensor electrode arrangement with electrode configuration for deliberate partial compensation.

Fig. 7 is a schematic cross section of the embodiment of the invention.

Fig. 8 shows a block diagram of signal transmitter, signal receiver and signal processing unit in the preferable embodiment of the invention.
Fig. 9 shows an example of a sensor signal in the presence of an electrically conductive feature. Fig. 10 shows a transport arrangement of the embodiment of the invention.

Fig. 1 illustrates the underlying physical process of the present invention. A conductive object in the vicinity of electrodes forms two planar capacitors thus forming additional coupling between TX and RX electrodes. In its simplest form a conductivity sensor comprises a signal generator connected to transmitting electrode and a signal receiver connected to receiving electrode. In the absence of a conductive feature proximate to the sensor, a signal comes only through stray capacitance between the electrodes. When a conductive feature, like a conductive security thread, occurs proximate to the sensor electrodes an additional signal path appears due to capacitance coupling between the conductive thread and the electrodes, therefore an increase of the received signal can be observed in the presence of a security thread. The equivalent circuit is shown in Fig. 2. C12 is a stray capacitance between electrodes, C13 and C23 are capacitances between the security thread and transmitting and receiving electrodes, respectively. A relative increase in received signal due to security thread is roughly the ratio of the thread coupling cumulative capacitance of C13 and C23 to the stray capacitance C12. Thus, reduction of the stray capacitance makes for easily detecting the signal change in the presence of the security thread.

An important practical issue is stability of compensation over time or from sample to sample. Changes of environment conditions, like temperature and humidity, cause variations of a stray capacitance and a capacitance of a separate capacitor device and normally these variations are different. Therefore, in case of capacitor device used for stray capacitance compensation the degree of compensation is unstable and depends on the environment conditions. The efficient way for achieving a stable compensation is to use two identical items like two electrode pairs which can be arranged in a manner so that their stray capacitance are mutually compensated.

Though the differential arrangement of receiving or measuring electrodes in US 601,9208 serves another purpose, compensation of stray capacitance is the useful side effect. Fig. 3 shows the block diagram of the sensor configuration with differential receiving electrodes and a corresponding processing arrangement described in US 601,9208.

In the present invention the configuration with differential transmitting electrodes is used in order to avoid drawbacks of the invention in US 601,9208 listed earlier in this description. As shown in Fig. 4, in the present invention two transmitting electrodes are fed with opposite phases of the oscillator output signal, so that the stray capacitance compensation on transmitting side is provided and radiated EMI components caused by opposite high frequency signals are mutually compensated.

According to a preferred embodiment, the oscillator produces dual sideband (DSB) signal with suppressed carrier at 150MHz range. In this embodiment, modulation frequency is 455 kHz, which is standard intermediate frequency for amplitude modulation broadcast receivers. This simplifies the overall design, which is shown in Fig. 8. Signal peak to peak amplitude on the transmitting electrode is near 150mV, the level being a trade-off between low EMI susceptibility and allowable EMI radiation.

As can be seen from Fig. 5, a transport means (not shown) is moving a document 1, preferably a banknote, along a predetermined path in the direction 2, so that the sensor electrode arrangement extends in a direction orthogonal to the path of the document. The sensor electrode arrangement 3 comprises two pairs of electrodes TX1 - RX1 and TX2 - RX2, wherein TX1 and TX2 are transmitting electrodes of the first and the second pair respectively, and RX1, RX2 are receiving electrodes. The
sensor electrodes are implemented in the outer metal layer of a printed circuit board (PCB). PCB is made of FR4 substrate of 3 mm thick. TX1 and TX2 are fed with opposite phases of a high frequency signal (not shown). RX1 and RX2 are connected with a metal short forming a common receiving electrode. TX1 and TX2 are positioned on opposite sides of receiving electrodes RX1, RX2 connected into the common receiving electrode. Each pair of sensor electrodes TX1 - RX1 and TX2 - RX2 is aligned in the direction orthogonal to the path of a document moving. The ground electrode is implemented as a metal plane surrounding sensor electrodes in the same PCB surface layer. In the embodiment shown in Fig. 5 transmitting electrodes TX1 and TX2 are positioned at the same distance from the common receiving electrode RX1 - RX2. This configuration provides perfect stray capacitance compensation. Overall sizes of the sensor electrode arrangement in the preferable embodiment are 12 mm in the direction of moving and 56 mm in the orthogonal direction. The width of electrodes is 1.2 mm.

In an embodiment shown in Fig. 6, partial compensation of the stray capacitance is performed. As mentioned earlier in this description, partial compensation is required when, due to a receiver internal noise, variations of the received signal caused by capacitive coupling with a conductive feature are below the receiver sensitivity threshold. In this case a solution for stray capacitance compensation adjustment is required which allows keeping the compensation slightly out of balance. Partial stray capacitance compensation in this embodiment is obtained by positioning transmitting electrodes at unequal distances from the common receiving electrode. This is illustrated in Fig. 6 as cutting the left edge of Tx1 electrode, which is close to Rx1 electrode.

