UNITED STATES INTERNATIONAL TRADE COMMISSION
WASHINGTON, D.C.

Before the Honorable Cameron R. Elliot
Administrative Law Judge

In the Matter of **CERTAIN CAPACITIVE TOUCH-CONTROLLED MOBILE DEVICES, COMPUTER AND COMPONENTS THEREOF**	Investigation No. 337-TA-1193

RESPONDENTS' INITIAL MARKMAN BRIEF

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Respondents Amazon.com, Inc., Apple Inc., ASUSTeK Computer Inc., ASUS Computer International, LG Electronics Inc., LG Electronics U.S.A., Inc., Microsoft Corporation, Motorola Mobility LLC, Samsung Electronics, Co., Ltd., Samsung Electronics America, Inc., Sony Corporation, and Sony Mobile Communications Inc. hereby submit their Initial Markman Brief.[1,2]

I. INTRODUCTION

Like the 1162 Investigation before, Complainant Neodron Ltd. ("Neodron") asserts four patents in this Investigation directed to a variety of systems and functions relating to capacitive touch sensing, each with specific requirements. The parties have agreed to several constructions across all four patents (attached hereto as Exhibit 1) leaving just three terms across two of the patents—U.S. Patent No. 8,749,251 ("the '251 Patent") and U.S. Patent No. 9,411,472 ("the '472 Patent"). Respondents submit their constructions are the appropriate ones.

Starting with the '251 Patent, there is one disputed element appearing in dependent claims 2 and 17: "deactivation of measurement of changes in capacitance." Respondents' proposed construction—"stopping all current and scheduled measurements of changes in capacitance"—is consistent with the claim term's ordinary meaning and the intrinsic evidence. Neodron proposes that the element be given its plain and ordinary meaning without defining that plain and ordinary meaning. But Neodron made clear during the meet and confer process that it contends "deactivation of measurement" encompasses merely slowing down the scheduled rate of measurement. Thus, the substantive dispute between the private parties regarding the scope of this claim phrase is clear and should be resolved.

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[1] Not all patents are asserted against each respondent. Each respondent joins those portions of this brief relevant to the patents asserted against it.

[2] Throughout this brief, all emphasis and color annotations are added unless otherwise noted.

Turning to the ’472 Patent, there are two claim construction disputes of somewhat similar character, namely, the order of the claimed steps and the relationship between them. The first disputed term of the ’472 Patent is directed to a controller that is “configured” or “operable” to perform certain steps (“receive . . . access . . . determine . . . and adjust . . .” certain signals, threshold values, or grounding statuses). Respondents and Staff agree that the “receive,” “determine,” and “adjust” steps must occur in that order and that the “access” step can occur whenever so long as it occurs before the “adjust” step. That proposal is consistent with the claim language itself, the specification, and logic. Although Neodron also agrees that there are ordered relationships between some of the steps, Neodron’s construction—that the “receive” step need not be performed in any particular order or have any temporal relationship to the other steps—is untethered to the intrinsic evidence and falls short. Accordingly, Respondents and Staff’s proposed ordering is the proper one.

The second disputed claim term of the ’472 Patent involves the relationship between two steps, which the parties agree must occur serially as written. Specifically, the disputed element requires determining a non-touch situation for a particular amount of time and then changing a threshold value back to an original value. Although the parties agree that there is an order, they disagree as to whether the second “changing” step is ***in response*** to the first “determining” step. Respondents submit that the change must occur in response to the determination. Conversely, Neodron and Staff’s constructions impose no causal relationship between the two steps, which would allow the second “changing” step to occur any time after the first “determining” step without any nexus between the two and would allow the steps to occur coincidentally even if hours, days, or months apart. That cannot be the proper construction; Respondents’ construction is the proper one.

II. LEGAL STANDARDS

When construing a patent's claims, each claim term should be given the "meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention." *Phillips v. AWH Corp.*, 415 F.3d 1303, 1313 (Fed. Cir. 2005). The patent (the claims and specification) and its prosecution history are the most reliable form of evidence in interpreting claims because this "intrinsic evidence" provides "evidence of how the Patent Office and the inventor understood the patent." *Id.* at 1317. The Federal Circuit "has often emphasized that claims must be read in view of the specification, of which they are a part, and has explained that the specification is always highly relevant to the claim construction analysis. Usually, it is dispositive; it is the single best guide to the meaning of a disputed term." *Praxair, Inc. v. ATMI, Inc.*, 543 F.3d 1306, 1324 (Fed. Cir. 2008) (citations and quotations omitted). Thus, constructions "in tension with . . . the objectives of the [patent] as expressed in the specification and the prosecution history" should be rejected. *Asyst Techs. v. Emtrak, Inc.*, 402 F.3d 1188, 1194 (Fed. Cir. 2005).

The specification may define terms explicitly or by implication. *Irdeto Access, Inc. v. Echostar Satellite Corp.*, 383 F.3d 1295, 1300 (Fed. Cir. 2004) ("Even when guidance is not provided in explicit definitional format, the specification may define claim terms by implication such that the meaning may be found in or ascertained by a reading of the patent documents."); *Phillips*, 415 F.3d at 1321. For example, a claim "requires an ordering of steps . . . when the specification directly or implicitly requires an order of steps" or "when the claim language, as a matter of logic or grammar, requires that the steps be performed in the order written." *mFormation Techs., Inc. v. Research in Motion Ltd.*, 764 F.3d 1392, 1398 (Fed. Cir. 2014) ("As a matter of logic, a mailbox must be established before the contents of said mailbox can be transmitted.").

III. PERSON OF ORDINARY SKILL IN THE ART

The private parties and Staff agree that a person of ordinary skill in the art ("POSITA") would have had a bachelor's degree in electrical engineering, computer engineering, computer science, or a related field, and at least two years of experience in the research, design, development, and/or testing of touch sensors, human-machine interaction and interfaces, and/or graphical user interfaces, and related firmware and software, or the equivalent, with additional education substituting for experience and vice versa. This is the same definition of level of ordinary skill in the art used in U.S.I.T.C. Inv. No. 337-TA-1162. *See Certain Touch-Controlled Mobile Devices, Computers, and Components Thereof*, Inv. No. 337-TA-1162, Order No. 15 at 7-8 (Nov. 25, 2019).

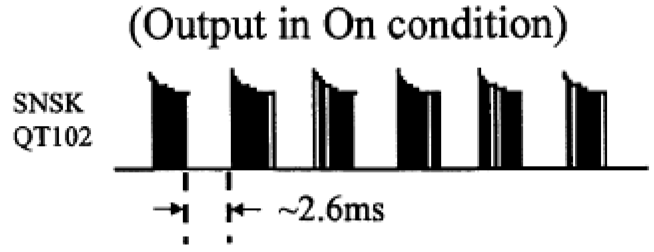
IV. ARGUMENT

The parties dispute terms in only two of the four patents and those disputes are addressed below on a patent-by-patent basis. Respondents have attached as Exhibit 1 a chart identifying the claim constructions to which the parties have agreed for all four patents.

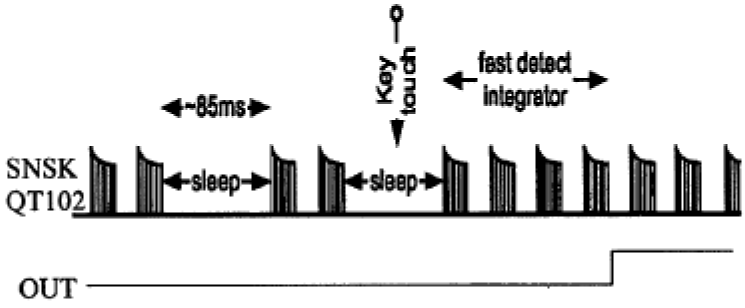
A. U.S. Patent No. 8,749,251

The parties dispute one term in the '251 Patent, "deactivation of measurement of changes in capacitance," which appears in dependent claims 2 and 17. By way of the background, the '251 Patent describes a proximity sensor that automatically switches off a device after a period of nonuse. The patent explains that touch-controlled devices may "remain 'on' or 'active' despite the user having moved away from the device or a particular function no longer being required," thereby wasting power. JX-3, '251 Patent at 1:36-38. To solve this power-wasting problem, the '251 Patent describes a "switch-off" or "auto-off" function that can "deactivate, turn-off, or power down the capacitance measurement circuit" or "power down" the entire apparatus after the user has not touched a key for a predetermined time duration. *See, e.g.*, *id.* at 1:45-54, 2:39-40, 4:55-62, 5:5-7, 16:22-31.

The ’251 Patent describes an integrated circuit chip that acquires measurements of changes in capacitance by employing “bursts of charge-transfer cycles” at regular intervals, which can be incorporated into a device “to provide and control a proximity sensor functionality for the device.” *See id.* at 2:41-42, 4:7-12, 5:57-65. The delay between each burst depends on the “acquisition mode” of the chip—when the chip is in “fast mode,” the “delay between bursts is approximately 2.6 ms,” as shown in Figure 4 below.



Id. at 9:44-49; Fig. 4 (showing time between bursts as 2.6 ms in fast mode). When the chip is in “low power mode,” the chip “sleeps for approximately 85 ms at the end of each burst, saving power but slowing response.” *Id.* at 9:50-53. Upon detection of a possible key touch, the chip “temporarily switches to Fast mode” from its “normal [low power] mode” operation. *Id.* at 9:53-59; *see also id.* at 9:60-10:3. The transition from low power mode to sleep mode is shown in Figure 5:



Id. at Fig. 5 (showing transition from low power mode to fast mode after detection of key touch). "If the touch is confirmed," the chip "will switch to Fast mode." *Id.* at 9:56-57. If a touch is not confirmed, the chip "will revert to normal LP mode operation automatically." *Id.* at 9:57-59.

The '251 Patent also discloses an "auto-off" feature that is relevant to construction of the disputed term. Unlike the previously described fast and low power acquisition modes, the patent explains that the "auto-off" feature can "deactivate, turn-off, or power down the capacitance measurement circuit where an apparatus has inadvertently been left on or with the erroneous perception that a user is still present." *Id.* at 4:47-62. The "auto-off" feature is triggered when, after a set period without a key touch, the chip "produce[s] an output signal automatically to prevent the capacitance measurement circuit from continually measuring changes in capacitance due to, for example, the perceived presence of an object in proximity with the sensor." *Id.* at 4:47-62.

1. "deactivation of measurement of changes in capacitance" (Claims 2 and 17)

Respondents' Construction	Staff's Construction	Neodron's Construction
"stopping all current and scheduled measurements of changes in capacitance"	Plain and ordinary meaning	Plain and ordinary meaning

The "deactivation" limitation appears in dependent claims 2 and 17, which recite "the particular function comprises *deactivation of measurement of changes in capacitance* by the sensing element." JX-3, '251 Patent at 17:55-57; *see also id.* at 18:50-52. Respondents' proposed construction is the only one consistent with the intrinsic record. The plain contextual meaning of "deactivation" of measurement of changes in capacitance means stopping current and any scheduled measurements—not merely scheduling them to occur at a slower rate. Although Neodron asserts a "plain and ordinary meaning," Neodron disclosed during the meet-and-confer process that it seeks to expand this term to include merely slowing down measurements of changes in capacitance, which the specification distinguishes from deactivating measurements.

The ’251 Patent only uses “deactivation” to describe turning the capacitance measurement circuit off and preventing further measurement—the word appears in no other context. The specification explains that after a predetermined time without an object in the sensor’s proximity, “the control circuit can produce an output signal automatically to prevent the capacitance measurement circuit from continually measuring changes in capacitance due to, for example, the perceived presence of an object in proximity with the sensor.” *Id.* at 4:47-54. The patent characterizes this measurement prevention as the ability to “deactivate, turn-off, or power down the capacitance measurement circuit where an apparatus has inadvertently been left on or with the erroneous perception that a user is still present.” *Id.* at 4:55-59.

The ’251 Patent connects “deactivation” with turning off or powering down the capacitance measurement circuit, stating that these may “be referred to as an ‘auto-off’ feature.” *Id.* at 4:55-59. The auto-off feature provides a “signal for preventing the capacitance measurement circuit from continually measuring changes in capacitance [that] may be referred to as an auto-off signal.” *Id.* at 4:60-65. The “auto-off signal” is repeatedly and consistently described as turning off or “effect[ing] powering down the capacitance measurement circuit due to no presence of the user.” *Id.* at 4:66-5:5; *see, e.g., Hologic, Inc. v. SenoRx, Inc.*, 639 F.3d 1329, 1338 (Fed. Cir. 2011) (“Because the specification, including the figures, consistently and exclusively shows radiation sources located asymmetrically about the longitudinal axis, and because that is clearly what the inventors of the ’142 patent conceived of, claim 1 is properly construed as referencing radiation sources [consistent with this exclusive disclosure].”); *ICU Med., Inc. v. Alaris Med. Sys.*, 558 F.3d 1368, 1374-76 (Fed. Cir. 2009) (construing “spike” to require a "pointed tip for piercing" a seal, when the patent "repeatedly and uniformly describe[d] the spike as a pointed instrument."). Thus, the '251 Patent describes the claimed "deactivation" as stopping both current measurements by the capacitance measurement circuit ***and*** scheduled measurements—the system prevents the continued measurement of changes in capacitance. JX-3, '251 Patent at 4:47-5:5.

Respondents' construction finds further support in the invention's purpose. *See Apple Comp., Inc. v. Articulate Sys., Inc.*, 234 F.3d 14, 25 (Fed. Cir. 2000) ("[T]he claim must be interpreted in light of the teachings of the written description and purpose of the invention described therein."); *Kaken Pharm. Co. v. Iancu*, 952 F.3d 1346, 1352 (Fed. Cir. 2020) ("A patent's statement of the described invention's purpose informs the proper construction of claim terms . . . ."). The stated aim of the '251 Patent's invention was to address the problem of "touch-controlled devices [that] remain 'on' or 'active' despite the user having moved away from the device or a particular function no longer being required." JX-3, '251 Patent at 1:37-39. The patent explains that leaving a device on or active "results in the device consuming a large amount of power which is not efficient," *id.* at 1:49-41, and that turning off or deactivating the device when the user has moved away was a "beneficial[]," "green" solution to this problem. *See id.* at 5:11-20 ("The sensor of particular embodiments may be useful in various applications . . . . For example, a coffee machine . . . may be programmed to power-down after a time period of, say, 30 minutes, where the coffee machine has been left on inadvertently. This will beneficially conserve energy use and minimize the possibility of damage or accidents . . . ."), 10:45-46 (explaining that auto-off "can be used to save power in situations where the switched device could be left on inadvertently"), 16:24-26 (describing invention as "oriented towards power control of small appliances and battery-operated products").

Accordingly, the "auto-off" feature "power[s] down" the capacitance measurement circuit (*see id.* 4:47-5:2), "switch[es] off" functions of the apparatus (*id.* at 2:39-40, 2:62-63, 5:48-50), or "turn[s] off power after a specified time delay ranging from minutes to hours" (*id.* at 16:29-34; *see also id.* at 5:5-7 ("[T]he control circuit may be programmed by a user so that it may power down an apparatus based on a user-selected time duration."), 11:59-60 ("In normal operation the QT102 output is turned off automatically after the auto-off delay."), 16:35 (describing "time to shutoff")). In other words, "off" means off, not less frequently. No portion of the '251 Patent's specification or prosecution history suggests a contrary conclusion.

Extrinsic evidence further supports Respondents' construction. Dictionaries define "deactivate" consistent with its use in the specification. One explains "deactivate" means "to make inactive or ineffective." Ex. 2. Another defines deactivate as to "make equipment . . . inactive by disconnecting or destroying it." Ex. 3. This further confirms that a POSITA would have understood the term "deactivation of measurement of changes in capacitance" to mean stopping all current and scheduled measurements of changes in capacitance, as Respondents propose. Neither the intrinsic nor extrinsic evidence indicates that a POSITA would have understood "deactivation" to mean less frequently as Neodron apparently contends.

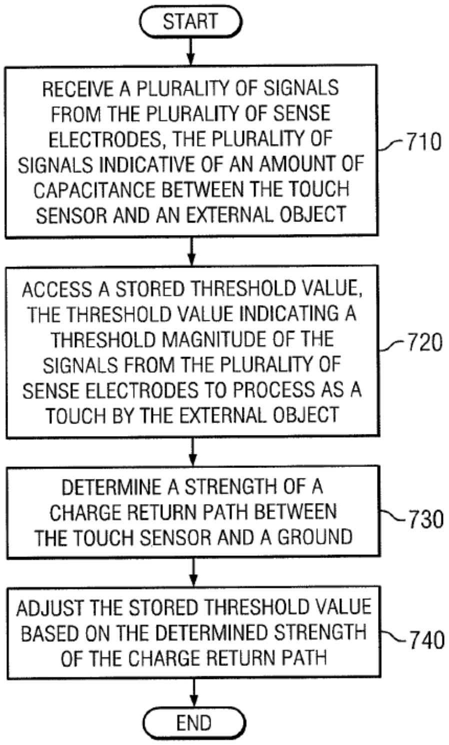
Despite the intrinsic (and extrinsic) evidence, Neodron asserted during the meet-and-confer process that "deactivation" encompasses the 85 ms pauses between bursts in low power or sleep mode as illustrated in Figure 5, crystalizing the dispute that requires resolution. *O2 Micro Int'l Ltd. v. Beyond Innovation Tech. Co.*, 521 F.3d 1351, 1361 (Fed. Cir. 2008) ("A determination that a claim term 'needs no construction' or has the 'plain and ordinary meaning' may be inadequate when a term has more than one 'ordinary' meaning or when reliance on a term's 'ordinary' meaning does not resolve the parties' dispute."). Despite Respondents' repeated requests, Neodron has failed to disclose whether it also contends that "deactivation" encompasses the 2.6 ms pauses between bursts in fast mode as illustrated in Figure 4 above. Regardless, the acquisition modes are distinct concepts described separately in the specification from deactivation or "auto off." *Compare* JX-3, '251 Patent at 9:33-10:3 ("3.1 Acquisition Modes"), *with id.* at 10:41-54 ("3.5 Auto Off Delay"). The specification describes the low power mode as the "normal" mode of operation when the system is intermittently at regular intervals measuring for changes in capacitance. *See, e.g.*, *id.* at 9:57-59. Indeed, the specification refers to "known technologies for measuring capacitance" as including U.S. Patent No. 6,466,036 (*id.* at 4:40-46), which describes the same acquisition modes. *See* Ex. 4, U.S. Patent No. 6,466,036 at 11:23-29, Fig. 16. Deactivation, in contrast, is described as preventing continued measurement of changes in capacitance (JX-3, '251 Patent at 4:47-62), not simply measuring at a different rate (*id.* at 9:50-10:3).

The claims in the '251 Patent's parent patent, U.S. Patent No. 7,952,366, which shares the same specification as the '251 Patent as to the portions relevant here, also make clear that "low power" and "fast" modes are distinct from deactivating the measurement of capacitance. Like the independent claims of the '251 Patent, the independent claims of the '366 Patent also require performing a "function of an apparatus" when no touch has been detected for a predetermined time duration. *Compare* JX-3 at 17:49-54 (claim 1 of the '251 Patent) with Ex. 5 ('366 Patent) at 17:31-37 ('366 Patent claim 1). Dependent claim 2 of the '366 Patent requires that the "capacitance measurement circuit" of claim 1 be "configured to operate in one of more than one acquisition modes," and claims 3 and 4 specify that those acquisition modes are low-power mode (claim 3) and fast mode (claim 4). Ex. 5 ('366 Patent) at 17:48-54 (claims 2-4 of the '366 Patent). Low power and fast modes are acquisition modes of the capacitance measurement circuit; they are not the deactivation or auto-off "function" performed by the apparatus when no touch is detected for a predetermined amount of time. Neodron thus should not be permitted to argue "deactivation" means the time between intermittent bursts in a low-power or fast mode under the guise of "plain and ordinary" meaning. *See In re Katz Interactive Call Processing Patent Litig.*, 639 F.3d 1303, 1325 (Fed. Cir. 2011) (interpreting "customer number" as distinct from "credit card number" in part because claims of parent patent "treat[e]d the two elements as distinct"). Accordingly, Respondents respectfully request that the Court construe "deactivation of measurement of changes in capacitance" as "stopping all current and scheduled measurements of changes in capacitance."

B. U.S. Patent No. 9,411,472

According to the '472 Patent, touch sensors "detect the presence and location of a touch or the proximity of an object (such as a user's finger or a stylus) to the device." JX-4, '472 Patent at 1:60-64. Touch sensors are typically "configured with a single touch detection threshold that is used to determine whether an object is touching the touch sensor." *Id.* at 2:17-19. However, "different grounding scenarios" may occur each time a user "interact[s] with the touch screen." *Id.* at 1:64-2:12. For example, "a device with a touch sensor may be utilized in a 'floating' environment (e.g., an environment where the device is not grounded at all or only has a weak path to ground) such as when a user is interacting with the touch screen of the device as it is sitting on a table or is mounted on a wall." *Id.* The device may also be used in a "grounded" environment, such as "when a user is holding the device with one hand and touching the screen of the device with the other hand, or when the device is plugged into another system while the user is touching the screen." *Id.* The patent explains that changes in grounding status impact the signals measured by the touch sensor "by up to 30% or more" and that as a result, devices with a single touch detection threshold may not “accurately detect[] touches in all grounding scenarios.” *Id.* at 1:64-2:16.

To address this problem, the ’472 Patent’s alleged invention purports to “automatically adapt” or “dynamically adjust touch threshold 52 to account for various grounding scenarios device 20 may encounter” each time the user interacts with the device so it does not “falsely identify noise as a touch” or “result in an undetected touch.” *Id.* at 2:28-33, 6:56-61, 7:15-28. Figure 7 of the ’472 Patent sets forth the method proposed by the patent to dynamically change the touch threshold:



Id. at Fig. 7. First, the touch sensor receives a plurality of signals from the sense electrodes indicating an external object has come close to or has touched the touch sensor. *Id.* at 10:58-11:2. Next, the touch sensor accesses a “stored threshold value,” which refers to a “touch detection threshold” used to determine whether to process the interaction from the external object as a touch. *Id.* at 11:3-10. After the stored threshold value is accessed, the touch sensor determines the grounding status of the device and then adjusts the stored threshold value based on the determined grounding status. *Id.* at 11:11-57.

1. "[a/the] controller communicatively coupled to [a/the] plurality of sense electrodes, the controller [configured/operable] to: receive a plurality of signals from the plurality of sense electrodes associated with an interaction with the touch sensor by an external object, the plurality of signals indicative of an amount of capacitance between the [touch sensor/touch sensitive device] and the external object; access a stored threshold value, the threshold value indicating a threshold magnitude of capacitance; determine a grounding status of the touch sensor based on a strength of a charge return path between the [touch sensor/touch sensitive device] and a ground; adjust the stored threshold value based on the determined grounding status of the touch sensor" (Claims 1 and 13)

Respondents' Construction	Staff's Construction	Neodron's Construction
Order of steps: The step "receive a plurality of signals" must be performed before the step "determine a grounding status," which must be performed before the step "adjust the stored threshold value." The step "access a stored threshold value" can occur at any time before the step "adjust the stored threshold value."	Order of steps: The step "receive a plurality of signals" must be performed before the step "determine a grounding status," which must be performed before the step "adjust the stored threshold value." The step "access a stored threshold value" can occur at any time before the step "adjust the stored threshold value."	The controller is [configured/operable] to perform: • the "access a stored threshold value…" function before the "adjust the stored threshold value..." function; • the "determine a grounding status…" function before the "adjust the stored threshold value" function.

The dispute here centers on the order in which the claimed steps must be performed. The disputed claim element requires a controller configured to perform the following four steps:

> "[1] ***receive*** a plurality of signals from the plurality of sense electrodes associated with an interaction with the touch sensor by an external object, the plurality of signals indicative of an amount of capacitance between the touch sensor and the external object;

> [2] ***access*** a stored threshold value, the threshold value indicating a threshold magnitude of capacitance;
>
> [3] ***determine*** a grounding status of the touch sensor based on a strength of a charge return path between the touch sensor and a ground;
>
> [4] ***adjust*** the stored threshold value based on the determined grounding status of the touch sensor;"

Respondents and Staff agree the claim language and specification require performing these steps in a particular order, namely, step "[1] receiv[ing] a plurality of signals from the plurality of sense electrodes associated with an interaction with the touch sensor by an external object" must occur before step "[3] determin[ing] a grounding status," which must occur before step "[4] adjust[ing] the stored threshold value." Every embodiment in the specification performs the steps in this order, and the alleged invention requires such an order.