In another embodiment not shown in the Figures, transmitting electrodes are of different length and width to obtain deliberate partial stray capacitance compensation.

In yet another embodiment not shown in the Figures, an external capacitor device can be connected in parallel to one pair of electrodes TX1 - RX1 or TX2 - RX2 to arrange deliberate partial stray capacitance compensation.

A person skilled in the art can use various methods for calculating the distances separating the electrodes and various methods for designing electrodes for partial compensation of the stray capacitance. One practical way is based on simulation. First, a 3D model of electrodes with substrate is modeled using the finite element method (FEM) electrostatic simulator. For example, Elmer FEM simulator can be used for modelling (http://www.csc.fi/english/pages/elmer). The result of electrostatic simulation is capacitance matrix, which can be inserted into the SPICE circuit simulator. A person skilled in the art is aware that additional information for SPICE simulation is required, such as appropriate voltage sources and values of input/output impedances of components connected to electrodes. The result of SPICE simulation is voltage at receiving electrode. If the achieved compensation is different from the desired value, the electrode geometry is adjusted, and the simulations are repeated. Usually stray capacitance value is the most sensitive to distance between receiving and transmitting electrodes.

A cross-section of the preferable embodiment is shown in Fig. 7. Electrodes on the surface of PCB are covered by 0.7mm plastic lid. If the similar arrangement is positioned on the opposite side of a document then their air gap between these arrangements is 2.35mm. A document under test is transported in the middle of this gap, hence its distance to sensor's cover is roughly 1.2mm.

A simplified diagram of transport means used for banknote transportation is shown in Fig. 10. Driving rollers are rotated by electric motor (not shown), idle rollers are spring loaded to provide a
predefined pressure onto banknote. The banknote is held between the rollers and is transported at near constant speed. Sensor 1 and Sensor 2 are optocouplers or other position sensors situated between pairs of driving rollers and idle rollers, and they are close to the banknote surface. In the embodiment shown in Fig. 10 two position sensors are used to trace the banknote position and its orientation inside the transportation mechanism at every moment with better accuracy. Signal of these sensors are provided to signal processing arrangement described below. These sensor signals are used to determine a position of expected conductive feature provided in a banknote in the direction of moving. The sensor electrode arrangement is shown schematically, other parts of the device of present invention are not shown in Fig. 10. Transport means of the present invention is not limited to the embodiment shown in Fig.10.

While a document is moving, an estimated conductive feature provided in the sheet of nonconductive material of the document overlaps at first the pair of electrodes TX1 - RX1 and then the pair of electrodes TX2 - RX2. Capacitance coupling of the conductive feature occurs with two pairs of electrodes consequently if the feature is a continuous security thread or a set of separate conductive elements provided across the document in the direction orthogonal to the path of moving. In case of a conductive feature of an arbitrary shape located close to a margin of the document then capacitive coupling occurs between the conductive feature and one pair of electrodes.

The configuration of electrodes according to the present invention is suitable for stable detecting the presence of a conductive feature of arbitrary shape and location provided in a document made of sheet of nonconductive material. A security thread provided in a banknote is an illustrative example only. The configuration of electrodes of the present invention is not limited to the embodiment shown in Fig.5. The distance between pairs of electrodes as well as mutual position of electrodes in the plane may vary depending on an objective of a particular embodiment. The shape of the observed change in the sensor signal generally depends on a number of factors such as the conductive feature size, conductivity, location in a document, the distance to the sensor electrodes and the distance between sensor electrode pairs in the direction of the document moving path.