By contrast, Neodron argues step "[1] receiv[ing] a plurality of signals" can occur any time, including before or after any of the other required steps. Neodron's proposal is inconsistent with the claim language, basic logic, and every embodiment of the specification. Neodron's construction is also contrary to the alleged advantage provided by the invention.

As described above, the '472 Patent purports to address the problem of variations in capacitance measurements based on the grounding status of the device by proposing a touch sensor that "automatically adapt[s]" or "dynamically adjust[s]" the touch threshold based on the device's grounding status when a user interacts with the device. JX-4, '472 Patent at 2:28-33, 6:56-61, 7:15-28. Respondents and Staff's construction therefore correctly requires that the device "[1] receive" the signals relating to a user's interaction with the device before performing the steps relating to dynamically adjusting the touch threshold for that interaction, namely, "[3] determine a grounding status. . ." and "[4] adjust the stored threshold value. . . ." Performing the "[1] receive" step before the "[3] determine" and "[4] adjust" steps (i.e., dynamically adjusting the threshold) ensures that the threshold used to evaluate the received signals reflects the grounding status of the device when the signals are received, thus making certain that the threshold used does not correspond to a previous, expired grounding status.

The ’472 Patent’s specification supports Respondents and Staff’s construction because the disclosed embodiments exclusively perform the “[1] receive” step before the “[3] determine” and “[4] adjust” steps in order to “dynamically” adjust the threshold based on the device’s grounding status.[3] Figure 7 of the ’472 Patent below—the only figure in the patent describing how the claim terms at issue relate to one another—shows the “RECEIVE” step is performed before the “ACCESS,” “DETERMINE, and “ADJUST” steps:

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[3] *See Regents of Univ. of Minn. v. AGA Med. Corp.*, 717 F.3d 929, 935-36 (Fed. Cir. 2013) (construing “first and second disks” to require “separate[] . . . physically distinct disks” because the “specification never teaches an embodiment constructed as a single piece. Quite the opposite: every single embodiment disclosed in the . . . patent’s drawings and its written description is made up of two separate disks”); *ICU Med., Inc. v. Alaris Med. Sys., Inc.*, 558 F.3d 1368, 1375-76 (Fed. Cir. 2009) (construing “spike” to require a “pointed tip” because “[t]he specification never suggests that the spike can be anything other than pointed” and “each figure depicts the spike as elongated and pointed”).

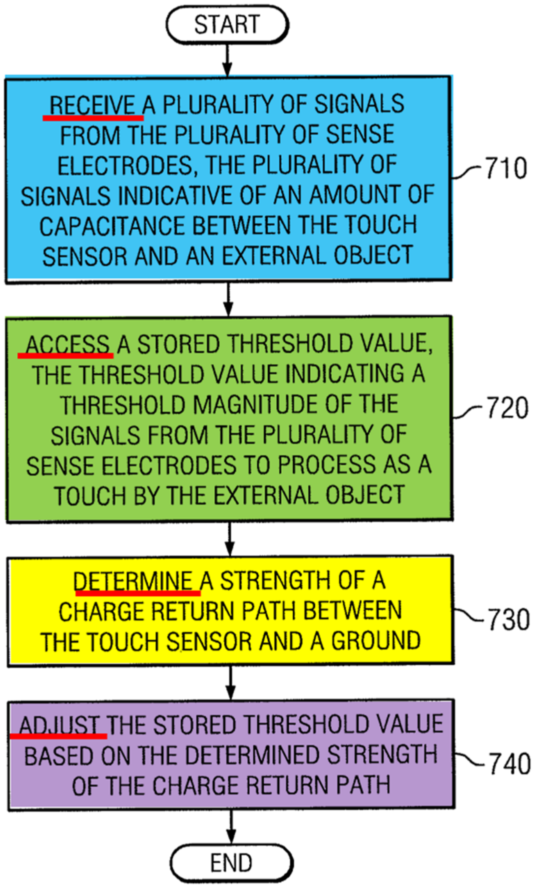

FIG. 7

JX-4, ’472 Patent at Fig. 7 (annotated), 10:58-11:57 (describing the steps in Figure 7). The patent expressly states the method “begins . . . where a plurality of signals from sense electrodes is received.” *Id.* at 10:60-65. Each of the other steps follows. *Id.* at 10:65-11:57.

Indeed, as a matter of “logic,” the “[1] receive,” “[3] determine,” and “[4] adjust” steps “must be performed in the order written.” *See mFormation Techs., Inc. v. Research in Motion Ltd.*, 764 F.3d 1392, 1398 (Fed. Cir. 2014) (requiring order in claim steps and explaining that “[a]s a matter of logic, a mailbox must be established before the contents of said mailbox can be transmitted”). For example, the only description of how the ’472 Patent’s alleged invention operates shows that the “[1] receive” step must occur before the “[3] determine” step, which occurs before the “[4] adjust” step. *See generally* JX-4, ’472 Patent at 7:36-11:57. In this description, the "operation" of the device starts when "an external object such as touch object 38 contacts or comes within close proximity to touch sensor 30"—*i.e.*, the "receive" step. *Id.* at 7:36-49. Then, "***[i]n response to receiving the signals from sense electrodes*** 34 that indicate an amount of capacitance between touch sensor 30 and the external object," the device "access[es] a threshold value . . . that is stored in one or more memory devices accessible to controller 12." *Id.* at 7:50-55. In other words, the "[1] receive" step triggers the "[2] access" step. Then, after describing how the touch sensor determines the grounding status of the device, the specification describes how "touch sensor 30 adjusts the stored threshold value." *Id.* at 10:15-27. Because the "stored threshold value" cannot be "adjust[ed]" unless it is first "accessed" (otherwise there is nothing to adjust), and because the stored threshold value is accessed "in response to" receiving an interaction, the "[1] receive" step must occur before the "[4] adjust" step.

The specification's description of the "[3] determine a grounding status" step also shows it must occur after the "[1] receive" step, but before the "[4] adjust" step by explaining that properties of the object interacting with the touch sensor impact the device's grounding status**.** For example, the specification describes determining the device's grounding status by evaluating whether the received interaction partially or completely covers any portion of any node on the touch screen. *Id.* at 9:6-38. The device's grounding status can also be determined by analyzing the capacitance graph generated by the received interaction and comparing that graph to graphs of known grounded or floating touches. *Id.* at 9:39-61. Determining the grounding status by evaluating whether the received interaction partially covers a touch screen node or comparing the capacitance graph generated by the received interaction to known grounded and floating capacitance graphs is possible only if the "[1] receive" step occurs before the "[3] determine" step. And because the "[4] adjust" step is based on determining the grounding status of the device (the "[3] determine" step), the "[3] determine" step must occur after the "[1] receive" step but before the "[4] adjust" step.

Finally, after describing that the adjusted threshold value can be adjusted back to its "initial value," the description ends by noting "touch sensor 30 stops adjusting touch detection threshold 52 ***until a subsequent interaction with touch sensor 30 is detected***." *Id.* at 10:50-54. This further reinforces the "[1] receive" step (i.e., detecting a subsequent interaction) triggers the remainder of the steps and must thus occur before the "[3] determine" and "[4] adjust" steps, as Staff and Respondents' construction requires. No part of the specification or prosecution history supports a contrary conclusion.

In contrast, Neodron's construction is illogical and inconsistent with the '472 Patent's alleged invention. Not requiring the "[1] receive" step to occur before the "[3] determine" and "[4] adjust" steps—as Neodron's proposed construction allows—would not permit "dynamically" adjusting the touch threshold to ensure that the sensor accurately determines whether or not the received signal is a touch based on the device's current grounding status. If the "[1] receive" step can occur any time ***after*** the "[3] determine" and "[4] adjust" steps, then the threshold value is not "dynamically" adjusted based on the device's current grounding status but is simply dependent on the grounding status of the device whenever the threshold value was last adjusted. For example, if the grounding status is determined and the threshold value is subsequently adjusted at time A, the grounding status of the touch sensor could change between time A and whenever the device receives an interaction at time B, which could be hours, days, or years later. In this scenario, the threshold used to evaluate the interaction at time B may reflect the wrong grounding condition because it was determined at some time—again, hours, days, or years earlier—before the interaction actually occurred. Neodron's proposed construction allows for this scenario, which is contrary to the purpose of the '472 Patent. Thus, Neodron's construction is contrary to the basic tenet of claim construction that claims should be construed in a manner that "achieve[s] the overall object of the invention" (*see Praxair*, 543 F.3d at 1324), and its construction, which is "in tension with . . . the objectives of the [patent] as expressed in the specification and the prosecution history," should be rejected (*see Asyst*, 402 F.3d at 1194).

2. "after adjusting the stored threshold value based on the determined grounding status of the touch sensor: determine that the external object has not touched the touch sensor within a predetermined amount of time; and change the stored threshold value back to an original value, the original value comprising a value of the stored threshold value before it was adjusted based on the determined grounding status of the touch sensor" (Claims 1 and 13)

Respondents' Construction	Staff's Construction	Neodron's Construction
Changing the stored threshold value back to an original value occurs in response to determining that the external object has not touched the touch sensor within a predetermined amount of time	These steps must be performed in the written order.	The controller is [configured/operable] to perform these functions in the written order.

Respondents disagree with Staff and Neodron as to whether the "determin[ing] that the external object has not touched the touch sensor within a predetermined amount of time" step must simply occur before the "chang[ing] the stored threshold value back to an original value" step, or whether the "determin[ing]" step must cause the "chang[ing]" step.

The disputed claim term requires that a controller be configured to perform the following two steps: "[1] determine that the external object has not touched the touch sensor within a predetermined amount of time; and [2] change the stored threshold value back to an original value, the original value comprising a value of the stored threshold value before it was adjusted based on the determined grounding status of the touch sensor." The private parties and Staff agree these steps must be performed in the written order. However, as Respondents propose, the claim language when read in the context of the intrinsic record further requires that the second step ("[2] change the stored threshold value back to an original value") occurs ***in response to*** the first step ("[1] determine that the external object has not touched the touch sensor within a predetermined amount of time"). Without such a construction, the claim term would have a scope that covers scenarios that have no logical connection to the alleged invention. For example, the "[1] determine" step would serve no purpose and effectively be superfluous because the claim would not require that anything be triggered in response to determining that the predetermined amount of time has passed.

The patent's only disclosure relating to determining that no external object has touched the touch sensor within a predetermined amount of time explicitly states that the "determining" step triggers changing the stored threshold value back to an original value:

> In some embodiments, touch sensor 30 periodically drifts the threshold value back to an original threshold value when touch sensor 30 is not tracking any interactions with device 20. ***If*** ***touch sensor 30 does not detect any interactions with device 20 within a predetermined amount of time after an initial touch detection threshold 52 has been adjusted to a new touch detection threshold 52, touch sensor 30 periodically adjusts touch detection threshold 52 back to its initial value at a predetermined rate***. As an example for illustrative purposes only, consider FIG. 5B where initial touch detection threshold 52c of 900 was adjusted to new touch detection threshold 52d of 500. In this example, certain embodiments of touch sensor 30 start a timer after initial touch detection threshold 52c is adjusted to new touch detection threshold 52 d of 500. ***If*** ***the timer reaches a certain predetermined time without touch sensor 30 detecting any subsequent interactions with touch sensor 30, touch detection threshold 52 is periodically adjusted back to initial touch detection threshold 52c of 900 at a predetermined rate***.

JX-4, '472 Patent at 10:28-46. This supports the requirement in Respondents' construction that the second step of "[2] chang[ing] the stored threshold value back to an original value" occurs in response to the first step of "[1] determin[ing] that the external object has not touched the touch sensor within a predetermined amount of time." *See St. Clair Intellectual Prop. Consultants, Inc. v. Apple, Inc.*, No. 10-982-LPS, 2012 WL 3238252, at *4-6 (D. Del. Aug. 7, 2012) (requiring "causal connection or trigger" between two steps in part because the specification supported that requirement); *Regents of Univ. of Minn.*, 717 F.3d at 935-36; *ICU Med.*, 558 F.3d at 1375-76. The specification does not describe any purpose for determining that no external object has touched the touch sensor within a predetermined amount of time other than to trigger changing the stored threshold value back to an original value. Moreover, as explained above, unless the first step ("[1] determine that the external object has not touched the touch sensor within a predetermined amount of time") triggers the second step ("[2] change the stored threshold value back to an original value"), the first step serves no purpose and is effectively superfluous.

The prosecution history also supports Respondents' construction. The applicant achieved allowance only by adding these claim steps, together, to the independent claims. Applicant distinguished a reference that taught periodic adjustment and normalization of output values by asserting:

> while the cited portions of *Land* may disclose a periodic baseline adjustment algorithm where values are incremented or decremented, they do not disclose, teach, or suggest a controller that is configured to "after adjusting the stored threshold value based on the determined grounding status of the touch sensor: ***determine that the external object has not touched the touch sensor within a predetermined amount of time; and change the stored threshold value back to an original value, the original value comprising a value of the stored threshold value before it was adjusted based on the determined grounding status of the touch sensor.***"

Ex. JX-8, '472 Prosecution History at JX-0008.538-539. The applicant added these claim steps to the claim together because there is a causal relationship between them, namely, determining that the external object has not touched the touch sensor within a predetermined amount of time triggers the step of changing the stored threshold value back to an original value. By placing and indenting both of these limitations after the introductory clause "after adjusting the stored threshold value," the applicant created a clear link between these two limitations in order to distinguish them from the periodic threshold adjustment of the prior art, which occurs without regard to touches detected on the sensor.

Staff and Neodron's constructions merely require that the first step occur any time before the second step. Such constructions incorrectly omit any causal relationship between the first step ("[1] determine that the external object has not touched the touch sensor within a predetermined amount of time") and the second step ("[2] change the stored threshold value back to an original value"). Without a causal relationship, the claim term could be satisfied by (1) determining an object has not touched the touch sensor for a period of time, with nothing occurring in response to the determination; and (2) at any time in the future (e.g., minutes, hours, or years later) and for any reason changing the stored threshold back to an original value, where that change is unrelated to an object not touching the touch sensor for a period of time. That does not make sense in view of the intrinsic evidence.

Because the "determine [no touch has occurred]" limitation only makes sense in the broader claim if it causes the threshold value to change back to an original value, Respondents' construction should be adopted.

V. CONCLUSION

For the above reasons, Respondents request their proposed constructions be adopted.

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EXHIBIT 1

EXHIBIT 1 – AGREED CONSTRUCTIONS

U.S. Patent No. 7,821,425

Term	Agreed Construction
"key" (claims 25, 28, 30-39)	"A touchable portion of a mechanical to electrical transducing device that is non-bistable in nature. This term specifically excludes conventional mechanical switches in which two or more electrical conductors are moved into or away from contact with each other to make or break an electrical connection. A 'key' can also be a dimensional sensing surface such as an XY touch screen or a 'trackpad.'"
"sensor values" (claims 25, 30-36, 39)	"sensor signal values"
"bias a determination of [a selected/an active] key as a function of a [previously selected/current active] key" (claims 25, 33)	"bias or skew a determination of [a selected/an active] key as a function of, but not locked to, a [previously selected key/current active key]"

U.S. Patent No. 7,903,092

Term	Agreed Construction
"touch" (claims 1-12)	"human or mechanical contact or proximity to a key"
"activation output signal level" (claim 2)	"output signal level associated with the sensing area above which that sensing area can be selected"

U.S. Patent No 8,749,251

None

U.S. Patent No. 9,411,472

None

EXHIBIT 2

Merriam-Webster's Collegiate® Dictionary

ELEVENTH EDITION

Merriam-Webster, Incorporated
Springfield, Massachusetts, U.S.A.

A GENUINE MERRIAM-WEBSTER

The name *Webster* alone is no guarantee of excellence. It is used by a number of publishers and may serve mainly to mislead an unwary buyer.

Merriam-Webster™ is the name you should look for when you consider the purchase of dictionaries or other fine reference books. It carries the reputation of a company that has been publishing since 1831 and is your assurance of quality and authority.

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day-to-day \ˈdā-tə-ˌdā\ *adj* (1862) **1 :** taking place, made, or done in the course of days ⟨in charge of ~ operations⟩; *also* **:** EVERYDAY ⟨~ life⟩ **2 :** providing for a day at a time with little thought for the future ⟨an aimless ~ existence⟩

day trader *n* (1953) **:** a speculator who seeks profit from the intraday fluctuation in the price of a security or commodity by completing double trades of buying and selling or selling and covering during a single session of the market — **day-trade** \ˈdā-ˌtrād\ *n or vb*

day-trip·per \ˈdā-ˌtri-pər\ *n* (1897) **:** one who takes a trip that does not last overnight

daze \ˈdāz\ *vt* **dazed; daz·ing** [ME *dasen,* fr. ON **dasa;* akin to ON *dasask* to become exhausted] (14c) **1 :** to stupefy esp. by a blow **:** STUN **2 :** to dazzle with light — **daze** *n* — **da·zed·ly** \ˈdā-zəd-lē\ *adv* — **dazed·ness** \ˈdā-zəd-nəs, ˈdāzd-\ *n*

daz·zle \ˈda-zəl\ *vb* **daz·zled; daz·zling** \-z(ə-)liŋ\ [freq. of *daze*] *vi* (15c) **1 :** to lose clear vision esp. from looking at bright light **2 a :** to shine brilliantly **b :** to arouse admiration by an impressive display ~ *vt* **1 :** to overpower with light **2 :** to impress deeply, overpower, or confound with brilliance ⟨*dazzled* us with her wit⟩ — **dazzle** *n* — **daz·zler** \-z(ə-)lər\ *n* — **daz·zling·ly** \-z(ə-)liŋ-lē\ *adv*

dB *abbr* decibel

Db *symbol* dubnium

DB *abbr* daybook

d/b/a *abbr* doing business as

DBA *abbr* doctor of business administration

DBCP \ˌdē-(ˌ)bē-(ˌ)sē-ˈpē\ *n* [*d*i- + *b*rom- + *c*hlor- + *p*ropane] (1967) **:** a compound $C_3H_5Br_2Cl$ used esp. formerly as an agricultural pesticide that is a suspected carcinogen and cause of sterility in human males

DBE *abbr* Dame Commander of the Order of the British Empire

DBH *abbr* diameter at breast height

dbl *or* **dble** *abbr* double

DBMS *abbr* database management system

DBS *abbr* direct broadcast satellite

DC *abbr* **1** [It *da capo*] from the beginning **2** decimal classification **3** direct current **4** District of Columbia **5** doctor of chiropractic **6** double crochet

DChE *abbr* doctor of chemical engineering

DCL *abbr* **1** doctor of canon law **2** doctor of civil law

dd *abbr* **1** dated **2** delivered

DD *abbr* **1** days after date **2** demand draft **3** dishonorable discharge **4** doctor of divinity **5** due date

D-day *n* [*D,* abbr. for *day*] (1918) **:** a day set for launching an operation; *specif* **:** June 6, 1944, on which Allied forces began the invasion of France in World War II

ddC \ˌdē-(ˌ)dē-ˈsē\ *n, often all cap* [*d*i- + *d*eoxy + *c*ytidine] (1986) **:** a synthetic nucleoside $C_9H_{13}N_3O_3$ that inhibits replication of retroviruses and is used in the treatment of advanced HIV infection — called also *zalcitabine*

DDC *abbr* Dewey Decimal Classification

DDD \ˌdē-(ˌ)dē-ˈdē\ *n* [*d*ichlor- + *d*iphenyl + *d*ichlor-] (1946) **:** an insecticide $C_{14}H_{10}Cl_4$ closely related chemically and similar in properties to DDT

DDE \ˌdē-(ˌ)dē-ˈē\ *n* [*d*ichlor- + *d*iphenyl + *e*thylene] (1949) **:** a persistent organochlorine $C_{15}H_8Cl_4$ that is produced by the metabolic breakdown of DDT

ddI \ˌdē-(ˌ)dē-ˈī\ *n, often all cap* [*d*i- + *d*eoxy + *i*nosine, a nucleoside] (1988) **:** a synthetic nucleoside $C_{10}H_{12}N_4O_3$ having properties and uses similar to those of ddC — called also *didanosine*

DDS *abbr* doctor of dental surgery

DDT \ˌdē-(ˌ)dē-ˈtē\ *n* [*d*ichlor- + *d*iphenyl + *t*richlor- (fr. *tri-* + *chlor-*)] (1943) **:** a colorless odorless water-insoluble insecticide $C_{14}H_9Cl_5$ that is an aromatic organochlorine banned in the U.S. that tends to accumulate and persist in ecosystems and has toxic effects on many vertebrates

DDVP \ˌdē-(ˌ)dē-ˌvē-ˈpē\ *n* [*d*imethyl + *d*ichlor- + *v*inyl + *p*hosphate] (1954) **:** DICHLORVOS

DE *abbr* **1** defensive end **2** Delaware **3** diatomaceous earth **4** doctor of engineering

de- *prefix* [ME, fr. AF *de-, des-,* partly fr. L *de-* from, down, away (fr. *de,* prep.) and partly fr. L *dis-;* L *de* akin to OIr *di* from, OE *tō* to — more at TO, DIS-] **1 a :** do the opposite of ⟨*de*activate⟩ **b :** reverse of ⟨*de*-emphasis⟩ **2 a :** remove (a specified thing) from ⟨*de*louse⟩ **b :** remove from (a specified thing) ⟨*de*throne⟩ **3 :** reduce ⟨*de*value⟩ **4 :** something derived from (a specified thing) ⟨*de*compound⟩ **:** derived from something (of a specified nature) ⟨*de*nominative⟩ **5 :** get off of (a specified thing) ⟨*de*train⟩ **6 :** having a molecule characterized by the removal of one or more atoms (of a specified element) ⟨*de*oxy-⟩

DEA *abbr* Drug Enforcement Administration

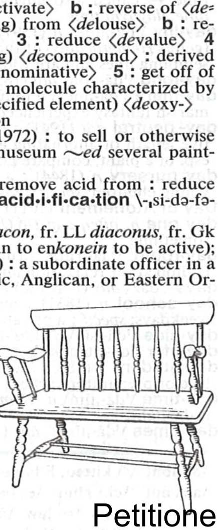
de·ac·ces·sion \ˌdē-ik-ˈse-shən, -ak-\ *vt* (1972) **:** to sell or otherwise dispose of (an item in a collection) ⟨the museum ~*ed* several paintings⟩ — **deaccession** *n*

de·acid·i·fy \ˌdē-ə-ˈsi-də-ˌfī\ *vt* (1786) **:** to remove acid from **:** reduce the acidity of (as by neutralization) — **de·acid·i·fi·ca·tion** \-ˌsi-də-fə-ˈkā-shən\ *n*

dea·con \ˈdē-kən\ *n* [ME *dekene,* fr. OE *dēacon,* fr. LL *diaconus,* fr. Gk *diakonos,* lit., servant, fr. *dia-* + *-konos* (akin to en*konein* to be active); perh. akin to L *conari* to attempt] (bef. 12c) **:** a subordinate officer in a Christian church: as **a :** a Roman Catholic, Anglican, or Eastern Orthodox cleric ranking next below a priest **b :** one of the laymen elected by a church with congregational polity to serve in worship, in pastoral care, and on administrative committees **c :** a Mormon in the lowest grade of the Aaronic priesthood

dea·con·ess \ˈdē-kə-nəs\ *n* (15c) **:** a woman chosen to assist in the church ministry; *specif* **:** one in a Protestant order

deacon's bench *n* (1922) **:** a bench with usu. spindled arms and back



deacon's bench

de·ac·ti·vate \(ˌ)dē-ˈak-tə-ˌvāt\ *vt* (1926) **:** to make inactive or ineffective ⟨~ a bomb⟩ ⟨~ a chemical compound⟩ — **de·ac·ti·va·tion** \(ˌ)dē-ˌak-tə-ˈvā-shən\ *n* — **de·ac·ti·va·tor** \(ˌ)dē-ˈak-tə-ˌvā-tər\ *n*

^{1}**dead** \ˈded\ *adj* [ME *deed,* fr. OE *dēad;* akin to ON *dauthr* dead, *deyja* to die, OHG *tōt* dead — more at DIE] (bef. 12c) **1 :** deprived of life **:** no longer alive **2 a (1) :** having the appearance of death **:** DEATHLY ⟨in a ~ faint⟩ **(2) :** lacking power to move, feel, or respond **:** NUMB **b :** very tired **c (1) :** incapable of being stirred emotionally or intellectually **:** UNRESPONSIVE ⟨~ to pity⟩ **(2) :** grown cold **:** EXTINGUISHED ⟨~ coals⟩ **3 a :** INANIMATE, INERT ⟨~ matter⟩ **b :** BARREN, INFERTILE ⟨~ soil⟩ **c :** no longer producing or functioning **:** EXHAUSTED ⟨a ~ battery⟩ **4 a (1) :** lacking power or effect ⟨a ~ law⟩ **(2) :** no longer having interest, relevance, or significance ⟨a ~ issue⟩ **b :** no longer in use **:** OBSOLETE ⟨a ~ language⟩ **c :** no longer active **:** EXTINCT ⟨a ~ volcano⟩ **d :** lacking in gaiety or animation ⟨a ~ party⟩ **e (1) :** lacking in commercial activity **:** QUIET **(2) :** commercially idle or unproductive ⟨~ capital⟩ **f :** lacking elasticity ⟨a ~ tennis ball⟩ **g :** being out of action or out of use ⟨the phone went ~⟩; *specif* **:** free from any connection to a source of voltage and free from electric charges **h (1) :** being out of play ⟨a ~ ball⟩ **(2) :** temporarily forbidden to play or to make a certain play in croquet **5 a :** not running or circulating **:** STAGNANT ⟨~ water⟩ **b :** not turning ⟨the ~ center of a lathe⟩ **c :** not imparting motion or power although otherwise functioning ⟨a ~ rear axle⟩ **d :** lacking warmth, vigor, or taste **6 a :** absolutely uniform ⟨a ~ level⟩ **b (1) :** UNERRING **(2) :** EXACT ⟨~ center of the target⟩ **(3) :** certain to be doomed ⟨he's ~ if he's late for curfew⟩ **(4) :** IRREVOCABLE ⟨a ~ loss⟩ **c :** ABRUPT ⟨brought to a ~ stop⟩ **d (1) :** COMPLETE, ABSOLUTE ⟨a ~ silence⟩ **(2) :** ALL-OUT ⟨caught it on the ~ run⟩ **7 :** devoid of former occupants ⟨~ villages⟩ — **dead·ness** *n* — **dead in the water 1 :** incapable of being effective **:** STALLED ⟨peace talks were *dead in the water*⟩ **2 :** as good as dead **:** DOOMED ⟨most books are *dead in the water* long before their publication —Phillip Lopate⟩ — **dead to rights :** with no chance of escape or excuse **:** RED-HANDED ⟨had him *dead to rights* for the robbery⟩ — **over one's dead body :** only by overcoming one's utter and determined resistance ⟨vows that they'll raise his taxes *over his dead body*⟩

syn DEAD, DEFUNCT, DECEASED, DEPARTED, LATE mean devoid of life. DEAD applies literally to what is deprived of vital force but is used figuratively of anything that has lost any attribute (as energy, activity, radiance) suggesting life ⟨a *dead,* listless performance⟩. DEFUNCT stresses cessation of active existence or operation ⟨a *defunct* television series⟩. DECEASED, DEPARTED, and LATE apply to persons who have died recently. DECEASED is the preferred term in legal use ⟨the estate of the *deceased*⟩. DEPARTED is used usu. as a euphemism ⟨our *departed* sister⟩. LATE is used esp. with reference to a person in a specific relation or status ⟨the company's *late* president⟩.

^{2}**dead** *n, pl* **dead** (bef. 12c) **1 :** one that is dead — usu. used collectively **2 :** the state of being dead ⟨raised him from the ~ —Col 2:12(RSV)⟩ **3 :** the time of greatest quiet ⟨the ~ of night⟩

^{3}**dead** *adv* (14c) **1 :** ABSOLUTELY, UTTERLY ⟨~ certain⟩ ⟨finished ~ last⟩ **2 :** suddenly and completely ⟨stopped ~⟩ **3 :** DIRECTLY ⟨~ ahead⟩

dead air *n* (ca. 1943) **:** a period of silence esp. during a broadcast

dead-air space \ˈded-ˈer-\ *n* (1902) **:** an unventilated air space

^{1}**dead·beat** \ˈded-ˌbēt\ *n* (1863) **1 :** LOAFER **2 :** one who persistently fails to pay personal debts or expenses

^{2}**deadbeat** *adj* (ca. 1864) **:** having a pointer that gives a reading with little or no oscillation

dead bolt *n* (ca. 1902) **:** a lock bolt that is moved by turning a knob or key without action of a spring

dead-cat bounce *n* [fr. the facetious notion that even a dead cat would bounce slightly if dropped from a sufficient height] (1985) **:** a brief and insignificant recovery (as of stock prices) after a steep decline

dead duck *n* (1943) **:** one that is doomed

dead·en \ˈde-dᵊn\ *vb* **dead·ened; dead·en·ing** \ˈded-niŋ, ˈde-dᵊn-iŋ\ *vt* (1613) **1 :** to impair in vigor or sensation **:** BLUNT ⟨~*ed* his enthusiasm⟩ ⟨~*ed* the pain⟩ **2 a :** to deprive of brilliance **b :** to make vapid or spiritless ⟨oxygen ~*s* wine⟩ **c :** to make (as a wall) impervious to sound **3 :** to deprive of life **:** KILL ~ *vi* **:** to become dead **:** lose life or vigor — **dead·en·er** \ˈded-nər, -dᵊn-ər\ *n* — **dead·en·ing·ly** \-niŋ-lē, -dᵊn-iŋ-\ *adv*

^{1}**dead-end** \ˈded-ˌend\ *adj* (1919) **1 a :** lacking opportunities esp. for advancement ⟨a ~ job⟩ **b :** lacking an exit ⟨a ~ street⟩ **2 :** UNRULY ⟨~ kids⟩ — **dead-end·ed·ness** \ˌded-ˈen-dəd-nəs\ *n*

^{2}**dead-end** \ˈded-ˈend\ *vi* (1944) **:** to come to a dead end **:** TERMINATE ⟨the road ~*s* at the lake⟩ ⟨the investigation ~*ed*⟩

dead end \ˈded-ˈend\ *n* (1886) **1 :** an end (as of a street) without an exit **2 :** a position, situation, or course of action that leads to nothing further

dead·en·ing *n* (ca. 1874) **:** material used to soundproof walls or floors

dead·eye \ˈded-ˌī\ *n* (1748) **1 :** a rounded wood block encircled by a rope or an iron band and having holes to receive the lanyard that is used esp. to set up shrouds and stays **2 :** an unerring marksman

deadeye

dead·fall \-ˌfȯl\ *n* (1598) **1 :** a trap so constructed that a weight (as a heavy log) falls on an animal and kills or disables it **2 :** a tangled mass of fallen trees and branches

dead hand *n* (14c) **1 :** MORTMAIN 1 **2 :** the oppressive influence of the past

^{1}**dead·head** \ˈded-ˌhed\ *n* (1841) **1 :** one who has not paid for a ticket **2 :** a dull or stupid person **3 :** a partially submerged log

^{2}**deadhead** *vi* (1911) **1 :** to make esp. a return trip without a load **2 :** to deadhead a plant ~ *vt* **:** to remove the faded flowers of (a plant) esp. to keep a neat appearance and to promote reblooming by preventing seed production

dead heat *n* (1796) **:** a tie with no single winner of a race; *broadly* **:** TIE

dead horse *n* (1830) **:** an exhausted or profitless topic or issue — usu. used in the phrases *beat a dead horse* and *flog a dead horse*

dead letter *n* (1627) **1 :** something that has lost its force or authority without being formally abolished **2 :** a letter that is undeliverable and unreturnable by the post office

EXHIBIT 3

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Catherine Soanes
with Sara Hawker
and Julia Elliott

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deacon /dee-kuhn/ • n. **1** (in the Roman Catholic, Anglican, and Orthodox Churches) a minister ranking below a priest. **2** (in some Protestant Churches) a person who assists a minister but is not a member of the clergy.
– ORIGIN Greek *diakonos* 'servant'.

deaconess • n. a woman with duties similar to those of a deacon.

deactivate • v. (**deactivates, deactivating, deactivated**) make equipment or a virus inactive by disconnecting or destroying it.

dead • adj. **1** no longer alive. **2** (of a part of the body) numb. **3** showing no emotion: *a cold, dead voice.* **4** no longer current or important. **5** lacking activity or excitement. **6** (of equipment) not working. **7** complete: *dead silence.* • adv. **1** completely; exactly: *dead on time.* **2** directly: *dead ahead.* **3** Brit. informal very.
– PHRASES **the dead of night** the quietest, darkest part of the night. **the dead of winter** the coldest part of winter. **from the dead** from being dead.
– DERIVATIVES **deadness** n.
– ORIGIN Old English.

deadbeat • adj. (**dead beat**) informal completely exhausted. • n. informal a lazy or unreliable person.

dead duck • n. informal an unsuccessful or useless person or thing.

deaden • v. **1** make a noise or feeling less intense. **2** make something numb.

dead end • n. a road or passage that is closed at one end.

dead hand • n. an undesirable and long-lasting influence.

dead heat • n. a result in a race in which two or more competitors finish at exactly the same time.

dead letter • n. a law or treaty which is no longer applied in practice.

deadline • n. the latest time or date by which something should be completed.

deadlock • n. **1** a situation in which no progress can be made. **2** Brit. a lock operated by a key. • v. (**be deadlocked**) be unable to make progress.

dead loss • n. an unproductive or useless person or thing.

deadly • adj. (**deadlier, deadliest**) **1** causing or able to cause death. **2** (of a voice, glance, etc.) filled with hate. **3** very accurate or effective. **4** informal very boring. • adv. **1** in a way that resembles death. **2** very: *she was deadly serious.*
– DERIVATIVES **deadliness** n.

deadly nightshade • n. a poisonous plant with purple flowers and round black fruit.

deadly sin • n. (in Christian tradition) a sin seen as leading to damnation.

deadpan • adj. not showing any emotion; expressionless.

dead reckoning • n. a way of finding out your position by estimating the direction and distance travelled.

dead ringer • n. a person or thing that looks very like another.

deadweight • n. **1** a person or thing that is very heavy and difficult to lift. **2** the total weight which a ship can carry.

dead wood • n. useless or unproductive people or things.

deaf • adj. **1** wholly or partially unable to hear. **2** (**deaf to**) unwilling to listen to.
– PHRASES **fall on deaf ears** be ignored. **turn a deaf ear** refuse to listen or respond.
– DERIVATIVES **deafness** n.
– ORIGIN Old English.

deafen • v. **1** make someone deaf. **2** (as adj. **deafening**) very loud.

deaf mute • n. offens. a person who is deaf and unable to speak.

deal¹ • v. (**deals, dealing, dealt**) **1** (**deal something out**) distribute something. **2** (usu. **deal in**) buy and sell a product commercially. **3** buy and sell illegal drugs. **4** give out cards to players for a game or round. • n. **1** an agreement between two or more parties. **2** a particular form of treatment given or received: *working mothers get a bad deal.*
– PHRASES **a big deal** informal an important thing. **deal someone/thing a blow** hit or be harmful to someone or something. **a deal of** a large amount of. **deal with 1** do business with. **2** take action to put right. **3** cope with. **4** have something as a subject. **a good** (or **great**) **deal 1** a large amount. **2** much; a lot. **a square deal** a fair bargain or treatment.
– ORIGIN Old English.

deal² • n. fir or pine wood (as a building material).
– ORIGIN German and Dutch *dele* 'plank'.

dealer • n. **1** a person who buys and sells goods. **2** a person who sells illegal drugs. **3** a player who deals cards in a card game.
– DERIVATIVES **dealership** n.

dealt past part. of DEAL¹.

dean • n. **1** the head of the governing body of a cathedral. **2** the head of a university department or of a medical school. **3** a college officer who deals with discipline and welfare.
– ORIGIN Old French *deien*.

deanery • n. (pl. **deaneries**) the official house of a dean.

EXHIBIT 4

US006466036B1

(12) United States Patent
Philipp

(10) **Patent No.: US 6,466,036 B1**
(45) **Date of Patent: Oct. 15, 2002**

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(54) **CHARGE TRANSFER CAPACITANCE MEASUREMENT CIRCUIT**

(76) Inventor: **Harald Philipp**, 7 Cirrus Gardens, Hamble Hampshire SO31 4RH (GB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Sep. 7, 1999**

Related U.S. Application Data

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(51) **Int. Cl.^{7}** **G01R 27/26**
(52) **U.S. Cl.** **324/678**; 324/658
(58) **Field of Search** 324/678, 658, 324/661, 663, 665, 676, 679

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Primary Examiner—N. Le
Assistant Examiner—T. R. Sundaram
(74) *Attorney, Agent, or Firm*—David Kiewit

(57) **ABSTRACT**

Pulse circuits for measuring the capacitance to ground of a plate may be used in control equipment to provide an indication of the proximity of a person or object to be sensed. Pulse circuits are disclosed that are made from sets of three or more electrical switching elements arranged so that each of the switching elements has one side electrically connected to either a supply voltage or to an electrical ground. These arrangements are compatible with existing integrated circuit fabrication technology. In addition, the circuitry can be configured as a proximity sensing switch that requires only a two wire connection to a host apparatus.

39 Claims, 14 Drawing Sheets

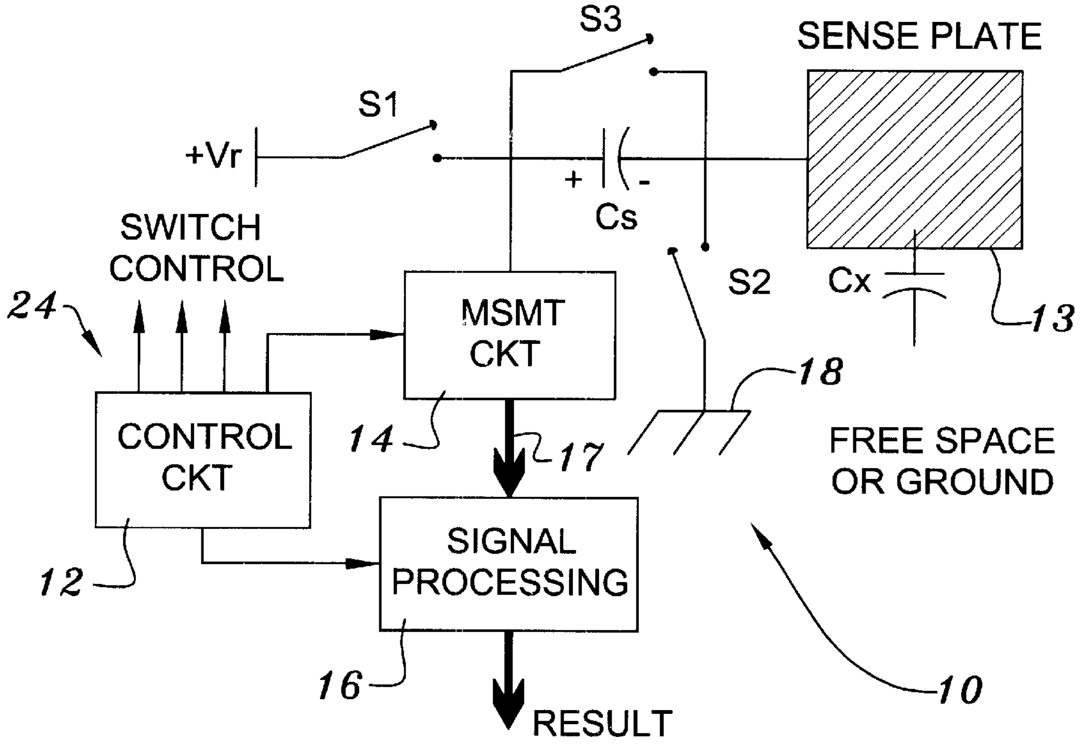
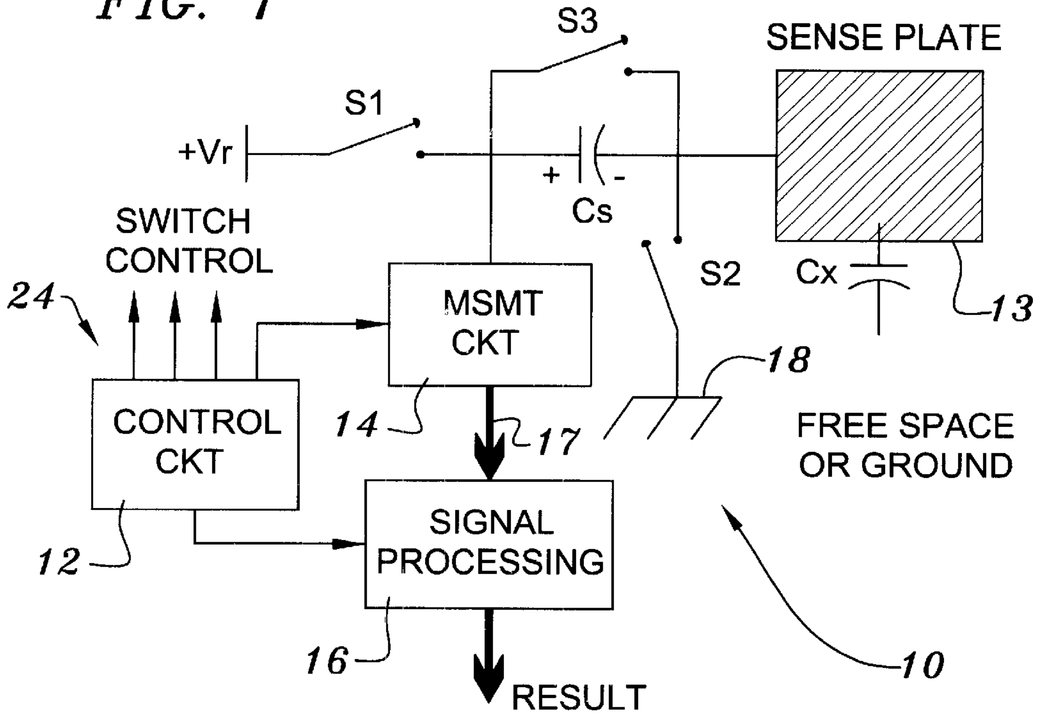


FIG. 1



LOOP

STEP	S1	S2	S3	FUNCTION
A	-	X	X	RESET ALL
B	-	-	-	DEADTIME
C	X	-	-	CHARGE-TRANSFER
D	-	-	-	DEADTIME
E	-	X	-	HOLD
F	-	X	-	MEASURE

FIG. 2

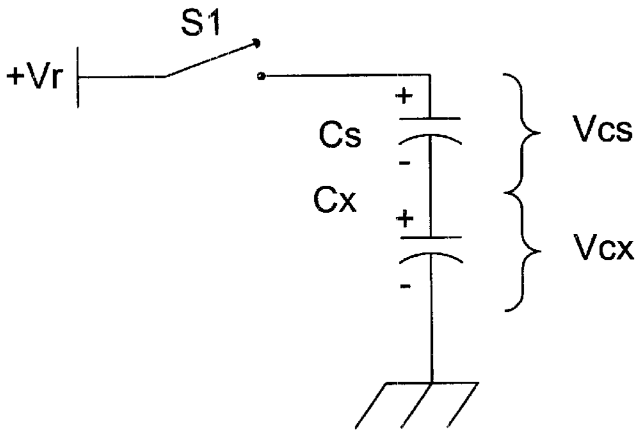


FIG. 3

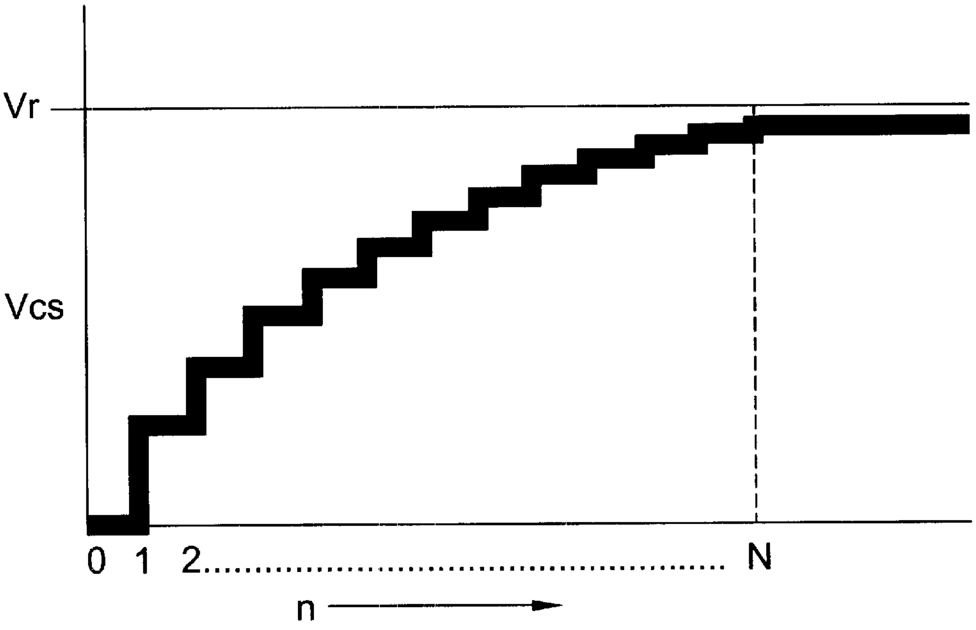
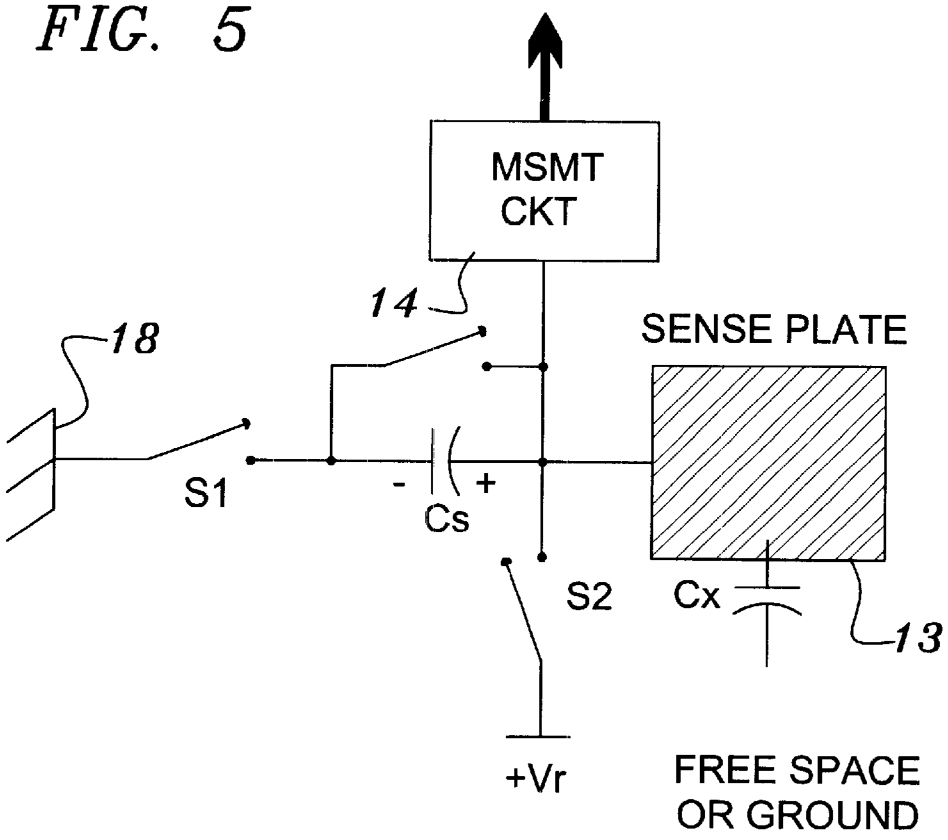