Fig. 8 shows a block diagram of signal transmitter, signal receiver and signal processing unit in the preferable embodiment of the invention. In this embodiment an oscillator produces opposite DSB signals supplied to TX1 and TX2 electrodes. For clarity, we assign TX prefix to the parts signal transmitter and RX prefix to the parts engaged in signal receiver correspondingly. As shown in Fig. 8, the signal transmitter (TX) comprises an intermediate frequency (IF) oscillator, TX mixer and optional phase shifting circuit. One input of TX mixer is fed with 455 KHz output signal of IF oscillator, another input of TX mixer is fed with 150 MHz signal (F_LO), which is supplied from an RX local oscillator in a receiver (RX). The receiver comprises Rx local oscillator, Rx mixer, intermediate frequency (IF) bandpass filter and IF amplifier. These parts effectively form a superheterodyne receiver without input filter. It is obvious for a person skilled in the art that it receives a signal at two frequencies which can be presented as (F_LO + IF) and (F_LO - IF). To make these frequencies exactly the sidebands of transmitted DSB signal, the RX local oscillator output signal is supplied to both RX mixer and TX mixer. RX local oscillator output signal is supplied to TX mixer through optional phase shifting circuit. TX mixer operates as a balanced modulator with respect to the FJ_0, therefore in the resulting signal F_LO carrier is suppressed. For balanced mixers implemented on Gilbert cell their output is available as a pair of differential signals. This resulting
DSB signal with suppressed carrier comes to two differential transmitter outputs connected to two
transmitting electrodes Tx1 and Tx2, so that two opposite phases of the signal are transmitted. The
receiver is mostly a standard super heterodyne receiver, but without input filtering. This means that both
sidebands of DSB signal spaced by twice IF value are coherently added on reception. A signal received
by the receiving electrode Rx is supplied to the RX mixer input. The received signal is of much smaller
amplitude than transmitted one, and its amplitude and phase depend on the type of detected conductive
object, its size and its distance to electrodes. When this received DSB signal comes to RX mixer, both its
sidebands are converted to the same IF, thus they are coherently added up. As a result, Rx mixer output
depends on RX signal amplitude and total phase shift from Rx local oscillator output through phase
shifting circuit, TX mixer and sensor electrodes. Since RX mixer output is proportional to cosine of this
phase shift and can go too low for shifts close to 90 degrees, it might be beneficial to keep it at
reasonable level. This is achieved by appropriate choice of phase shift provided by the phase shifting
network. Then the output signal of RX mixer is filtered by IF filter. After that the signal is amplified by IF
amplifier, and then the amplitude of this amplified IF signal is measured by logarithmic receiving signal
strength indicator (RSSI) which provides an output proportional to logarithm of IF amplifier output signal.
The RSSI output is supplied to the signal processing unit (SPU) comprising a scaling amplifier, analog -
to - digital converter (ADC) and a central processor (CPU). To match the range of RSSI output signal to
ADC input voltage range a scaling amplifier is used. The output signal of scaling amplifier is supplied to
ADC. In this embodiment ADC takes samples at predefined time intervals. In other embodiment ADC
takes samples basing on actual banknote position, being clocked by pulses coming from rotary encoder
mechanically coupled to the transport. ADC output digital signal is processed by CPU to make a decision
about the banknote authenticity.

Fig. 9 shows an example of the sensor signal received in case of a security thread provided in a
banknote. A banknote is transported at constant speed in the vicinity of conductivity sensor. The transport
means is designed to provide near constant banknote speed and its distance to the sensor, however
some variations are unavoidable. For each banknote sensor output signal received by the signal
processing unit is digitized and stored for analysis. Since capacitance sensor responds to both banknote
dielectric properties and on size and conductivity of a security thread, the received signal contains all
information needed for the signal processing unit, which makes decision about the banknote authenticity.

In Fig. 9 is the background level of the sensor signal in the absence of a banknote. Normally a
banknote paper slightly increases the background signal level, from s0 to s1, and adds some noise due to
a banknote wobbling. Since stray capacitance of both TX/RX electrode pairs is equally affected by
banknote paper, its wobbling is significantly compensated. A conductive feature provided in the banknote
is detected by a sudden signal increase. As a side effect, a conductive thread positioned between
electrode pairs symmetrically with respect to electrode pairs may cause no signal change. This leads to
dual-hump peak response. When conductive thread approaches first electrode pair the sensor signal
increases. The first peak appears when the thread overlaps first electrode pair. While further moving the
security thread it takes a position between two pairs of electrodes, in this time interval the sensor signal
drops down, because additional capacitance due to coupling through the thread for first and second
electrode pairs are compensated. The second peak occurs when the thread is overlapping the second
TX/RX electrode pair. Amplitude of the security thread peaks depends on the security thread width, its
resistance, the distance to the sensor electrodes and the sensor electrode area overlapped by the security thread.

Using a set of signal records obtained from genuine banknotes one can define authenticity criteria for this type of banknotes. Security thread peak position and amplitude and absence of signal spikes outside of the security thread area can be checked. For instance, aluminium foil strips or other kind of false metal security thread produce peaks of higher amplitude than the one produced by the original security thread, while graphite marks may cause very little increase in the signal level.

Since banknote position and its orientation inside the transportation mechanism is known for each moment of time with sufficient accuracy, from sensors in the transport arrangement in Fig. 10, for typical signal shown in Fig. 9 the expected time interval for security thread peak is known too. A simple method of validating the authenticity may include two comparisons. The first comparison checks that maximum sample in vicinity of expected peak exceeds a predefined level. The second comparison makes sure that signal before and after expected peak vicinity is below another predefined level.