FIG. 4

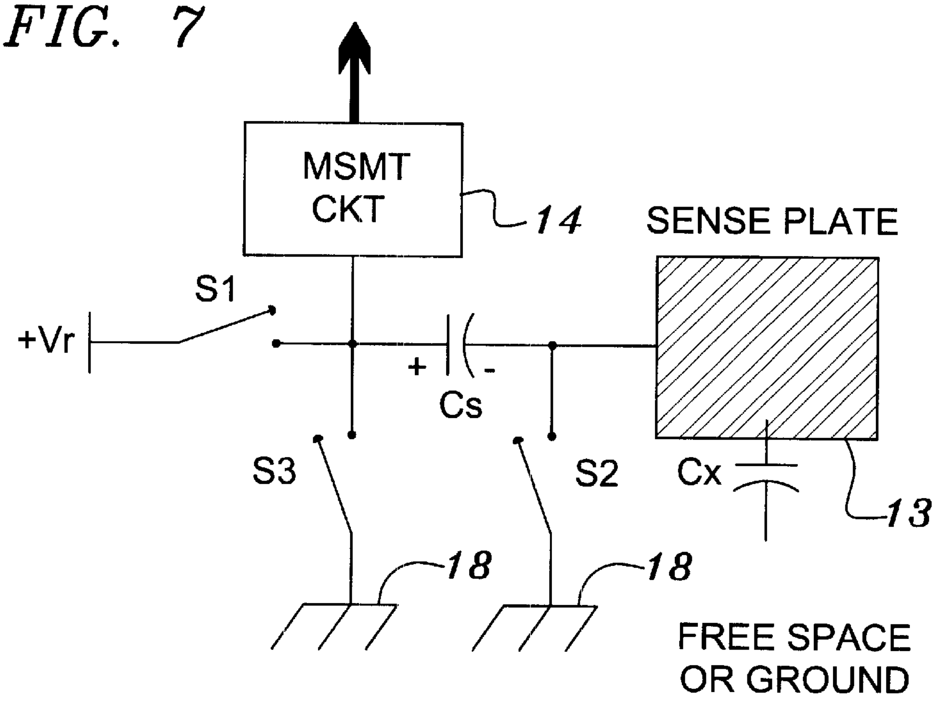
FIG. 5



	STEP	S1	S2	S3	FUNCTION
	A	X	-	X	RESET ALL
LOOP	B	-	-	-	DEADTIME
	C	-	X	-	CHARGE
	D	-	-	-	DEADTIME
	E	X	-	-	TRANSFER
	F	X	-	-	MEASURE

FIG. 6

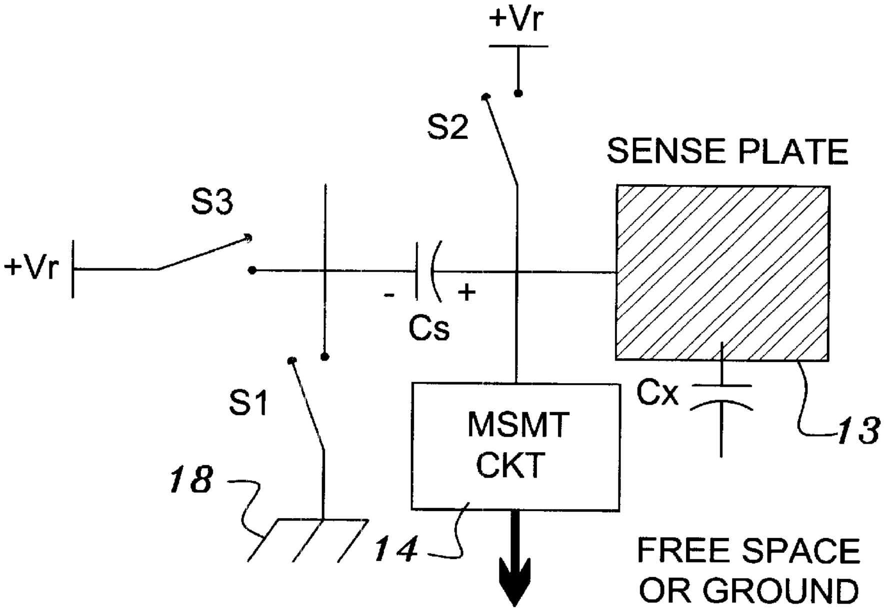
FIG. 7



	STEP	S1	S2	S3	FUNCTION
	A	-	X	X	RESET ALL
LOOP	B	-	-	-	DEADTIME
	C	X	-	-	CHARGE-TRANSFER
	D	-	-	-	DEADTIME
	E	-	X	-	HOLD
	F	-	X	-	MEASURE (HOLD)

FIG. 8

FIG. 9



LOOP

STEP	S1	S2	S3	FUNCTION
A	-	X	X	RESET Cs, CHARGE Cx
B	-	-	-	DEADTIME
C	-	X	-	CHARGE
D	-	-	-	DEADTIME
E	X	-	-	TRANSFER
F	X	-	-	MEASURE

FIG. 10

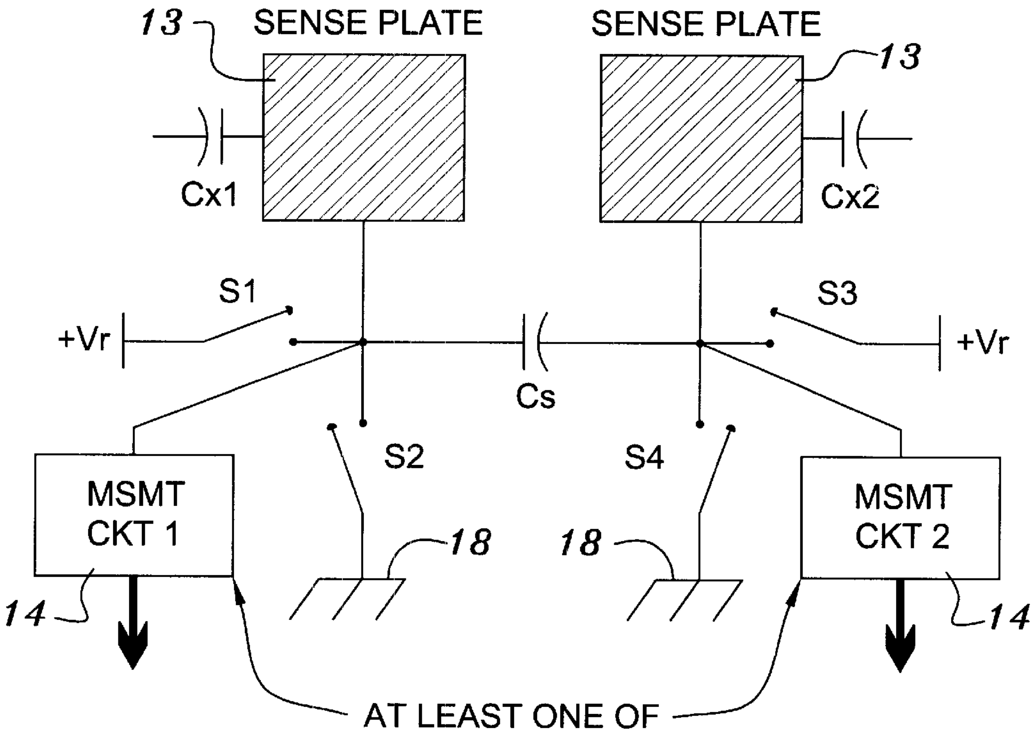

13
SENSE PLATE
SENSE PLATE
13
Cx1
Cx2
S1
S3
+Vr
+Vr
Cs
S2
S4
MSMT
CKT 1
MSMT
CKT 2
18
18
14
14
AT LEAST ONE OF

FIG. 11

						Cx FUNCTION	
	STEP	S1	S2	S3	S4	Cx1	Cx2
	A	-	X	-	X	RESET	RESET
LOOP	B	-	-	-	-	DEADTIME	DEADTIME
	C	X	-	-	-	CHARGE	CHG-TRANS
	D	-	-	-	-	DEADTIME	DEADTIME
	E	-	-	-	X	TRANSFER	HOLD
	F	-	-	-	-	DEADTIME	DEADTIME
	G	-	-	-	X	MEASURE 2	
	G'	X	-	-	-	MEASURE 1	

FIG. 12

						Cx FUNCTION	
	STEP	S1	S2	S3	S4	Cx1	Cx2
	A	-	X	-	X	RESET	RESET
LOOP	B	-	-	-	-	DEADTIME	DEADTIME
	C	-	-	X	-	CHG-TRANS	CHARGE
	D	-	-	-	-	DEADTIME	DEADTIME
	E	-	X	-	-	HOLD	TRANSFER
	F	-	-	-	-	DEADTIME	DEADTIME
	G	-	X	-	-	MEASURE 2	
	G'	-	-	X	-	MEASURE 1	

FIG. 13

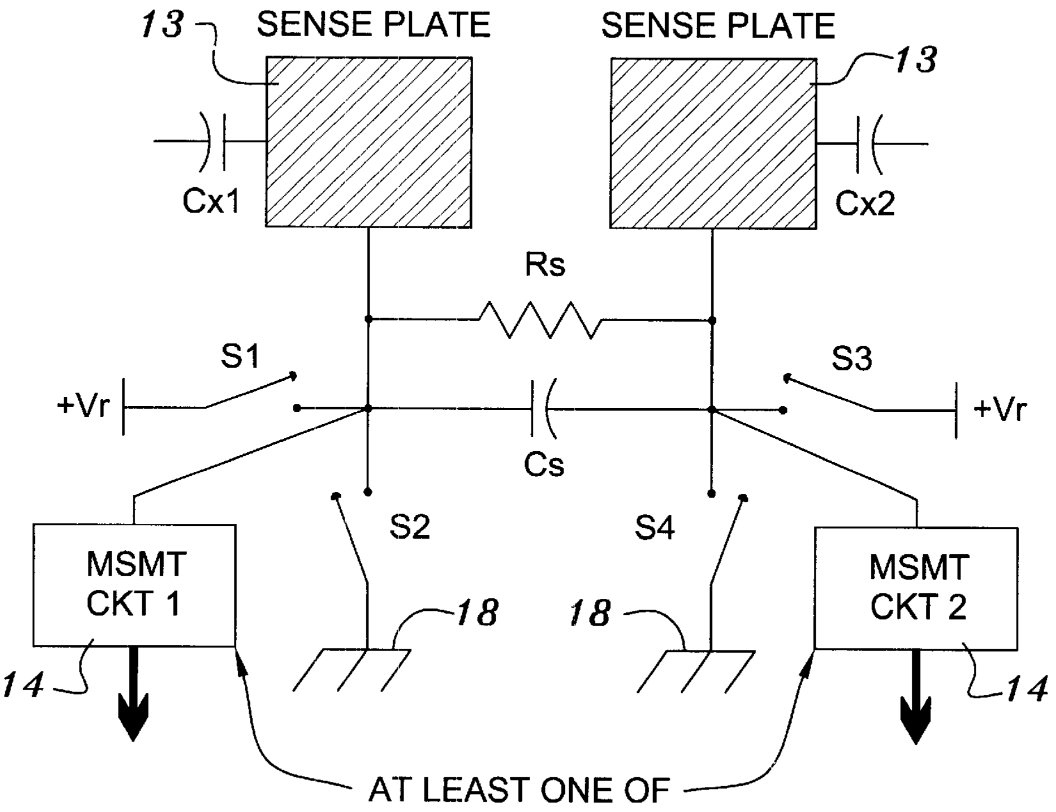

13
SENSE PLATE
SENSE PLATE
13
Cx1
Cx2
Rs
S1
S3
+Vr
+Vr
Cs
S2
S4
MSMT CKT 1
MSMT CKT 2
18
18
14
14
AT LEAST ONE OF

FIG. 14

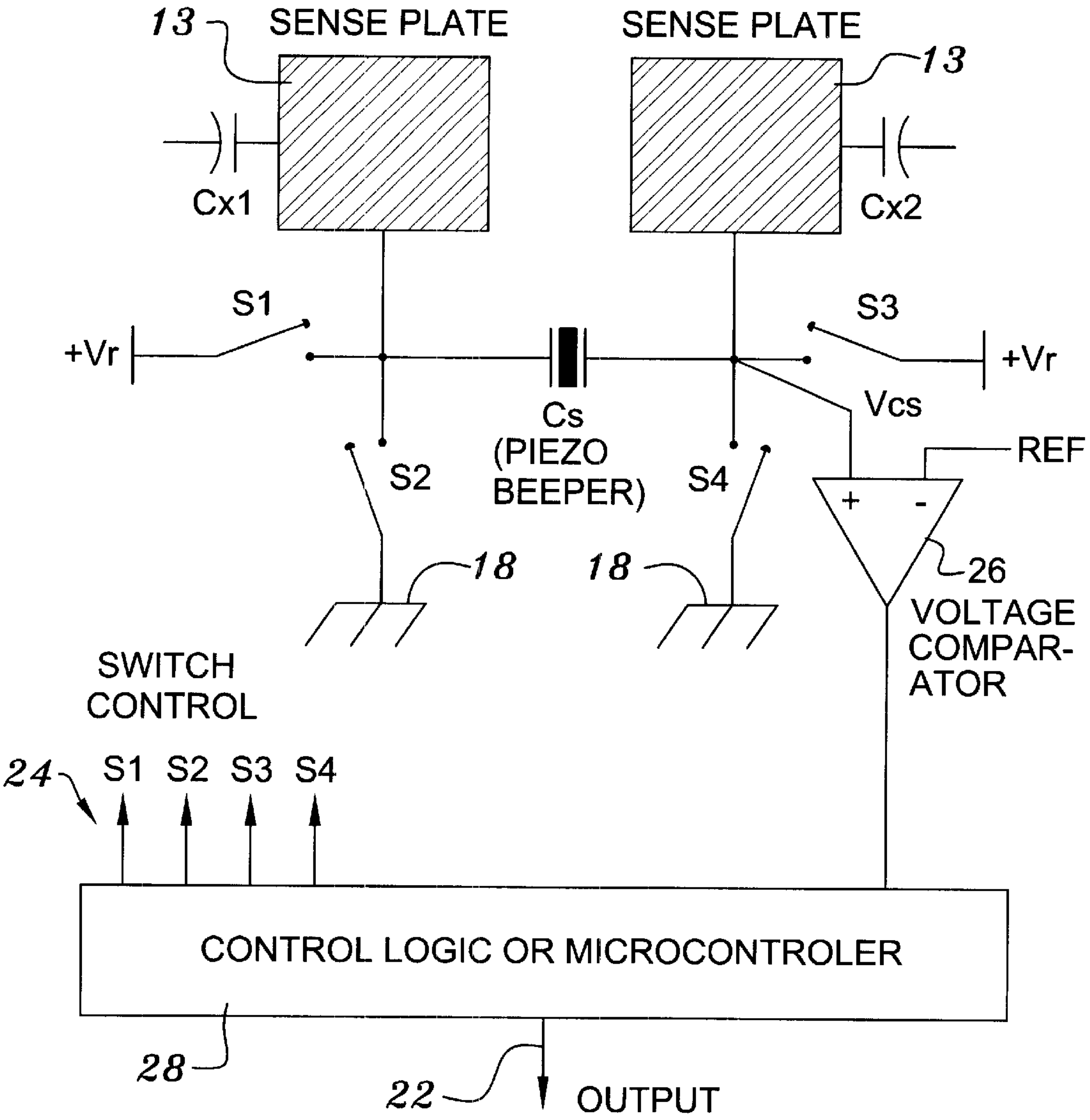

13
SENSE PLATE
SENSE PLATE
13
Cx1
Cx2
S1
+Vr
S3
+Vr
Cs
(PIEZO
BEEPER)
Vcs
REF
S2
S4
+
-
26
18
18
VOLTAGE
COMPAR-
ATOR
SWITCH
CONTROL
24
S1 S2 S3 S4
CONTROL LOGIC OR MICROCONTROLER
28
22
OUTPUT

FIG. 15

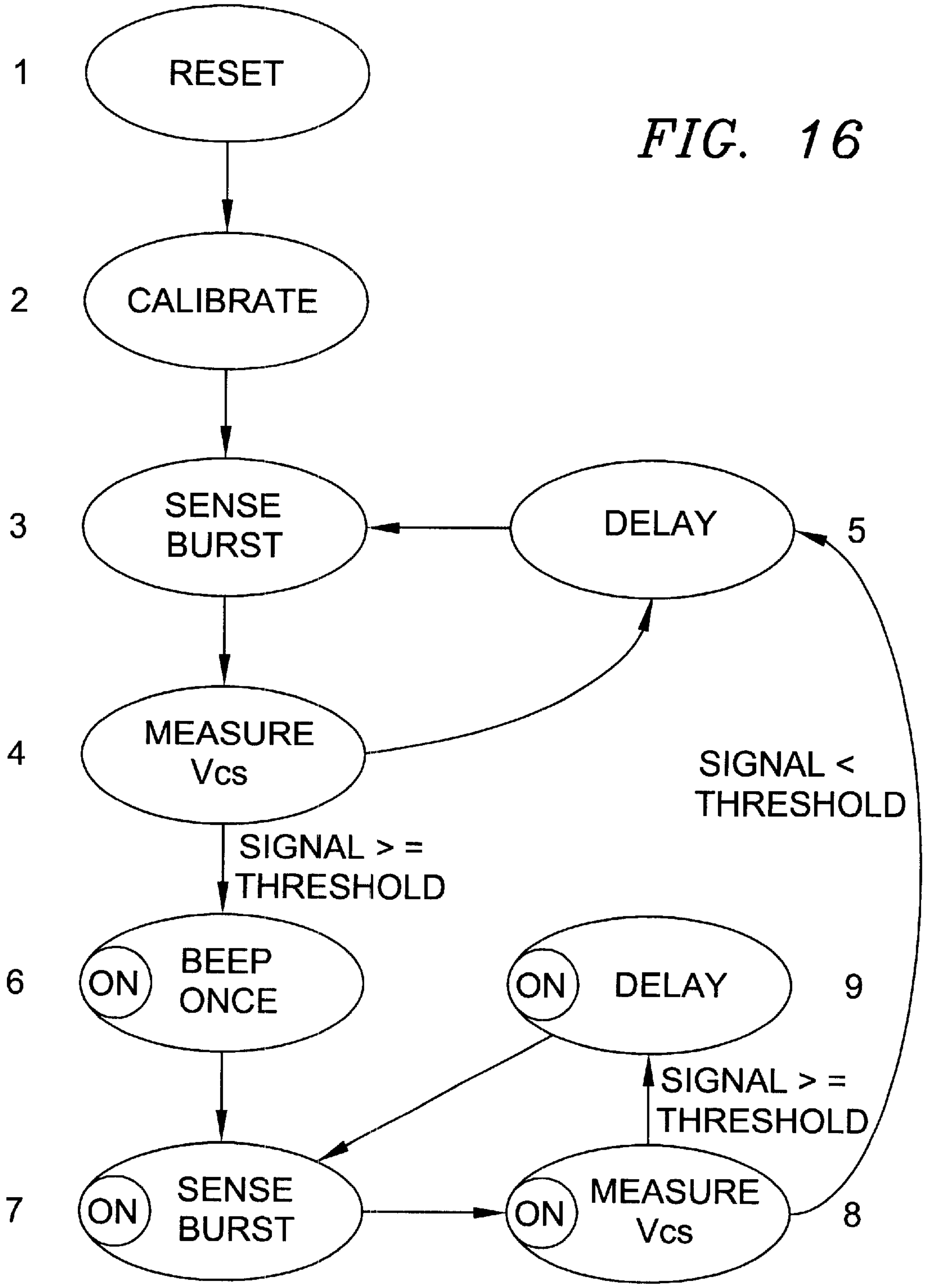

1
RESET
2
CALIBRATE
3
SENSE BURST
DELAY
5
4
MEASURE Vcs
SIGNAL <
THRESHOLD
SIGNAL > =
THRESHOLD
6
ON
BEEP ONCE
ON
DELAY
9
SIGNAL > =
THRESHOLD
7
ON
SENSE BURST
ON
MEASURE Vcs
8

FIG. 16

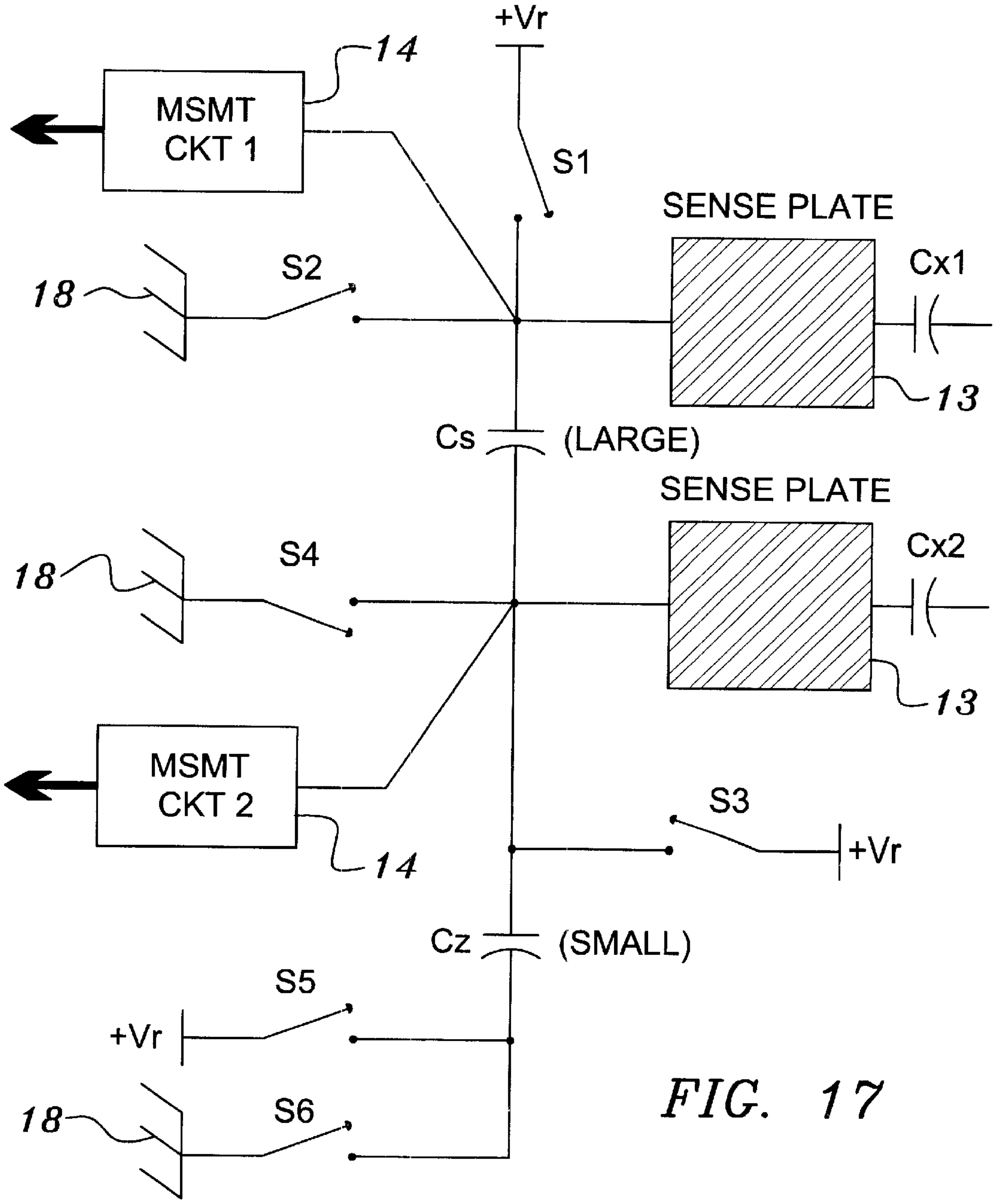
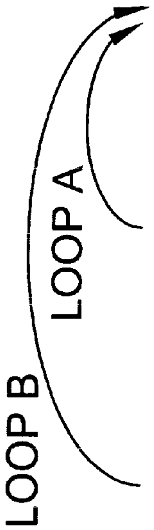

+Vr
14
MSMT CKT 1
S1
SENSE PLATE
S2
18
Cx1
13
Cs
(LARGE)
SENSE PLATE
S4
18
Cx2
13
MSMT CKT 2
S3
+Vr
14
Cz
(SMALL)
S5
+Vr
S6
18

FIG. 17



STEP	S1	S2	S3	S4	S5	S6	Cx2 FUNCTION
A	-	X	-	X	-	X	RESET ALL
B	-	-	-	-	-	-	DEADTIME
C	-	-	X	-	X	-	CHARGE; Cz = 0
D	-	-	-	-	-	-	DEADTIME
E	-	X	-	-	-	-	TRANSFER; Cz = 0
F	-	-	-	-	-	-	DEADTIME
G	-	-	-	X	X	-	CHARGE Cz
H	-	-	-	-	-	-	DEADTIME
I	-	X	-	-	-	X	Cz BUCKS Cs
J	-	-	-	-	-	-	DEADTIME
K	-	X	-	-	-	-	MEASURE Cx2

LOOP A: INNER QT LOOP

LOOP B: OUTER CANCELLATION LOOP

FIG. 18

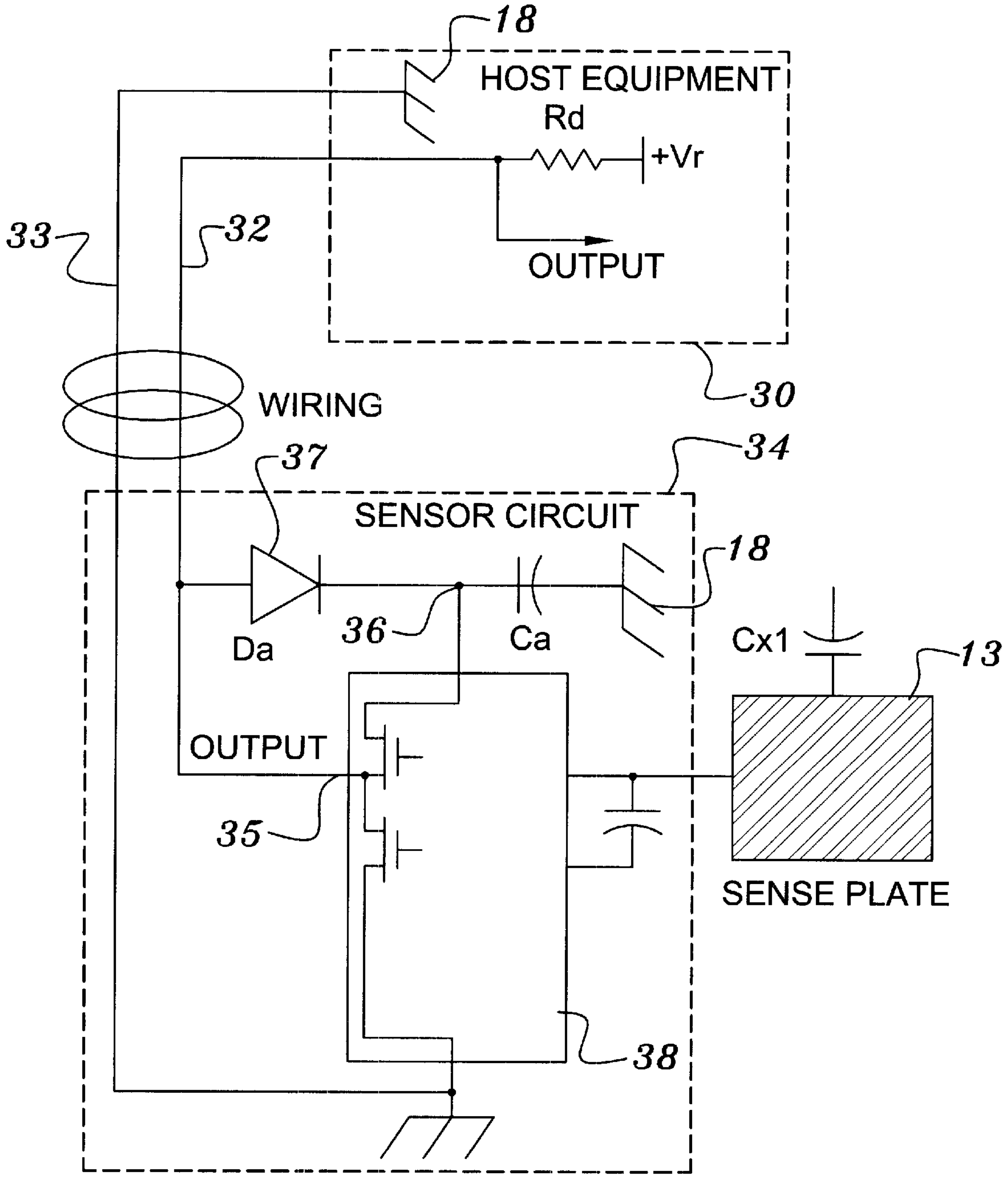

18
HOST EQUIPMENT
Rd
+Vr
OUTPUT
33
32
30
WIRING
37
34
SENSOR CIRCUIT
18
Da
36
Ca
Cx1
13
OUTPUT
35
SENSE PLATE
38

FIG. 19

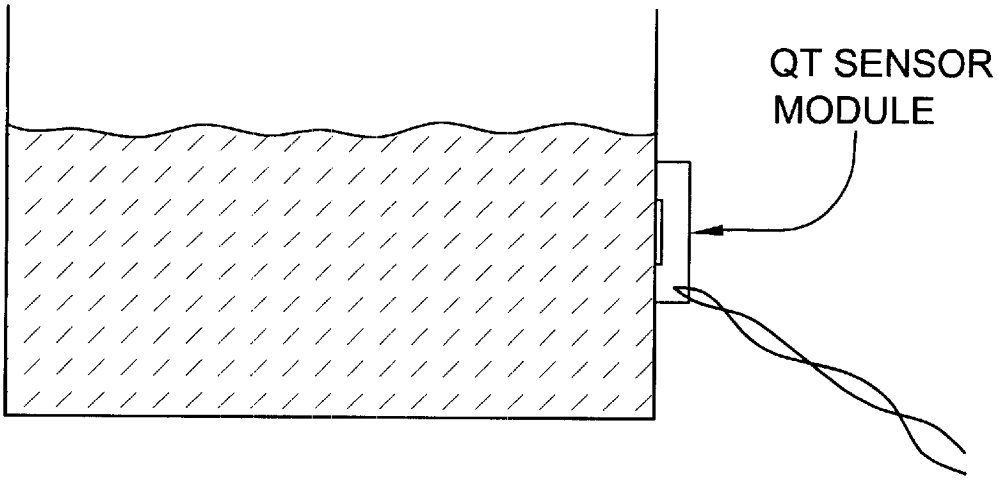


FIG. 20

CHARGE TRANSFER CAPACITANCE MEASUREMENT CIRCUIT

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the priority o of a U.S. Provisional Application for Patent filed on Nov. 25, 1998 and having Ser. No. 60/109,889.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention pertains to the sensing or measurement of electrical capacitance, and in particular to the sensing an object's proximity to or contact with a sense plate connected to a capacitance measurement circuit

2. Background Information

In his U.S. Pat. No. 5,730,165, the inventor teaches a capacitive field sensor employing a single coupling plate and a method of detecting a change in capacitance of the coupling plate, Cx, to ground. The apparatus taught in U.S. Pat. No. 5,730,165 comprises pulse circuitry for charging the coupling plate and for subsequently transferring the charge from the plate into a charge detector, which may be a sampling capacitor, Cs. The transferring operation is carried out by means of a transfer switch electrically connected between the coupling plate and the charge detector. The disclosure of U.S. Pat. No. 5,730,165 is herein incorporated by reference.

In U.S. Pat. No. 4,806,846, Kerber teaches a pulse circuit for measuring an unknown capacitance. His arrangement is characterized by careful elimination of effects of stray capacitances, such as a capacitance to ground. Kerber employs two clocked switches and a buffer amplifier to charge and discharge the capacitor under test.

BRIEF SUMMARY OF THE INVENTION

The invention provides apparatus and method for measuring an absolute or relative value of the capacitance of a capacitor or other element having the electrical property of capacitance, as well as for measuring changes in a capacitive value. In many uses of interest, a change in the capacitance to ground of a sense plate is measured and a control output is generated responsive to the change.

A feature of some embodiments of the invention is the provision of novel pulse circuitry for measuring capacitance to ground, the circuitry comprising a plurality of electrical switching elements, each of which has one side electrically connected to either a power supply voltage or to a circuit ground point. This circuit arrangement is more compatible with available integrated circuit design and manufacturing practices than is prior art pulse circuitry, which commonly had one side of at least one switching element floating. These improved arrangements thereby provide superior performance at a lower manufacturing cost.

Another aspect of the invention is that it provides a proximity sensing means having only two electrical wires connecting it to a host apparatus. This sensing means can directly replace a magnetic reed switch or a mechanical switch having two contacts and connecting wires.

Another benefit of the invention is the ability to compensate for environmental changes such as signal drift and erroneous 'stuck sensor' conditions.

Yet another benefit of the invention is that it provides a small, inexpensive "beeper" switch having an audible output responsive to a user's touch and taking up no more room than a conventional silent switch.

Although it is believed that the foregoing recital of features and advantages may be of use to one who is skilled in the art and who wishes to learn how to practice the invention, it will be recognized that the foregoing recital is not intended to list all of the features and advantages, Moreover, it may be noted that various embodiments of the invention may provide various combinations of the hereinbefore recited features and advantages of the invention, and that less than all of the recited features and advantages may be provided by some embodiments.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. **1** a schematic block circuit diagram showing an implementation of the invention using three switches.

FIG. **2** a switching table depicting the switching sequence of the three switches of FIG. **1**.

FIG. **3** is a schematic circuit diagram depicting a rearrangement of the circuit of FIG. **1**.

FIG. **4** is a plot of a voltage across Cs as a function of cycle number during a burst-mode operation.

FIG. **5** is a schematic circuit diagram depicting a circuit having topology analogous to that depicted in FIG. **1**.

FIG. **6** is a switching table describing the switching sequence of the three switches of FIG. **5**.

FIG. **7** is a schematic circuit diagram depicting a rearrangement of the switches of FIG. **1**.

FIG. **8** is a switching table corresponding to the switch array of FIG. **7**.

FIG. **9** is a schematic circuit diagram depicting a rearrangement of the switches of FIG. **5**.

FIG. **10** is a switching table corresponding to the switch array of FIG. **9**.

FIG. **11** is a schematic circuit diagram depicting a switch arrangement that can provide the functions of the arrangements depicted in FIGS. **7** and **9**, and by inference, those depicted in FIGS. **1** and **5**.

FIG. **12** is a switching table corresponding to the switch arrangement of FIG. **11**, wherein the depicted sequence provides the functionality of FIG. **7** with respect to Cx**2**, and the functionality of FIG. **9** with respect to Cx**1**.

FIG. **13** is a switching table corresponding to the switch arrangement of FIG. **11**, wherein the depicted sequence provides the functionality of FIG. **9** with respect to Cx**2**, and the functionality of FIG. **7** with respect to Cx**1**.

FIG. **14** is a schematic circuit diagram similar to that of FIG. **11**, but wherein a resistor is placed across Cs, and the sensor is operated in a continuous ("CW") mode as opposed to a burst mode.

FIG. **15** is a schematic block diagram of an embodiment of the invention wherein Cs is a portion of a piezoelectric transducer, thus providing a touch switch having an audible beeper.

FIG. **16** is a flow diagram depicting the operation of the circuit of FIG. **15**.

FIG. **17** is a schematic circuit diagram depicting a sensor of the invention incorporating a charge cancellation means.

FIG. **18** is a switching table depicting one possible sequence of incorporating charge cancellation in the circuit of FIG. **17**.

FIG. **19** is a schematic block diagram depicting a 2-wire configuration of the sensor.

FIG. **20** is a schematic view depicting a sensor of the invention being employed to monitor the level of fluid in a glass or plastic tank.

GLOSSARY OF TERMS

The symbols and terms used herein are defined as follows unless specifically noted otherwise within a particular context:

sensor a circuit for measuring the absolute or relative capacitance of either a two-leaded capacitor or of a free-space sense plate, and for providing as an output, a measurement of the capacitance in a usable form. A device only capable of generating a single-bit thresholded "detect" output is still considered a "sensor" for purposes of this disclosure.

sensing the sensing of capacitance by means of a sensor. Of particular interest to the invention is the sensing of "ground referenced capacitance", which refers to capacitance from a sense plate to any object in the environment thereof.

Cx an unknown capacitance to be measured by the sensor. Cx may be either a 2-leaded capacitor or a free-space sense plate. Plural unknown capacitances are referred to as Cxl, Cx**2** etc.

Cs a sample capacitor having a fixed value, normally much larger than the value of Cx. One of the two terminals of Cs, hereinafter called the proximal terminal, is connected to Cx. The second terminal of Cs is sometimes referred to hereinafter as the distal terminal. The voltage across Cs is used as an indication of the value of Cx.

switch an electronically controlled switch, which may be a bipolar or field effect transistor ("FET"), relay, optoelectronic device, or similar circuit.

proximity any event or circumstance resulting in a measurable capacitance or a measurable change in capacitance. Specific examples hereinafter provided are often drawn with respect to the physical proximity of a user to a sense plate.

Q The symbol of the fundamental unit of charge, expressed in Coulombs.

QT (Also referred to as charge-transfer) A method of sensing capacitance by transferring electrical charge in a controlled manner by the use of one or more switching elements, which are preferably FETs.

burst a finite, discrete number of QT cycles used to accumulate charge on Cs, where the accumulated charge is representative of the value of Cx. Burst operation differs from continuous QT cycling.

measurement circuit—A voltage sensing means that measures a voltage on Cs and converts that voltage to a another form. A "measurement circuit" can be an Analog-To-Digital converter ("ADC"), a simple voltage comparator (which can be viewed as an ADC having only a single output bit), an analog buffer or amplifier chain, etc., all of which are well known in the art. In several of the figures, this element is indicated as a block labeled "MSMT CKT".

controller A control means comprising a circuit or system capable of generating digital control signals. The controller may control the sensor (including control of switching elements therein) and the measurement circuit and may generate a decision output if required. The controller preferably comprises digital logic means such as random logic, a state machine, or a microprocessor.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to FIG. **1**, one finds a schematic depiction of a first embodiment of the invention **10**. In the circuit depicted in FIG. **1** a first switching element, S**1**, is used to drive electric charge through both a sampling capacitor, Cs, and a capacitance to be measured, Cx, during Step C (as summarized in the table of FIG. **2**). This leaves residual charges on both Cs and Cx after S**1** opens in step D of FIG. **2**. Kirchoff's current law and the principle of charge conservation dictate that these charges, Qx and Qs, are equal. However, because Cs>>Cx, a greater residual voltage is found on Cx, and conversely, a lesser voltage is measured on Cs. FIG. **3** reveals that the arrangement of FIG. **1** may be viewed as a capacitive voltage divider in considering the closure of S**1** in step C of FIG. **2**.

In FIG. **1**, as in some other figures of the drawing, a sense plate **13** is explicitly depicted to indicate that in many uses of the invention the presence or motion of an object that is not part of the apparatus of the invention is to be sensed by a capacitive measurement. Although the drawing sometimes shows both a sense plate **13** and an unknown capacitance, Cx, it will be understood to those skilled in the art that in these depictions Cx is the capacitance of the sense plate **13** to free space or to an electrical ground.

Again referring to the depiction of FIG. **1**, a second switching element, S**2**, is used to clear the voltage and charge on Cs, and also to allow the measurement of Vcs, the voltage across Cs. It may be noted that the use of S**2** allows S**1** to be cycled repeatedly in order to build up the charge on Cs. This provides a larger measurable voltage value and greater accuracy, increasing sense gain or sensitivity without the use of active amplifiers. A third switching element, S**3**, acts as a reset switch and is used to reset the charge on Cs prior to beginning a QT burst as explained below.

A preferred control circuit **12** of FIG. **1** controls the switching sequence and also the operation of the measurement circuit **14**. A signal processing module, indicated as block **16**, may be required to translate an output of the measurement circuit into a usable form. For example, this may involve converting cycle counts to a binary representation of signal strength. The signal processing block **16** may also contain other linear signal processing elements such as filters and/or nonlinear functions such as threshold comparisons as described elsewhere herein, so as to provide an output suitable for an intended application Although the control circuit **12** and processing circuit **16** are depicted only in FIG. **1**, it will be clear to those skilled in the art that such circuit elements would be used with the circuits depicted elsewhere in the drawing (e.g., as indicated by the bold output arrow from the MSMT CKT), but that these elements have been omitted in the interest of clarity of presentation.

The table of FIG. **2** shows the switching sequence required in one implementation using the circuit of FIG. **1**. First, in step A, switching elements S**2** and S**3**, which were previously in their respective open states, are closed to clear charge on Cs and Cx. After a suitable pause in step A, S**1** is closed to drive charge through Cs and Cx (Step C). The resulting first voltage increment across Cs is defined by the capacitive divider equation:

$$\Delta Vcs(1)=V_rCx/(Cs+Cx), \qquad \text{(Eqn. 1)}$$

where Vr is the reference voltage connected to S**1**.

In Step E of the table in FIG. **2**, S**2** is closed, and ΔVcs appears as a ground-referenced signal on the positive, distal, terminal of Cs. Deadtime steps B and D are employed to prevent switch cross-conduction, which would degrade the charge build-up on Cs. Deadtime can be quite short, measuring a few nanoseconds, or longer if desired. Steps B through E may be repeated in a looping manner, to provide a "burst" of QT cycles. After a suitable QT burst length, the QT cycle is terminated and Vcs is measured in the aforementioned manner, perhaps by an ADC, in Step F, with S**2** closed and the other switches open. Following the measurement of Vcs, S**3** may also be closed to reset Cs in preparation for the next QT burst.

In an alternative embodiment, steps E and F of FIG. **2** are combined so that a measurement is made at each QT cycle. This switch sequence variation is also applicable to all the variants of the circuit to be discussed below in conjunction with the remaining figures. By combining steps E and F, which are functionally identical, the measurement circuit can be made to consist of a simple voltage comparator with a fixed reference. In such cases, the looping action of the QT cycles is terminated when the voltage comparison indicates that Vcs has risen above a selected threshold value. The number of cycles taken to reach this point becomes the signal reading. This method is explained in greater detail hereinafter.

During the repeating loop of steps B through E of FIG. **2**, voltage builds up on Cs but not Cx. Cx is continuously being discharged in step E, and hence Cx cannot build up an increasing amount of charge. However, Cs freely accumulates charge, so that the resulting incremental voltage is dependent on the difference in the voltages Vr and Vcs as follows:

$$\Delta Vcs(n)=K(Vr-Vcs(n-1)) \qquad \text{(Eqn. 2)}$$

where

Vr is a supply voltage that may be a fixed reference voltage;

n is the QT cycle number; and

K=Cx/(Cs+Cx).

The final voltage across Vcs is equal to the sum of the first value of Vcs plus all subsequent values of ΔVcs. That is:

$$Vcs(N)=\Delta Vcs(1)+\Delta Vcs(2)+\Delta Vcs(3)+\ldots+\Delta Vcs(N) \qquad \text{(Eqn. 3)}$$

or,

$$Vcs(N)=\Sigma\Delta Vcs(n)=K\Sigma(\Delta Vr-Vcs(n-1)), \qquad \text{(Eqn. 4)}$$

where the summation runs over the range from n=1 to n=N. During each QT cycle, the additional incremental voltage on Vcs is less than the increment from the prior cycle and the voltage build-up can be described as a limiting exponential function:

$$V(N)=Vr-Vre^{-dn} \qquad \text{(Eqn. 5)}$$

where d is a time scaling factor, as shown in FIG. **4**.

In practice, a burst is terminated well before Vcs rises to be approximately the same as Vr. In fact, if the rise in Vcs is limited to <10% of Vr, the linearity can be made acceptable for most applications. For simple limit sensing applications Vcs can be permitted to rise higher, at the expense of increasingly degraded signal-to-noise ratios in the threshold comparison function.

The QT burst can be terminated after a fixed or after a variable number of cycles. If a fixed number is used, the measurement circuit should be capable of representing continuous signals much as in the fashion of an ADC or an analog amplifier. If a variable burst length is used, a simple comparator with a fixed reference can be employed for the measurement circuit, and the length of the burst required is that at which Vcs has built up to a level where it equals the comparison voltage. The burst can continue beyond the required number, but the extra QT cycles are superfluous. A count of the QT cycles required to achieve the comparison voltage is the output result, and for all practical purposes is indistinguishable from an ADC result

Note that in FIG. **1** the voltage measuring means **14** is connected to the (+), distal, side of Cs, and the reading is taken when S**2** is closed. Although the (+) side of Cs is the most convenient measurement point for a ground-referenced signal, it is also possible to measure Vcs on the (–), proximal, side of Cs by holding S**1** dosed instead of S**2**. The reading is then Vr-referenced instead of ground referenced, which most designers will recognize as being generally inferior but still possible. In either case, the measurement being made is the de facto value of Vcs. Whether the reading is made with respect to ground or Vr is irrelevant to the invention; what is important is the differential voltage across Cs.

A switch arrangement similar to that of FIG. **1** is depicted in FIG. **5**, where the connections to Vr and the ground voltages are reversed. As depicted in the corresponding switching table of FIG. **6**, the charge and transfer operations are separated into two distinct steps C and D, whereas in the circuit of FIG. **1** they were combined in a single step (labeled C in FIG. **2**). The circuit of FIG. **5** first charges Cx to Vr, but the charge on Cx is not transferred into Cs until S**1** closes. Accordingly the switch sequence is different from that used with the circuit of FIG. **1**, but the looping process to create a QT burst requires the same number of steps. Also, the QT equations (Eqn. 1) through (Eqn. 5) hold exactly the same for the circuit of FIG. **5** as for that of FIG. **1**. Note that the measurement circuit **14** depicted in FIG. **5** monitors the voltage on the (+) side of Cs. This is the most convenient location to measure a ground-referenced reading of Cs. Moreover, a measurement can also be made on the (–), distal, terminal of Cs by holding S**2** closed during the measurement. The comments made above with respect to FIG. **1** apply to these measurements as well.

FIG. **7** shows a variation of the circuit of FIG. **1** that is identical as to form and that illustrates that the circuit of FIG. **1** can be modified slightly without altering its purpose or function. In FIG. **7** the reset switch S**3**, which had shunted the sample capacitor Cs of FIG. **1**, is now a ground-referenced switch. The reset of Cs, as depicted in the corresponding switching table of FIG. **8**, is accomplished by holding both S**2** and S**3** closed, thus shorting both ends of Cs to ground. The net result is absolutely identical to that provided by the circuit of FIG. **1** in all respects, including even the required switching sequence. An advantage of FIG. **7** over FIG. **1** is that the circuit of FIG. **7** has one side of each switching element connected either to the DC power supply, Vr, or to a chassis or circuit ground **18**. That is, the circuit of FIG. **7** does not require a floating switch, which is more difficult to manufacture in a CMOS integrated circuit than is a ground or Vr referenced switch. Thus, FIG. **7** represents a preferred embodiment of the circuit of FIG. **1** in most cases. In all the cases disclosed herein, each of the switching elements S**1**, S**2**, S**3** has both an open state and a single respective closed state.

FIG. **9** similarly alters the basic circuit of FIG. **5** into an all supply-rail referenced switching circuit operated in accordance with the switching table shown in FIG. **10**. The circuit of FIG. **9** has the same advantages over that of FIG. **5** that the circuit of FIG. **7** has over that of FIG. **1**. Hence, FIG. **9** depicts an embodiment that is preferred to that of FIG. **5** in most cases.

In both FIG. **7** and FIG. **9**, a switching element **S2** can be reconnected to the opposing supply rail (Vr or ground) with no change in functionality except for the 'reset' step. Variations in switch configuration, as shown in FIGS. **1** through FIG. **5**, use the same inventive principles of operation, resulting in identical functionality, and are all well within the scope and spirit of the invention as they do not change the fundamental mechanism of sensing and measurement.

FIG. **11** shows a unified version of the circuits of FIG. **7** and **9** and, by inference, the circuits of FIGS. **1** and **5**. The circuit of FIG. **11** can be operated in several switch sequences, and the measurement can be made at either terminal of the sample capacitor Cs. The switching tables of FIGS. **12** and **13** show how the circuit can be made to simulate action of any of the circuits of FIGS. **1** though **9**. Importantly, the plate capacitance, Cx can be attached to either end of the sample capacitor, Cs, and the circuit will still function. It is also possible to attach two plate loads, Cx**1** and Cx**2**, and to measure the sum of both of these unknown capacitance values at once.