It shall be obvious for those skilled in the art that the invention can be used for validating the authenticity of other sheets rather than banknotes. These sheets can be documents, papers of value, capital issues, etc. While a sheet is moving proximate to pairs of sensor electrodes the security thread provided in this sheet consequently overlaps the first pair of electrodes, and then the second one. A security feature of different forms may be provided in the sheet. For example, a security feature of an arbitrary shape, unlike the thread, is not extended across the document in the direction orthogonal to the path of moving. If this security feature is located close to one of document edges, it overlaps only one of the sensor electrode pairs, and the signal peak produced by this feature is observed during a shorter time interval. This allows detecting a position of electrically conductive feature in a document along the direction orthogonal to the document moving.
Claims

1. A device for detecting an electrically conductive feature in a sheet of non-conductive material, comprising
   a signal transmitter producing a high frequency time varying signal,
   at least one sensor electrode arrangement including two pairs of sensor electrodes and a ground electrode, wherein each pair of sensor electrodes comprises a transmitting electrode and a receiving electrode, and the device further comprises a signal receiver, and a signal processing unit;
   characterized in that
   said two pairs of sensor electrodes are arranged in the same plane and aligned in parallel, so that
   said two receiving electrodes are electrically connected together and placed between said two transmitting electrodes,
   said transmitting electrodes are fed with opposite phases of said high frequency signal of said signal transmitter, and
   said signal receiver is connected to said receiving electrodes to measure the signal of said receiving electrodes, and said signal processing unit is connected to said receiver and adapted to compare the output signal of the receiver with a predetermined signal to detect the presence of a conductive feature in the sheet of non-conductive material by detecting deviation of the measured signal.

2. The device of claim 1, wherein said pairs of sensor electrodes are implemented in a metal layer on a surface of a printed circuit board.

3. The device of claim 1, wherein the ground electrode is implemented as a conductive plane connected to ground.

4. The device of claim 1, wherein the transmitting electrodes are placed at opposite sides of said receiving electrodes, each transmitting electrode being equally spaced from said receiving electrodes.

5. The device of claim 1, wherein the transmitting electrodes are placed at opposite sides of receiving electrodes, the transmitting electrodes being unequally spaced from said receiving electrodes.

6. The device of claim 1, wherein the transmitting electrodes differ in linear sizes from each other.

7. The device of claim 1, wherein said signal transmitter comprises at least one high frequency oscillator.

8. The device of claim 1, wherein said signal transmitter produces a dual-sideband signal with suppressed carrier.

9. The device of claim 1, comprising a plurality of said sensor arrangements positioned in the same plane in multiple rows manner.

10. The device of claim 1, wherein at least two sensor arrangements are configured to be on opposite sides of the sheet of non-conductive material, and the signal processing unit is adapted to measure an average value of signals produced by the two sensor arrangements,
11. The device of claim 1, comprising transport means for moving a sheet of nonconductive material with constant speed along a predetermined path proximate to said sensor electrode arrangement so that said material overlaps at least one pair of electrodes while moving.
12. The device of claim 11, wherein said transmitting and receiving electrodes are of rectangle shape extended in the direction orthogonal to said predetermined path.
13. The device of claim 11, wherein said transport means comprises at least one position sensor.
Fig. 1.

Fig. 2.
Fig. 7.
Fig. 9.
Fig. 10
INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/006353

A. CLASSIFICATION OF SUBJECT MATTER
INV. G07D7/Q2

ADD.
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)
G07D

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<td>Y</td>
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<td>WO 96/30879 AI (LFP ELEKTRONISCHE SPEZIALSICHE [DE]: PUTTKAMMER FRANK [DE]; WOLF TÖRST) 3 October 1996 (1996-10-03)</td>
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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

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"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 or in combination with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search: 6 March 2012

Date of mailing of the international search report: 16/03/2012

Name and mailing address of the ISA/
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Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer: Nevi ile, David
### DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 4 355 300 A (WEBER HAROLD J) 19 October 1982 (1982-10-19) column 3, line 34 - column 4, line 35</td>
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**INTERNATIONAL SEARCH REPORT**

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   - because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   - because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   - because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

- see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [X] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

- ☐ No protest accompanied the payment of additional search fees.
This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claim: 2
   Electrodes as metal layers on a PCB

2. claim: 3
   Planar guard electrode connected to ground potential.

3. claim: 4
   Balanced spacing of electrodes.

4. claims: 5, 6
   Unbalanced spacing and dimensions of electrodes.

5. claim: 7
   Signal transmitter as high-frequency oscillator.

6. claim: 8
   Transmitted signal as dual-sideband signal with suppressed carrier.

7. claim: 9
   Multiple sensor arrangements in the same plane.

8. claim: 10
   Arrangement of sensors on each side of the banknote path.

9. claims: 11-13
   Transport means.
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<th>Patent family member(s)</th>
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