The tables of FIGS. **12** and **13** show two possible switch sequences for the circuit of FIG. **11**. The function of each switch state with respect to Cx**1** and Cx**2** is shown in the right two columns of each table. As can be seen, depending on the position of the load, Cx, the function of each switching stage can be different. If both Cx**1** and Cx**2** are present, both sets of functions apply simultaneously with respect to the respective Cx. Steps G and G' of FIGS. **12** and **13** depict two different ways of measuring the charge, depending on whether the voltage measurement means **14** is connected as indicated by the block labeled MSMT CKT1 or as indicated by the block labeled MSMT CKT2. Again, it is possible to combine the measurement function specified in G or G' with a prior step, and use a simple voltage comparator circuit along with a cycle counting means to generate a value representative of Cx, as was explained in conjunction with FIG. **1** above.

Several variations of the switching sequence of FIG. **11** are permissible and fall well within the scope of the invention. The inventive aspects of all of FIGS. **1** through **11** comprise the ability to measure charge transfer through the use of a plurality of switches, none of which is interposed between the sample capacitor, Cs, and the unknown capacitance, Cx. Moreover, all of the circuits discussed supra are compatible with the use of repetitive QT cycles to accumulate charge within Cs, thus increasing usable gain, resolution, and intrinsic noise filtering ability (via the inherent mechanism of charge averaging within Cs during the burst).

FIGS. **7** and **9**, and by inference FIG. **1** and **5**, can be seen as parings-down of the circuit of FIG. **11**, i.e., versions that simply have the respective unused switches removed. Examples of superfluous switching elements include the switch labeled **S1** in the switching sequence of FIG. **13**, and the switch labeled **S3** in the switching sequence of FIG. **12**. In essence, all of FIGS. **1** through **9** are subsets of the circuit of FIG. **11**.

Turning now to FIG. **14**, one finds a variation of FIG. **11** that uses a shunting resistor, labeled Rs, that is electrically connected across the sample capacitor, Cs. In this case, the switches must be cycled for a longer duration, or perhaps continuously, to develop a stable voltage across Cs that is representative of the value of Cx. In this circuit, the steady-state average voltage developed across Rs is given by:

$$V_{RS}=fVr\ Cx\ Rs, \qquad \text{(Eqn. 6)}$$

where V_{RS}<<Vr and f is the frequency of switch operation.

In this circuit, unlike in burst-mode QT operation, Cs does not play a part in determining gain. Here, Cs only acts to low-pass filter the voltage V_{RS}. Hence, Cs must be sized with respect to Rs to make superimposed voltage ripple across Rs appropriately low. The use of a resistor across Cs has the advantage that the measured result is dependent on the stability of the resistor, and not on the stability of Cs. It is generally easier to make stable resistors than to make stable capacitors, so some cost benefit may arise from the use of a circuit such as that depicted in FIG. **14**. However, this circuit will normally take longer to acquire signals than will a 'pure' burst-mode circuit, because the voltage across Rs rises asymptotically to a final value. Moreover, the voltage across Rs will lag changes in Cx, a situation that is not encountered in resistor-less versions. Since longer bursts are required to obtain an accurate reading, the sensor will generally be slower to respond, and/or will require more power to obtain a given sensitivity and response time, compared with versions that do not have Rs installed.

It may be noted that any of the circuits of FIGS. **1** through **9** can also be operated with a resistor across Cs.

While many continuous capacitance sensor designs are available in the literature and commercially, they suffer from the disadvantages of requiring continuous power, having a slow response time, and being prone to interference either from external noise sources or from adjacent capacitive sensing units. Therefore, the QT burst mode is generally preferred in most applications, but there may in certain cases be a reason to implement Rs-shunted QT sensing. This small modification is well within the spirit and scope of the invention as it does not alter the basic mechanism of capacitance sensing described herein.

The circuits described supra can be implemented in a standard CMOS process, because all of the switching elements can be MOSFETs of conventional design. Attention should preferably be paid to limiting charge injection by the gates of the transistors to reasonable values. In theory any type of electrical switch will do, but electronic switches (such as MOSFETs) are almost ideal in practice.

The control electronics **12**, used to manipulate the switches, can be made from random logic, which may be incorporated into a gate array or similar logic device, or which may be provided as discrete logic circuits. A clocked state machine design can also be used. An important implementation comprises a microcontroller to control the switching action. It is particularly beneficial to use a very fast microcontroller that can create sub-microsecond switching times, in order to create lengthy bursts in a short period of time. Such a controller can also measure and acquire the signal and perform further processing to provide operation of a variety of useful apparatus, such as a touch switch with an audible beeper, or a fluid level sensor.

Because the floating switches of FIGS. **1** and **5** are more difficult to implement in CMOS circuitry, the circuits of FIGS. **7**, **9**, **11**, **14** and **15** are generally easier to implement and thus more desirable.

Measurement means **14** can include A/D converters, comparators, or even the simple input of a logic gate having a more or less fixed threshold level. The final signal value can be derived directly by reading the output result of an

A/D converter, or indirectly by counting the QT cycles necessary for Vcs to reach a specific level. The resulting value can be further processed (e.g., via threshold comparison, or filtering and output as an analog or digital representation of the signal level.

Calibration and threshold level determination can be accomplished by simply reading the signal level during presumed quiescent interval and setting the threshold level based on that reading. The threshold may, of course, include a fixed or proportionate offset. If the latter is used, a great deal of insensitivity to absolute load levels can be achieved, which is an important design goal in many systems.

Charge Offsets

It is possible to implement charge offsetting in the apparatus of the invention, e.g., so that a sensing device can tolerate larger loads. The need for this technique is described in some detail in my U.S. Pat. No. 5,730,165 which also details a method for accomplishing charge transfer in the context of the implementation therein disclosed. In the context of the present invention, FIGS. **17** and **18** show a version of the sensor that incorporates a simple method of negative charge offsets i.e., charge cancellation. FIG. **17** shows a circuit similar to that of FIG. **11**, but with two additional switches, **S5** and **S6**. An exemplar timing sequence for subtracting charge is shown in FIG. **18**. During added steps G and I the fixed Cz capacitor is charged, and subsequently discharged into Cs in a manner so as to reduce, or buck, the charge on Cs. This has the effect of canceling the charge buildup due to large capacitive loads, thus extending the possible load range of the sensor. Steps G and I are not required on every QT cycle. These steps are only required after a number of conventional QT cycles have caused a near-excessive accumulation of charge on Cs. These additional steps may be executed within the course of a burst (or every 'n' cycles in the case of a more continuous QT circuit like that of FIG. **14**), or on an as-needed basis.

The downside of Cz charge cancellation is that each Cz cancellation also forms a capacitive divider during the time when **S5** and **S6** are closed. This, in turn, reduces system gain incrementally. However, the circuit allows extended QT bursts to occur, thus raising system gain more than enough to compensate for the loss of gain caused by charge division.

In versions of the sensor that use a simple voltage comparator **26** and rely on counting QT cycles until a threshold voltage across Cs is reached (e.g., as depicted in FIG. **15**) it is often desirable to use a positive charge offset when changing the amount of charge in the sample capacitor—i.e., performing charge addition instead of charge subtraction. Although at first glance counterintuitive, charge addition performed early in a burst will allow a truncated burst length while leaving differential sensitivity unchanged. Shortening a burst in this manner is advantageous from the standpoint of reducing power consumption and decreasing response time. To perform charge addition, the sequence shown in FIG. **18** is altered as follows: 1) in Step G, switches **S4** and. **S6** are closed to discharge Cz; 2) in Step I, switches **S2** and **S5** are closed, thus injecting charge from Vr through Cz and into Cs . Charge addition can be performed prior to the burst itself, e.g., steps G through I may be performed just after step A and before step B. Only one or a few charge injection cycles are usually required to bring the voltage on Cs to a level just below the threshold comparison level

Numerous switch sequences are possible using the circuit of FIG. **17** to accomplish charge offsets in Cs. This encompasses all manner of switching sequences as well as the use of alternate techniques, such as current sources, to provide a selected charge offset in the sample capacitor. The invention is not dependent on any one specific switch sequence, but instead anticipates that charge offsets can be accomplished by numerous means, all of which are more or less equal in intent and function.

Charge cancellation can be applied to any of the circuits of FIGS. **1** through **7**, which can be derived by pruning unused switches in FIG. **17** or by substituting electrically equivalent elements, such as switch **S3** in FIGS. **1** and **5**, as explained supra

Touch Switches

FIG. **15** shows the circuit of FIG. **11** used as a proximity switch capable of providing audible feedback to a user. In this case the sample capacitor, Cs, comprises a piezoelectric transducer **20** (ie., an audio 'beeper' providing an audible output responsive to an audio frequency AC electric signal applied to its two terminals), which has a characteristic capacitance typically in the range of five to thirty nanofarads. During normal operation the circuit of FIG. **15** samples a value of Cx (i.e., either Cx**1** or Cx**2** or both) via one of the switching sequences described previously. If an object is thereby detected proximate one of the plates (Cx**1** or Cx**2**), the circuit proceeds to generate an output on the output line **22**, and also to cause the audio transducer to briefly beep—e.g., by using the switch control lines **24** to sequentially operate the switching elements **S1**, **S2**, **S3** and **S4** to provide an audio frequency voltage across the beeper **20**. Because the beeper **20** is the only external component, the component count is as low as possible, and cost and space are also minimized (in the case of small piezoelectric beepers, an additional capacitor may have to be placed in parallel with the beeper to 'top up' the total capacitance used for Cs). Indeed, it is possible to house the entire assembly within the confines of an ordinary switch body by using well-known construction techniques such as chip-on-board assembly, or by mounting the IC directly on the piezoelectric element **20** itself. Alternatively, the circuit can be housed adjacent a metallic electrode on the inside of a control panel made of plastic, wood, or other insulating material, and the contact area marked as a legend on the user side. The sense field will penetrate through the insulating panel and create a proximity field on the user side.

The measurement circuit **14** depicted in FIG. **15** can be a simple voltage comparator **26** having a fixed threshold level as one of its two inputs. In this case the signal strength reading is obtained digitally by counting the number of QT cycles required to accumulate enough voltage on Cs so as to exceed a selected comparison threshold. The number of cycles required to cause this is an inverse digital representation of capacitance—that is, the fewer the number of QT cycles required to exceed the comparison threshold, the higher the capacitance, which in turn is proportionately related to proximity. Once the capacitance has fallen to a lower level again, the output is made to cease. This method of signal determination is not unique to touch switch applications, and can be employed for all manner of other applications.

Another control version might make use of a higher resolution measurement of Vcs after a burst. In this case Vcs would be compared to a stored threshold level to make a detection determination. The measurement circuit can consist of an ADC, or possibly a voltage comparator whose secondary input is a variable comparison level controlled by an algorithm in order to form a successive approximation converter.

In a preferred embodiment the controller can cycle the switches **S1**, **S2**, **S3**, **S4**, at a suitable audio drive frequency to drive the beeper for the duration of a momentary 'beep', at for example 4 kHz, a common resonant frequency of audio beepers. The capacitive signal acquisition process should occur at a higher frequency that is well above the range of resonance in order to be inaudible. In any case, the differential voltage applied across Cs during signal acquisition is on the order of millivolts, so that even if acquisition were to occur in the beeper's acoustic range it would be barely audible. Moreover, it is recognized by those skilled in the art that other known drive means, such as an audio frequency AC voltage source controlled by the controller, could also be employed to generate the audio output.

FIG. **16** shows a sample of a possible flow diagram for the control logic or microcontroller **28** used in the arrangement depicted in FIG. **15**. In state **1**, the device is reset after an initial power-up. State **2** is a calibration step wherein the logic acquires the value of Cx and sets both an internal reference level and a threshold level for later comparison. The threshold level is suitably distant in value from the reference level so that an appropriate increase in Cx will trigger the output during a later state. State **3** causes the QT burst to occur during an actual sensing cycle. The resulting signal, Vcs, is compared with the previously determined threshold level in state **4**. If the signal is less than the threshold level, no output is generated, and the device delays in state **5** until a new sense burst is required. This delay can suitably be a 'sleep' mode having low power. If, in state **4**, the signal is found to be greater than the threshold level, the unit is made to beep and the output line is activated in state **6**. A looping pattern involving states **7**, **8**, and **9** then takes place in a fashion similar to that involving states **3**, **4**, and **5**, so that the output will remain 'ON' until the signal reduces below a threshold level. Note that states **6** through **9** are labeled 'ON' to indicate that an active detection has been sensed, and the output line is made active.

Further improvements can be made by incorporating additional post-acquisition algorithms and other features such as:

- Toggle mode: the sensor circuit provides a bistable output which is presented as a persistent logic '1' when first touched, then a logic '0' when touched again, thus simulating the action of a bistable mechanical switch ("touch-on, touch-off" mode).
- Auto recalibration after time-out: after an interval of preset duration of continuous sensing, the sensor circuit recalibrates itself so as to terminate its active output, recalibrate, and thereafter become sensitive to only new touches which increase signal strength beyond the point of the most recent calibration.
- Drift compensation: the sensor circuit can continuously adjust its threshold in accordance with slow changes that affect signal strength. These changes may include temperature fluctuations, moisture buildup, or mechanical creep, etc. This can be accomplished by altering the reference level slowly at a slew-rate limited rate when no detection is being sensed.
- Hysteresis: to prevent 'contact bounce' the sensor can incorporate detection threshold hysteresis, so that the initiation detection level is different, i.e. higher, than the non-detection level, thus requiring the signal to transit though a lower signal level than the threshold level before a 'no detect' state is entered.

The above features and algorithms are also useful in various combinations and degrees in conjunction with any of the circuits described herein, to provide a more robust sensing solution that can adapt to a variety of real-world sensing challenges, such as dirt accumulation, thermal drift, etc.

2-Wire Interface Switch

The sensor of the invention can be configured to run from two metallic connections, **32**, **33** e.g., wires or printed wiring board traces, and thereby to directly replace magnetic reed switches or mechanical switches having only two contacts and two control lines. As is well known in the control arts, inputs from such switches are processed by a variety of host equipments **30** that are responsive to the input. Known host equipments **30** include, but are not limited to machine tool (e.g., stamping press) controllers, elevator controls, and automatic washroom valve controls, to name a few. The prior art requirement for a third connection to a capacitive sensor (e.g., separate wires for power, ground, and output) can sometimes cost more than an application will support. A low power QT circuit, as described herein, can be converted to two-wire operation as shown in FIG. **19**.

As depicted in FIG. **19**, a series resistor, Rd, is inserted in series with the signal lead **32** in or near whatever host equipment **30** is to process the signal from the sensor **34**. The sensor self-powers from the signal lead **32**. Inasmuch as the sensor **34** only requires a few microamps of current, an insignificant voltage drop occurs across Rd. The sensor **34** has associated with it a supply capacitor, Ca, connected between the signal/power lead **32** and a chassis ground **18**. The resistor-fed power is connected directly to the output **35** of the sensor, and the anode **37** of a diode, Da. The diode, Da, is connected between the power/signal lead **32** and the electrical power input **36** (Vcc) lead of the QT capacitive measurement circuit **38**. Also, as depicted in FIG. **19**, the cathode of the diode, Da, is also connected to the positive side of a supply capacitor, Ca. The sensor is normally off, in which state the output signal line **32** is forced high (using the signaling definition of "output high"="inactive") so that the signal line **32** is shorted to the Vcc line **36** via the IC's upper internal mosfet (p-channel) drive transistor.

When an object is proximate the plate **13**, the internal control logic forces the signal lead **32** to ground for a brief period (e.g., 100 milliseconds) after which the voltage on the signal lead **32** rises again. During this brief interval the power stored in the supply capacitor, Ca, does not drop much, and hence the sensor IC **38** remains under power. After the conclusion of the signal interval the sensor output goes high again, Ca is quickly recharged to its full value, and the device continues to function as a sensor. It will be understood that a second brief delay, for example another 100 ms, may be introduced at this point in the cycle in order to allow the voltage on the supply capacitor, Ca, to stabilize. The 100 ms activation pulse is detected easily by the host equipment **30** as a low logic level on a logic gate or control port pin. The durations specified above are merely illustrative examples.

In the illustrated circuit, the diode Da is used to provide power to the circuit on first power-up, when the circuit is not yet operational, and the p-mosfet is not yet conducting. After the circuit begins to run, Da is no longer used.

It should be noted that an external diode like Da is not usually required as a separate component Most logic IC's have internal electrostatic discharge (ESD) clamp diodes connected between the I/O pins to their Vcc. An ESD diode would suffice perfectly for the charging the supply capacitor. Thus, the sensor **34** really only requires one additional external part, Ca, and the host **30** only one additional component, a resistor, Rd, both of which are extremely inexpensive and small.

Those skilled in the art will observe that one could construct an equivalent circuit powered by a negative voltage source and having a diode connected in the opposite polarity to that depicted in the drawing.

The two-wire interface can also communicate more extensive data, for example signal strength, using one of many available binary sequential codes that are known in the art.

Analog Output

The value on Cs after a burst can be sampled via a sample-and-hold circuit to create a steady-state analog representation of the signal, preferably (but not necessarily) involving some form of amplification to normalize the signal into a common voltage range, e.g., 0 to 5V. Alternatively, the signal can be reconstructed from a digital representation within the circuit, perhaps after one or more filtering steps, and can be sent to a Digital to Analog converter (DAC) and then output for further use. Both an analog output and a binary decision output can be generated with the same overall circuit if desired.

Multiplexing

A sensor of the invention can be multiplexed if desired to acquire signals from two or more channels. This can be done simply by adding an analog multiplexer ("mux") to either or both of the ends of Cs, and controlling the mux in some sequence to interrogate all desired sensing plates (e.g., plural touch pads on the rear of a control panel). The analog mux can be powered from a single rail supply comparable to that of the sensing electronics. The readings obtained by the circuit can be time-correlated with each sense pad selected in order to obtain a measure of the load at each one. The mux can be controlled either by the sensor's own control means, or by an external controller.

Multiple Channel Sensor

Several sensing channels can be incorporated onto a single IC. Only two pins are required per sense channel. For example, an 8-channel sensor can be implemented in an IC package having only twenty-two pins (including power and ground). The output in such a device can be expressed as three parallel binary lines plus a strobe line that changes its output state when proximity is sensed. These signals could be non-multiplexed, resulting in simple circuit control and simplicity of use. The means of signal output are not important to the invention. For example, serial communication means can be employed to convey the results to a host system.

Level and Material Sensing; Gauging

Another important use of the methods disclosed herein is for level sensing, whereby a metal electrode is placed inside or on the exterior surface of a vessel (FIG. **20**). Point level sensing is simple to achieve, but a sensor having a linear response can also be fashioned by making use of the digital results of the measurement circuit and associated techniques, for example by QT cycle counting, or the use of an ADC.

The method is not restricted to level sensing. Material proximity, elevation, or distance gauging in a general sense can be provided economically using the sensor. The internal algorithms required for such applications are, of necessity, different from those for a practical touch switch, but these are elements of detail rather than substance, and should not be deemed as restricting the practice of the invention to any one application.

The invention can be used with all manner of applications normally implemented using alternative capacitive sensing circuits known in the electronic circuit design arts. Additionally the cost and size benefits of the circuit may facilitate new applications for capacitance sensing that remain unexplored, for example the Touch Switch detailed above.

Although the present invention has been described with respect to several preferred embodiments, many modifications and alterations can be made without departing from the invention. Accordingly, it is intended that all such modifications and alterations be considered as within the spirit and scope of the invention as defined in the attached claims.

What is claimed is:

1. Apparatus for measuring the capacitance to ground of a plate, the apparatus comprising:

- at least three switching elements, each of the at least three switching elements having both a respective open state and a single respective closed state, each of the at least three switching elements electrically connected to one of two distinct reference voltages;
- a sample capacitor having two terminals, a proximal one of the two terminals connected to the plate by means not comprising one of the switching elements, the second terminal distal from the plate;
- a voltage measurement circuit connected to one of the terminals of the sample capacitor by means not comprising one of the switching elements, the measurement circuit comprising one of a logic gate and a voltage comparator;
- wherein:
  - a first of the at least three switching elements connects the distal terminal of the sample capacitor to the first reference voltage when in its closed state and disconnects the distal terminal from the first reference voltage when in its open state;
  - a second of the at least three switching elements connects the proximal terminal of the sample capacitor to the second reference voltage when in its closed state and disconnects the proximal terminal from the second reference voltage when in its open state; and
  - the third of the at least three switching elements connects the distal terminal of the sample capacitor to the second reference voltage when in its closed state and disconnects the distal terminal from the second reference voltage when in its open state; the apparatus further comprising
    - a controller for operating the at least three switching elements so that at any time at least one of the at least three switching elements is in its respective open state.

2. The apparatus of claim **1** wherein the first reference voltage is an electric ground and wherein the second reference voltage is a DC supply voltage.

3. The apparatus of claim **1** wherein the first reference voltage is a DC supply voltage and wherein the second reference voltage is an electric ground.

4. The apparatus of claim **1** wherein the third switching element connects the distal terminal of the sample capacitor to the proximal terminal thereof when in its closed state.

5. The apparatus of claim **1** wherein the third switching element is in its respective closed state only when the second switching element is also in its respective closed state.

6. The apparatus of claim **1** wherein each of the at least three switching elements comprises a respective field effect transistor and wherein the controller further comprises a clocked voltage pulse source.

7. The apparatus of claim **1** further comprising a shunting resistor electrically connected between the distal and proximal terminals of the sample capacitor.

8. The apparatus of claim **1** wherein the sample capacitor comprises a portion of a piezoelectric transducer and wherein the controller applies an audio frequency AC voltage to the piezoelectric transducer responsive to the output.

9. Apparatus for measuring the capacitance to ground of a plate, the apparatus comprising:

a sample capacitor having two terminals, one of the two terminals directly connected to the plate by means not comprising an electric switching element;

a voltage measurement circuit connected to one of the two terminals of the sample capacitor;

a circuit ground;

a source of DC electric power,

a plurality of the electric switching elements, each of the switching elements having both a single respective closed state in which it connects one of the terminals of the sample capacitor only to one of the source of DC electric power and the circuit ground, each of the switching elements further having a respective open state in which it does not connect the one of the terminals to either the source of DC electric power or the circuit ground; and

a switch controller for selectively closing ones of the plurality of electric switching elements.

10. The apparatus of claim **9** wherein the voltage measurement circuit comprises an analog to digital converter.

11. The apparatus of claim **9** wherein each of the switching elements comprises a respective field effect transistor and wherein the apparatus further comprises a clocked voltage pulse source having an input to the switch controller.

12. The apparatus of claim **9** further comprising

a second capacitor having a capacitance value less than that of the sample capacitor; and

means for charging and discharging the second capacitor so as to offset charge in the sample capacitor.

13. Apparatus for providing an audible output responsive to proximity of an object that is not part of the apparatus, the apparatus comprising:

a circuit ground;

at least three electric switching elements;

a piezoelectric transducer having two terminals, the transducer providing an audible output responsive to an audio frequency electric signal applied to the two terminals;

a capacitive plate having a first value of an electrical capacitance to earth ground when the object is proximal to the plate and having a second value of the electrical capacitance to the earth ground when the object is distal therefrom, the plate electrically connected to one of the two terminals of the transducer by means not comprising any of the at least three switching elements;

a switching element controller for selectively controlling the at least three switching elements, each of the at least three switching elements having both a single respective closed state and a respective open state, each of the at least three switching elements directly electrically connected to one of the circuit ground and a reference voltage distinct therefrom; wherein:

a first of the at least three switching elements, when in its respective closed state, connects the first terminal of the transducer to a reference voltage other than the circuit ground, the first switching element, when in its an open state, not connecting the first terminal to the reference voltage other than the circuit ground;

a second of the at least three switching elements, when in its closed state, connects the first terminal of the transducer to the circuit ground, the second switching element, when in its open state, not connecting the first terminal to the circuit ground; and

the third of the at least three switching elements, when in its closed state, connects the second terminal of the transducer to the circuit ground, the third switching element, when in its open state, not connecting the second terminal to the circuit ground;

a voltage measurement circuit connected to one of the terminals of the transducer; and

means responsive to the voltage sensing means for applying the audio frequency signal to the transducer.

14. The apparatus of claim **13** wherein each of the at least three switching elements comprises a field effect transistor and wherein the switching element controller comprises a clocked voltage pulse source.

15. The apparatus of claim **13** wherein the switching element controller selectively controls the at least three switching elements at a frequency greater than the audio frequency.

16. The apparatus of claim **13** wherein the third switching element is controlled by the controller to be in its respective closed state only when the second switching element is also in its respective closed state.

17. The apparatus of claim **13** wherein the voltage measurement circuit comprises an analog to digital converter.

18. The apparatus of claim **13** wherein the means for applying the audio frequency signal comprises a clocked voltage pulse source having a selective output to each of the at least three switching elements.

19. Sensing apparatus for sensing a change in the capacitance to earth ground of a plate, the apparatus comprising:

a first metallic connection connecting the plate to a sample capacitor;

a second metallic connection for connecting an external apparatus, distinct from the sensing apparatus, to a circuit ground of the sensing apparatus;

a third metallic connection for connecting the external apparatus to an output of a charge transfer measurement circuit, the third connection having attached thereto a first terminal of a diode having two terminals, the second terminal of the diode attached both to a first terminal of a supply capacitor and to the charge transfer measurement circuit, the supply capacitor having a second terminal connected to the circuit ground;

wherein the charge transfer measurement circuit comprises means for repetitively charging the plate and means for measuring a voltage on the sample capacitor, the charge transfer circuit connecting the output to the circuit ground responsive to the capacitive change; and wherein the external apparatus is connected to the sensing apparatus only by the second and the third metallic connections.

20. The apparatus of claim **19** wherein the means for charging the plate comprises a field effect transistor controlled by a source of voltage pulses.

21. The apparatus of claim **19** wherein the means for measuring the voltage comprises an analog to digital converter.

22. The apparatus of claim **19** wherein the external apparatus comprises a DC voltage source that is connected to the third metallic connector through a series resistor.

23. Apparatus for detecting the proximity of an object to a plate and for supplying a control output responsive thereto, the apparatus comprising:

a host equipment for supplying the control output responsive to a signal received on a signal line connected to a capacitive sensor distinct from the host equipment, the host equipment comprising a host circuit ground and a source of DC voltage electrically connected to the signal line;

a ground conductor for connecting a circuit ground of the capacitive sensor circuit to the host circuit ground;

the capacitive sensor electrically connected to the plate, the capacitive sensor comprising

means for measuring the capacitance to ground of the plate, the means for measuring the capacitance having an electrical power input connected to a first terminal of a diode, a second terminal of the diode connected to the signal lead, the first terminal of the diode additionally connected to a first of two terminals of a supply capacitor, the second terminal of the supply capacitor connected to the sensor circuit ground; and means for generating the signal by connecting the signal line to the sensor circuit ground for a selected period;

wherein the signal lead and the ground lead are the only two conductors electrically connecting the capacitive sensor to the host equipment and wherein the capacitive sensor is electrically powered from the signal lead.

24. The apparatus of claim **23** wherein the source of DC voltage is connected to the signal line through a series resistor.

25. The apparatus of claim **23** wherein the means for measuring the capacitance comprises charge transfer means comprising a source of voltage pulses and a switching means for transferring charge from the plate into a charge detector.

26. A method of measuring a capacitance to earth ground of a plate connected to a proximal one of two terminals of a sample capacitor, the other one of the two terminals of the sample capacitor being distal from the plate, the method comprising the sequentially executed steps of:

a) closing both a first switch and a second switch, the first switch, when closed, connecting a first of the two terminals of the sample capacitor to a circuit ground, the second switch, when closed, connecting the distal terminal of the sample capacitor to the proximal terminal thereof;

b) opening both the first and the second switches;

c) closing a third switch to connect the second of the two terminals of the sample capacitor to a reference voltage;

d) waiting a selected interval, and then opening the third switch;

e) closing the first switch to thereby connect the first terminal to the circuit ground; and

f) measuring a voltage at the second of the two terminals of the sample capacitor, the voltage representative of the capacitance to earth ground of the plate.

27. The method of claim **26** wherein the first terminal of the sample capacitor is proximal to the plate and is directly connected thereto.

28. The method of claim **26** wherein the first terminal of the sample capacitor is distal from the plate.

29. The method of claim **26** further comprising a step e**1** intermediate steps e) and f), comprising repeating steps b) through e) a selected number of times.

30. The method of claim **26** further comprising a step after any one of steps b), d), or e) of providing a selected charge offset in the sample capacitor.

31. A method of measuring a capacitance to earth ground of a plate connected to a first terminal of a sample capacitor having two terminals, the first terminal of the sample capacitor connected to a circuit electric ground when a first switching element attached thereto is closed; the second terminal of the sample capacitor connected to the circuit ground when a second switching element connected thereto is closed, the second terminal of the sample capacitor connected to a supply voltage when a third switching element connected thereto is closed; the method comprising the sequentially executed steps of:

a) resetting the sample capacitor by closing the first and second switching elements and thereby connecting both the first and the second terminals to the circuit ground;

b) opening the first and the second switching elements;

c) charging the sample capacitor by closing the third switching element to connect the second terminal of the sample capacitor to the supply voltage, waiting an interval having a selected duration and thereafter opening the third switching element;

d) closing the first switching element to connect the first terminal to the circuit ground; and

e) measuring a voltage at the second terminal of the sample capacitor.

32. The method of claim **31** further comprising a step f), subsequent to step e), comprising repeating steps b), c), d) and e) a selected number of times.

33. The method of claim **31** further comprising a step d2), subsequent to step d) of repeating steps b), c), and d) a selected number of times.

34. The method of claim **31** further comprising a step prior to step c) of injecting a selected quantity of charge into the sample capacitor.

35. The method of claim **31** further comprising a step prior to step e) of changing the amount charge in the sample capacitor by a selected amount.

36. A method of measuring a capacitance to earth ground of a plate connected to a first terminal of a sample capacitor having two terminals, the first terminal of the sample capacitor connected to a supply voltage when a first switching element attached thereto is closed; the second terminal of the sample capacitor connected to the supply voltage when a second switching element connected thereto is closed, the second terminal connected to a circuit ground when a third switching element connected thereto is closed; the method comprising the sequentially executed steps of:

a) resetting the sample capacitor by closing the first and second switching elements and thereby connecting both the first and the second terminal to the supply voltage;

b) opening the first and the second switching elements;

c) charging the sample capacitor by closing the first switching element to connect only the first terminal to the supply voltage for an interval having a selected duration and thereafter opening the first switching element;

d) closing the third switching element to connect the second terminal to the circuit ground; and

e) measuring a voltage at the first terminal of the sample capacitor.

37. The method of claim **36** further comprising a step f), subsequent to step e), comprising repeating steps b), c), d) and e) a selected number of times.

38. The method of claim **36** further comprising a step d2), subsequent to step d) of repeating steps b), c), and d) a selected number of times.

39. The method of claim **36** further comprising a step prior to step c) of changing the amount charge in the sample capacitor by a selected amount.

* * * * *

EXHIBIT 5

US007952366B2

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Philipp et al.

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(54) **PROXIMITY SENSOR**

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G08B 13/08 (2006.01)

(52) **U.S. Cl.** **324/663**; 340/545.4

(58) **Field of Classification Search** 324/663, 324/658, 649, 600; 702/57; 340/545.4
See application file for complete search history.

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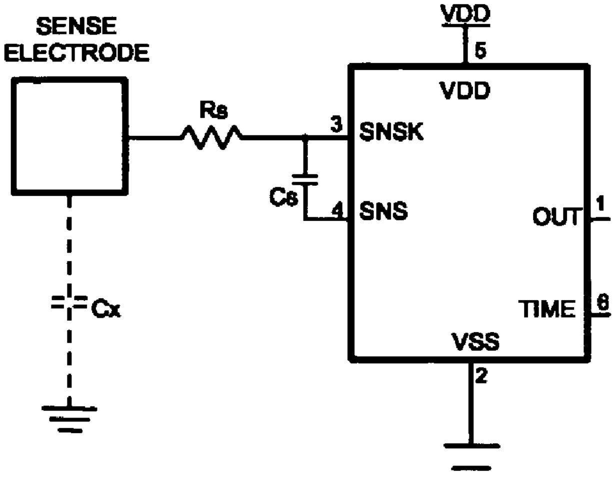
(57) **ABSTRACT**

A capacitive touch sensor providing an automatic switch-off function for an apparatus in which the sensor is incorporated is provided. The sensor includes a sensing element coupled to a capacitance measurement circuit for measuring the capacitance of the sensing element. A control circuit is operable to determine from the capacitance measurement whether an object is in proximity with the sensor. The determined presence of an object may he used to toggle a function of the apparatus. Furthermore, when it is determined that an object has not been in proximity with the sensor for a predetermined time duration, an output signal for switching off the apparatus is provided. The predetermined time duration may be selected from a number of predefined time durations, or may be programmed using a resistor-capacitor network. Pulses may be applied to the control circuit to override features of the automatic switch-off functionality.

17 Claims, 10 Drawing Sheets



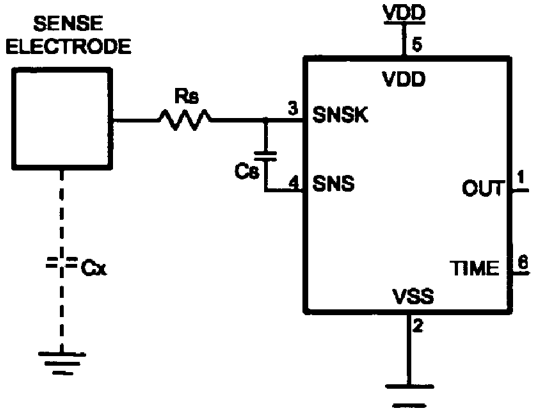


Fig. 1

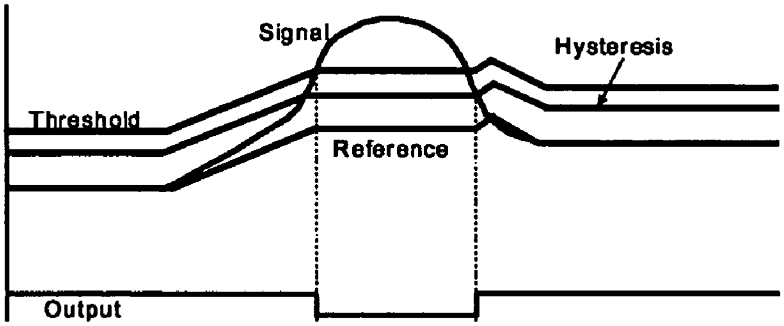


Fig. 2

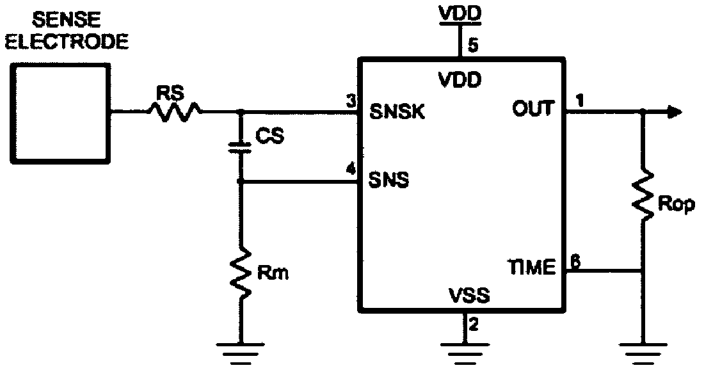
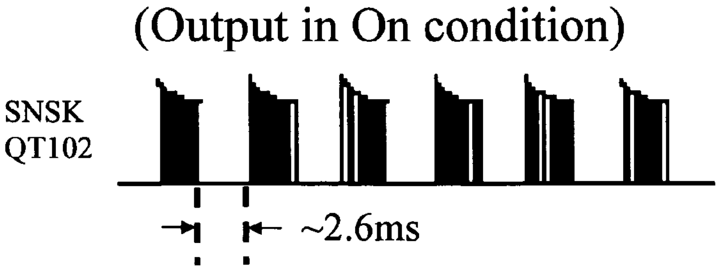


Fig. 3



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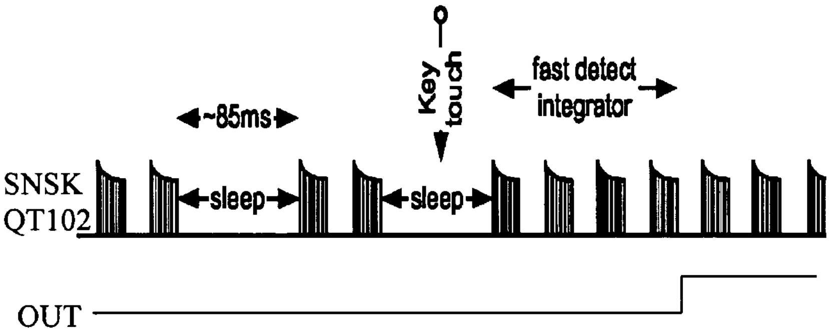
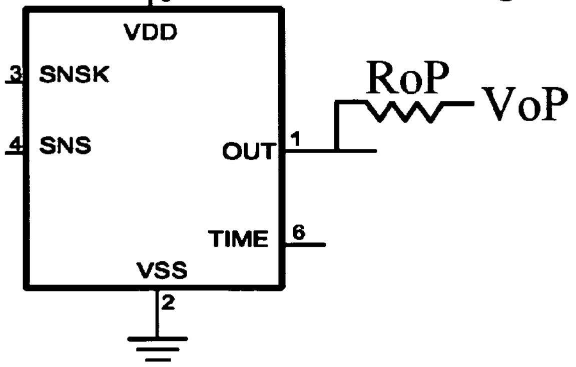


Fig. 5

Fig. 6



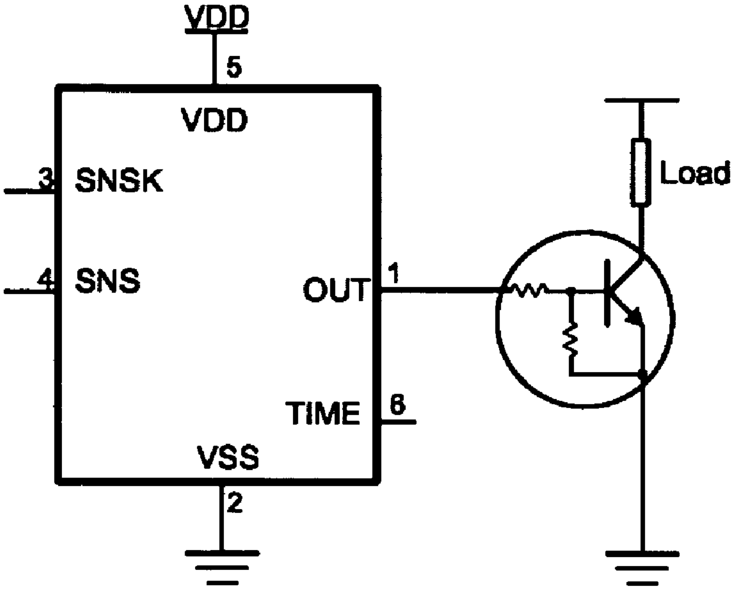

VDD
5
VDD
3 SNSK
4 SNS
OUT 1
TIME 6
VSS
2
Load

Fig. 7

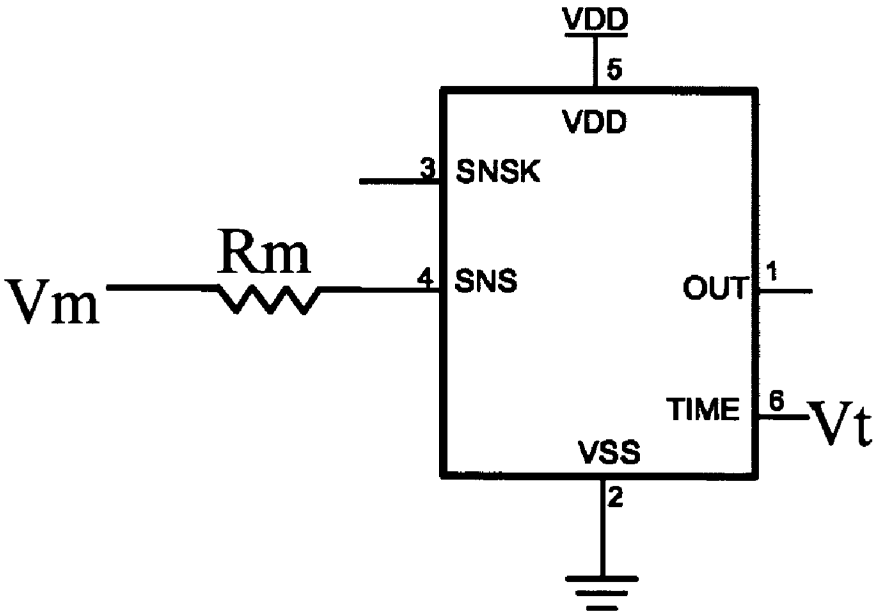

VDD
5
VDD
3 SNSK
Rm
Vm
4 SNS
OUT 1
TIME 6
Vt
VSS
2

Fig. 8

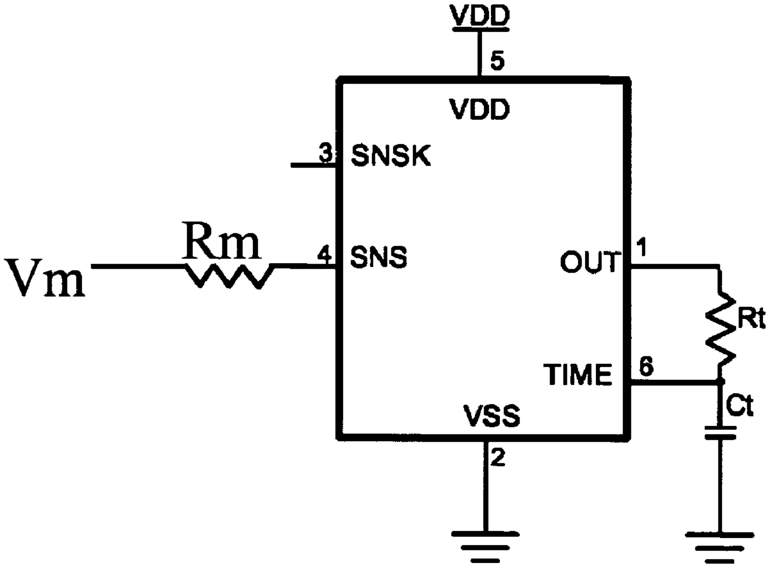

VDD
5
VDD
3
SNSK
Vm
Rm
4
SNS
OUT
1
Rt
TIME
6
Ct
VSS
2

Fig. 9

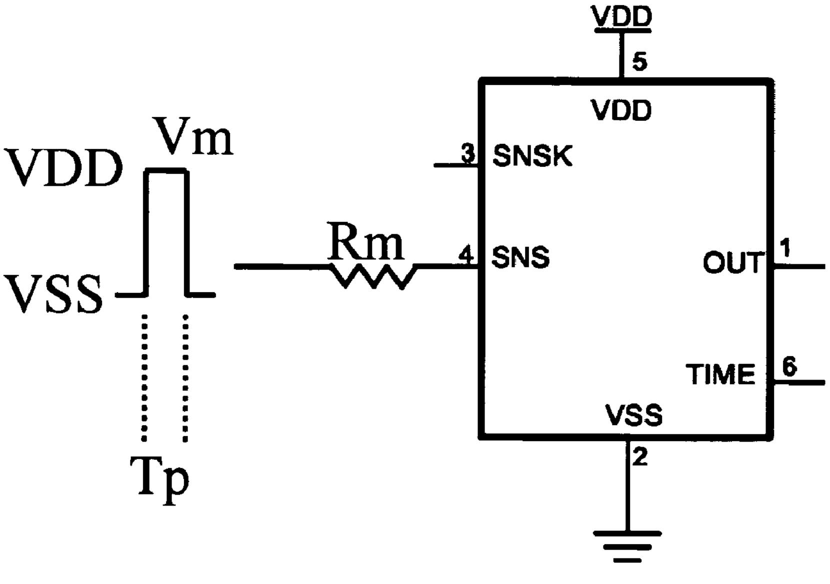

VDD
5
VDD
3
SNSK
VDD
Vm
VSS
Tp
Rm
4
SNS
OUT
1
TIME
6
VSS
2

Fig. 10

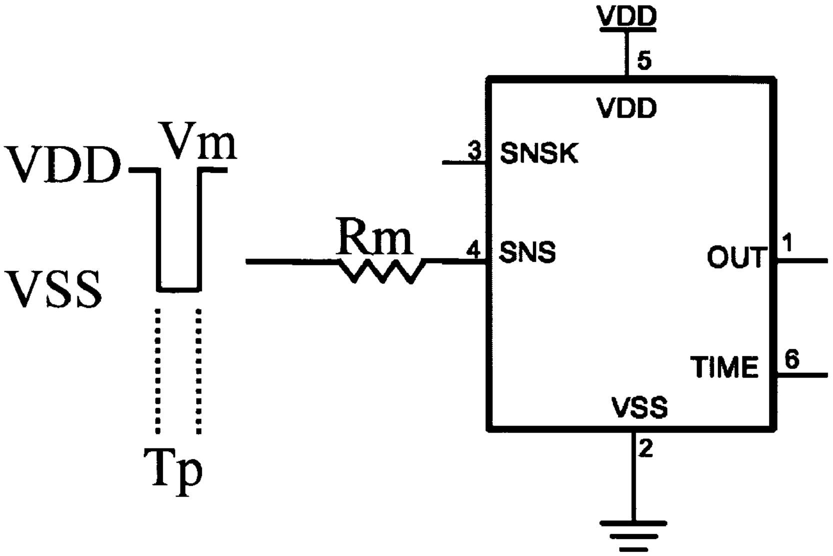


Fig. 11

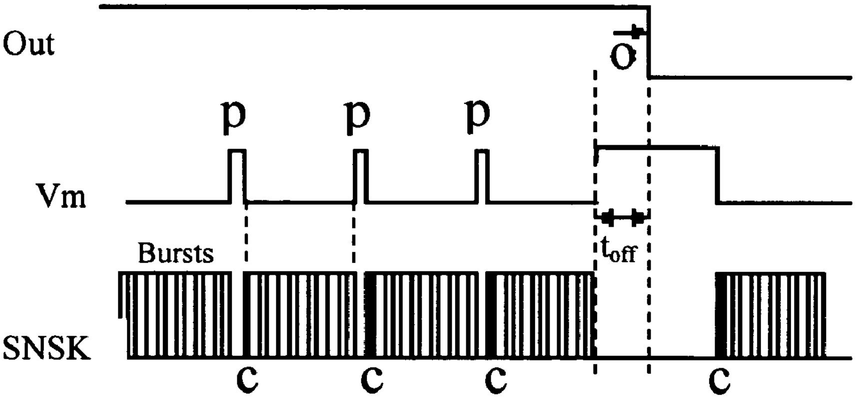


Fig. 12

P - override (reload auto off delay)
O - switch output off (t_{off} burst time + 50ms)
C - sensor recalibration

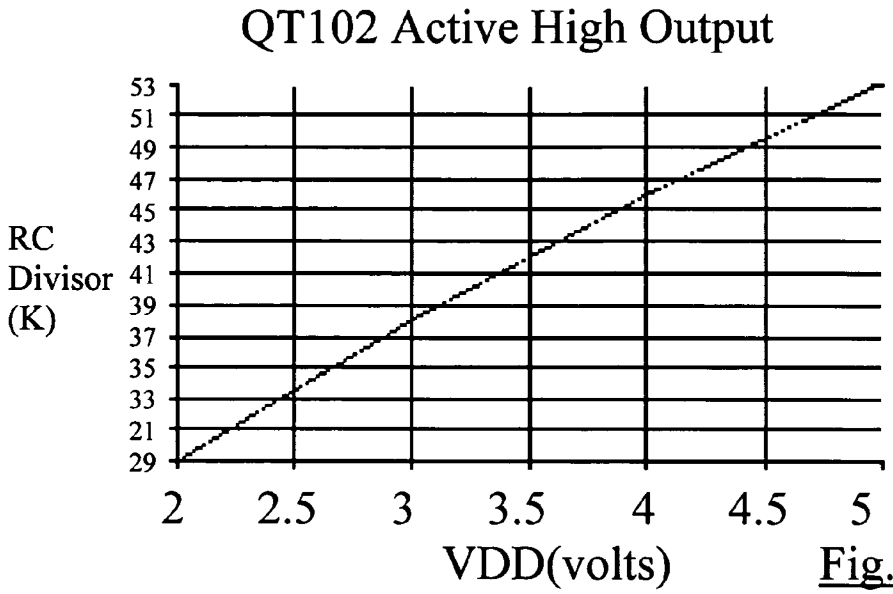

QT102 Active High Output
RC Divisor (K)
53
51
49
47
45
43
41
39
37
35
33
21
29
2
2.5
3
3.5
4
4.5
5
VDD(volts)

Fig. 13

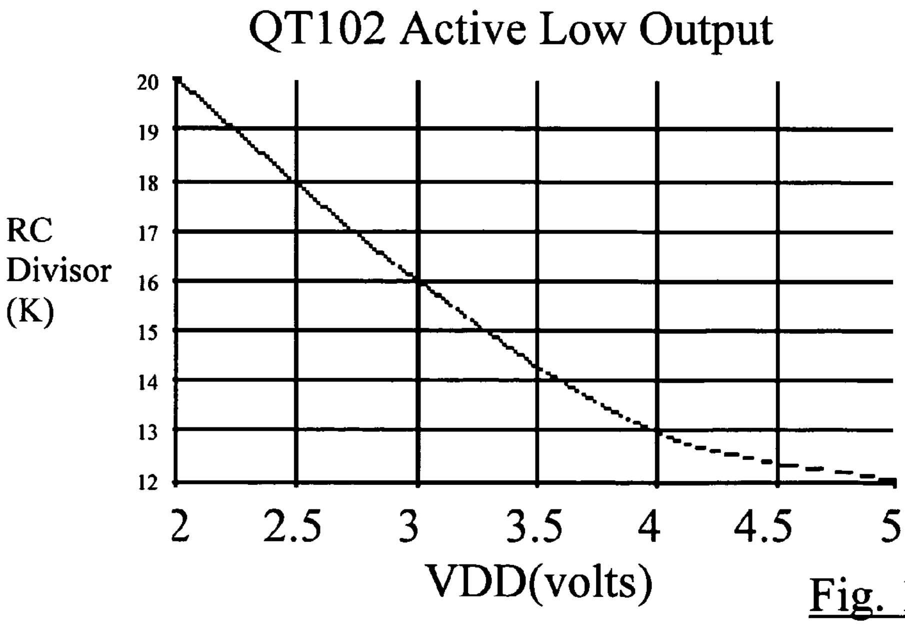

QT102 Active Low Output
RC Divisor (K)
20
19
18
17
16
15
14
13
12
2
2.5
3
3.5
4
4.5
5
VDD(volts)

Fig. 14

Vm = Vss (delay multiplier = x1)

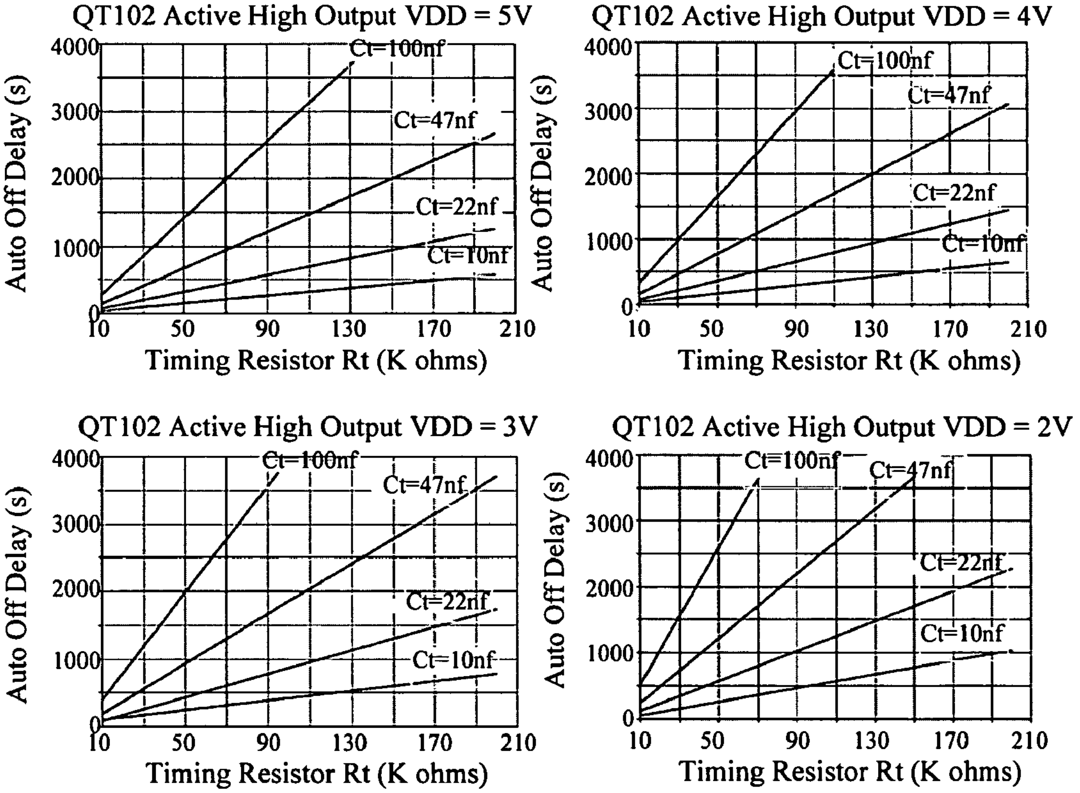
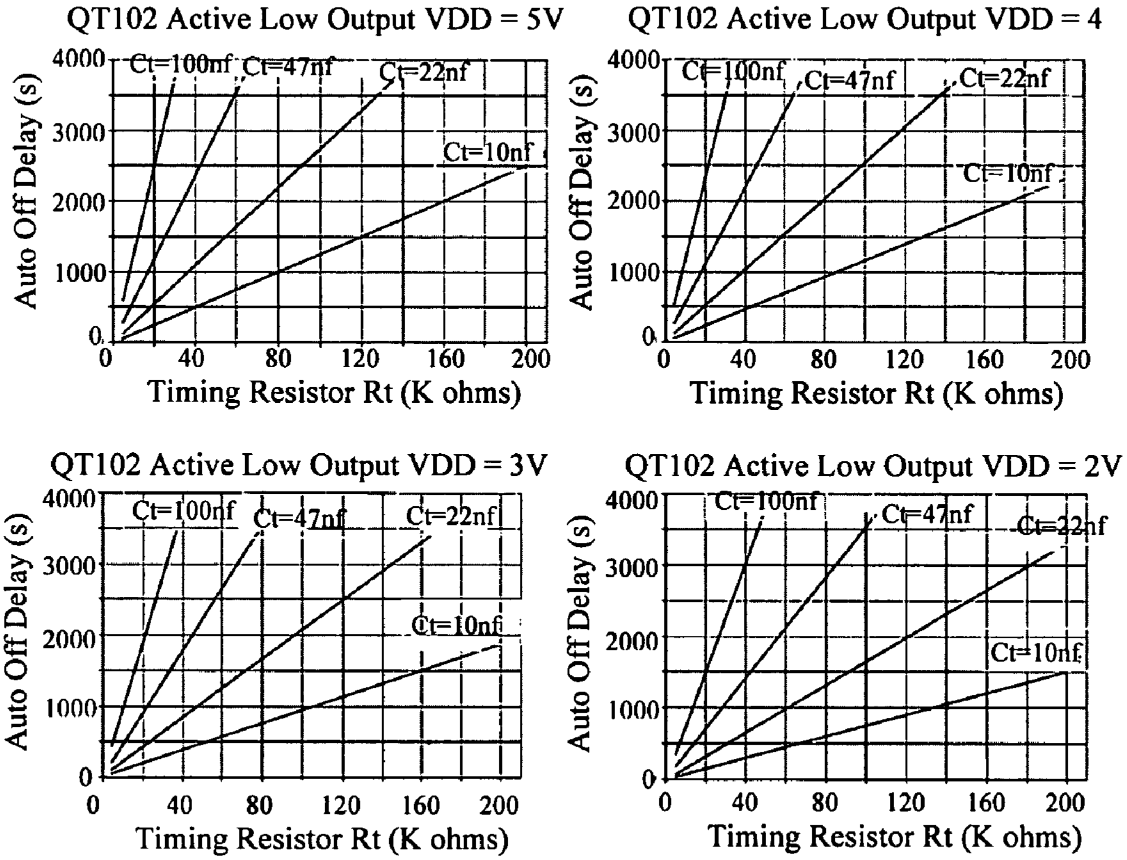


Fig. 15

Vm = Vss (delay multiplier = x1)



QT102 Active Low Output VDD = 5V

QT102 Active Low Output VDD = 4

QT102 Active Low Output VDD = 3V

QT102 Active Low Output VDD = 2V

Fig. 16

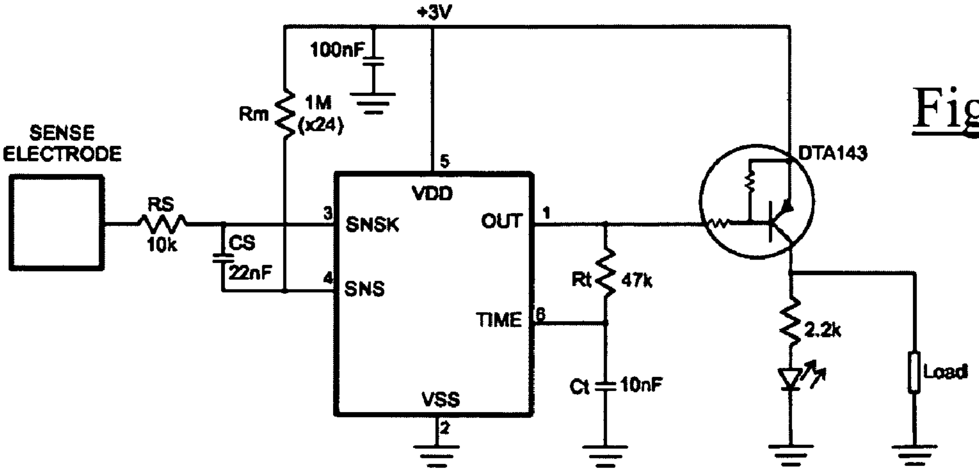

+3V
100nF
Rm
1M
(x24)
SENSE
ELECTRODE
RS
10k
CS
22nF
3
SNSK
4
SNS
5
VDD
OUT
1
TIME
6
VSS
2
Rt
47k
Ct
10nF
DTA143
2.2k
Load

Fig. 17

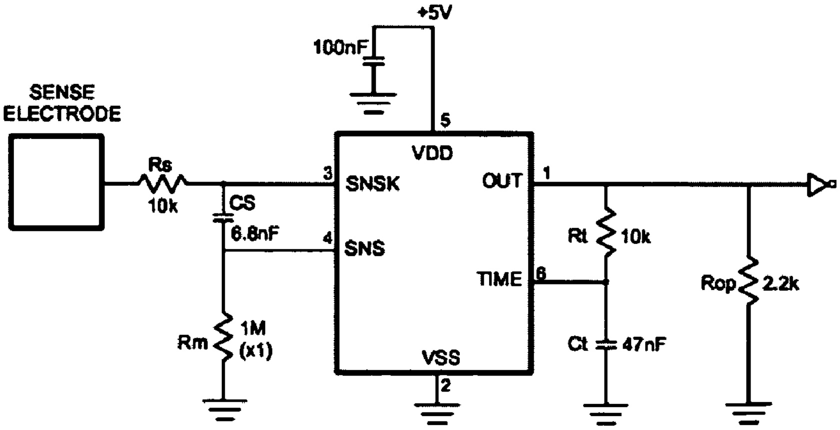

+5V
100nF
SENSE
ELECTRODE
Rs
10k
CS
6.8nF
Rm
1M
(x1)
3
SNSK
4
SNS
5
VDD
OUT
1
TIME
6
VSS
2
Rt
10k
Ct
47nF
Rop
2.2k

Fig. 18

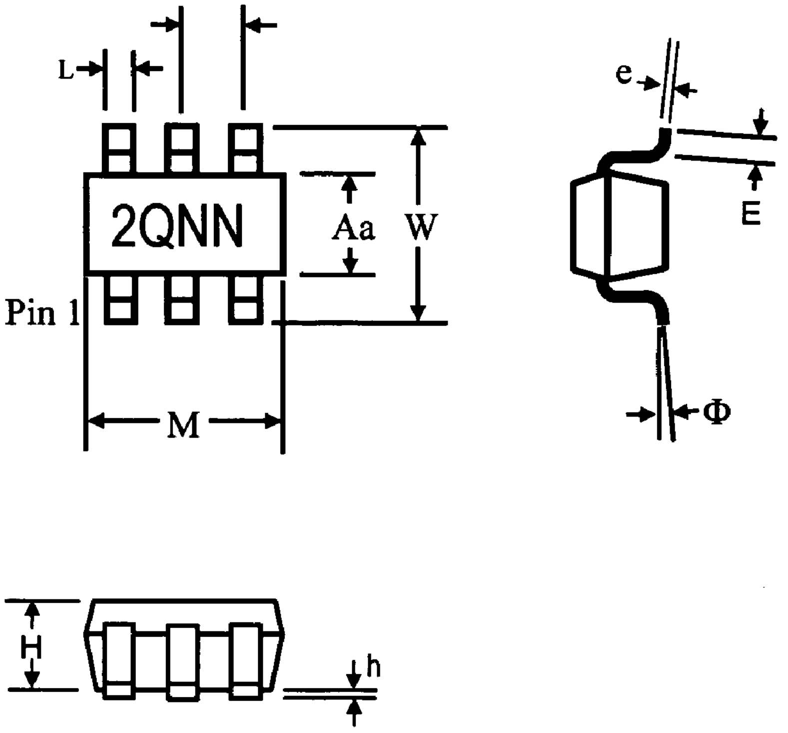


Fig. 19

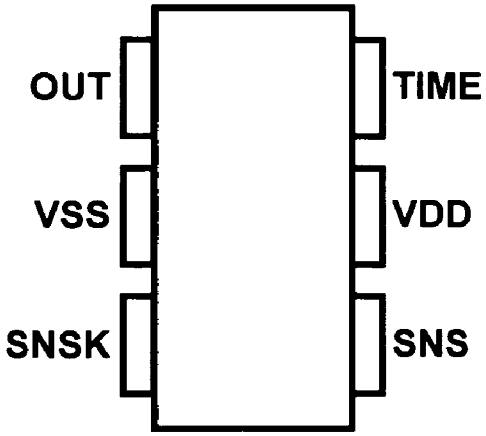


Fig. 20

PROXIMITY SENSOR

BACKGROUND ART

This invention relates to proximity sensors. In particular, the invention relates to capacitive sensors for sensing the presence or touch of an object adjacent to a sensor.

Capacitive position sensors have recently become increasingly common and accepted in human interfaces and for machine control. For example, in the fields of portable media players it is now quite common to find capacitive touch controls operable through glass or plastic panels. Some mobile (cellular) telephones are also starting to implement these kinds of interfaces.

Many capacitive touch controls incorporated into consumer electronic devices for appliances provide audio and/or visual feedback to a user indicating whether a finger or other pointing object is present or approaches such touch controls. A capacitive sensing microprocessor may typically be comprised in touch-controlled devices which are arranged to provide an "on" output signal when a finger is adjacent to a sensor and an "off" output signal when a finger is not adjacent to a sensor. The signals are sent to a device controller to implement a required function dependent on whether a user's finger is in proximity with or touching an associated touch control.

Some touch-controlled devices remain "on" or "active" despite the user having moved away from the device or a particular function no longer being required. This results in the device consuming a large amount of power which is not efficient.

There is therefore a need for an improved capacitive touch sensor which can regulate power usage.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a sensor for determining the presence of an object comprising: a sensing element; a capacitance measurement circuit operable to measure the capacitance of the sensing element; and a control circuit operable to determine whether an object is in proximity with the sensor based on a measurement of the capacitance of the sensing element, the control circuit further being operable to provide an output signal to control a function of an apparatus when it is determined that an object has not been in proximity with the sensor for a predetermined time duration.

The control circuit may be configured so that the predetermined time duration is selectable from a number of different predefined time durations.

The control circuit may include a time input terminal and the predetermined time duration may selectable from the number of different predefined time durations according to a voltage applied to the time input terminal.

The control circuit may include a delay multiplier terminal and be configured so that a selected one of the number of different predefined time durations is multiplied by a multiplication factor according to a voltage applied to the delay multiplier terminal so as to provide the predetermined time duration.

The control circuit may be configured so that the predetermined time duration is programmable by a user to provide a user-selected time duration.

The sensor may comprise a resistor-capacitor (RC) network coupled to the control circuit and the predetermined time duration may depend on a time constant of the RC network.

The control circuit may include a delay multiplier terminal and be configured so that the user-selected time duration is multiplied by a multiplication factor according to a voltage applied to the delay multiplier terminal to provide the predetermined time duration.

The control circuit may be configured such that the provision of the output signal to control a function of an apparatus after the predetermined time duration may be overridden so the output signal is not provided when it is determined that an object has not been in proximity with the sensor for a predetermined time duration. For example, the control circuit may be operable to receive an override pulse and on receipt of the override pulse to retrigger the predetermined time duration to so as to extend the time before the output signal to control a function of an apparatus is provided.

The control circuit may be configured such that the provision of the output signal to control a function of an apparatus after the predetermined time duration may be overridden so the output signal is provided before it is determined that an object has not been in proximity with the sensor for a predetermined time duration. For example, the control circuit may be operable to receive an override pulse and on receipt of the override pulse to provide the output signal to control a function of an apparatus.

The sensor may be configured to perform a recalibration when the sensor is powered up, when an object is determined to be in proximity with the sensor for more than a timer setting, and/or when an override is released.

The control circuit may be configured such that the output signal is toggled between a high state and a low state when an object is determined to be in proximity with the sensor.

The function of an apparatus controlled by the output signal may be a switch-off function.

The capacitance measurement circuit may employ bursts of charge-transfer cycles to acquire measurements.

The capacitance measurement circuit may be configured to operate in one of more than one acquisition modes depending on the output signal, for example a low-power mode or a fast mode.

The capacitance measurement circuit and the control circuit may be comprised in a general purpose microcontroller under firmware control.

The capacitance measurement circuit and the control circuit may be comprised within a six-pin integrated circuit chip package, such as an SOT23-6.

According to a second aspect of the invention there is provided apparatus comprising a sensor according to the first aspect of the invention.

According to a third aspect of the invention there is provided a method for controlling a function of an apparatus comprising: determining whether an object is in proximity with a sensor based on a measurement of the capacitance of a sensing element and providing an output signal to control the function of the apparatus when it is determined that an object has not been in proximity with the sensor for a predetermined time duration.

The function of the apparatus controlled by the output signal may be a switch-off function.

According to another aspect of the present invention, there is provided a sensor for determining the presence of an object comprising: a sensing element, a capacitance measurement circuit operable to measure the capacitance of the sensing element, and a control circuit operable to determine whether an object is in proximity with the sensor based on a measurement of the capacitance of the sensing element, the control circuit also being operable to provide an output signal to control a function of an apparatus based on an object not being in proximity with the sensor and the output signal being produced after a predetermined time duration.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and to show how the same may be carried into effect reference is now made by way of example to the accompanying drawings in which:

FIG. **1** schematically shows sense electrode connections for an example chip for implementing an auto-off function according to an embodiment of the invention;

FIG. **2** schematically represent an application of drift compensation in the chip of FIG. **1**;

FIG. **3** schematically shows a basic circuit configuration for providing a 15 minute auto switch-off function in an active high output implementation of an embodiment of the invention;

FIG. **4** schematically shows a series of fast mode bursts on the SNSK pin of the chip shown in FIG. **1** when in an on condition;

FIG. **5** schematically shows a series of low-power mode bursts and a switch to fast mode power bursts on the SNSK pin of the chip shown in FIG. **1** when switching from an off condition to an on condition;

FIG. **6** schematically shows use of an output configuration resistor Rop to configure the chip of FIG. **1** to have an active high or an active low output;

FIG. **7** schematically shows an example circuit configuration for the chip shown in FIG. **1** with the output connected to a digital transistor;

FIG. **8** schematically shows an example circuit configuration for the chip shown in FIG. **1** configured to provide a predefined auto-off delay;

FIG. **9** schematically shows an example circuit configuration for the chip shown in FIG. **1** configured to provide a programmable auto-off delay;

FIG. **10** schematically shows an example pulse applied to the chip shown in FIG. **1** to override an auto-off delay;

FIG. **11** schematically shows another example pulse applied to the chip shown in FIG. **1** to override an auto-off delay;

FIG. **12** schematically shows example voltage levels for the chip shown in FIG. **1** in overriding of an auto-off delay;

FIGS. **13** and **14** schematically show typical values of RC divisor K as a function of supply voltage VDD for the chip shown in FIG. **1** with active high output and active low output respectively;

FIG. **15** schematically shows typical curves of auto-off delay as a function of timing resistor value for different capacitor values and different supply voltages for an active high output configuration;

FIG. **16** schematically shows typical curves of auto-off delay as a function of timing resistor value for different capacitor values and different supply voltages for an active low output configuration;

FIG. **17** schematically shows an example application of the chip shown in FIG. **1** in an active low output configuration driving a PNP transistor with an auto-off time of 3.33 hours;

FIG. **18** schematically shows another example application of the chip shown in FIG. **1** in an active high output configuration driving a high impedance with an auto-off time of 135 seconds;

FIG. **19** schematically shows an implementation of the chip shown in FIG. **1** in an SOT23-6 package; and

FIG. **20** schematically shows a pin diagram for an implementation of the chip shown in FIG. **1** in an SOT23-6 package.

DETAILED DESCRIPTION

In one example, an embodiment of the invention may be implemented in an integrated circuit chip providing a proximity sensor function. The integrated circuit chip may thus be incorporated into a device or apparatus to provide and control a proximity sensor functionality for the device/apparatus in accordance with an embodiment of the invention. For the purposes of explanation, a specific integrated circuit chip providing the functionality of an embodiment of the invention will be described further below. The chip will in places be referred to by product name QT102. However, it will be appreciated that the QT102 chip is merely a specific example application of an embodiment of the invention. Other embodiments of the invention need not be implemented in a chip in this way, and furthermore, other embodiments of the invention may be provided in conjunction with all, some or none of the additional features of the QT102 chip described further below.

Before turning specifically to the QT102 chip embodiment, a summary is provided.

It is known that a touch sensitive sensor may comprise a sensor element, such as an etched copper electrode mounted on a PCB substrate, and a control circuit for measuring a capacitance of the sensor element to a system reference potential. The sensor element may be referred to as a sense electrode. The capacitance of the sense electrode is affected by the presence of nearby objects, such as a pointing finger. Thus the measured capacitance of the sense electrode, and in particular changes in the measured capacitance, may be used to identify the presence of an object adjacent the sense electrode. The control circuit may be configured to provide an output signal, e.g. by setting an output logic level as high or low, indicating whether or not an object is deemed to be adjacent the sense electrode. A controller of a device in which the touch sensitive sensor is implemented may receive the output signal and act accordingly.

There are various known technologies for measuring capacitance of a sense electrode in a capacitive touch sensor. Embodiments of the present invention may be implemented in conjunction with any of these technologies/measurement circuits. For example, the fundamental principles underlying the capacitive sensors described in U.S. Pat. Nos. 5,730,165, 6,466,036 and 6,452,514 could be used.

In accordance with embodiments of the invention, the control circuit of the sensor can determine whether an object or a user's finger is no longer in proximity with the sensor and based on a pre-determined time duration, the control circuit can produce an output signal automatically to prevent the capacitance measurement circuit from continually measuring changes in capacitance due to, for example, the perceived presence of an object in proximity with the sensor.

Therefore, the control circuit is able to deactivate, turn-off, or power down the capacitance measurement circuit where an apparatus has inadvertently been left on or with the erroneous perception that a user is still present. This may, for example, be referred to as an "auto-off" feature. The signal for preventing the capacitance measurement circuit from continually measuring changes in capacitance may be referred to as an auto-off signal. The capacitance measurement circuit and the auto-off control circuit may be comprised in a general-purpose microcontroller under firmware control, for example, such as the QT102 chip described further below.

As described in Section 3.5 of the below numbered sections, and in conjunction with the drawings, the control circuit of the sensor may be implemented by different methods—for example, the auto-off signal output may be produced automatically after different pre-determined time durations to effect powering down the capacitance measurement circuit due to no presence of the user; the control circuit may be programmed by a user so that it may power down an apparatus based on a user-selected time duration; the control circuit output signals may be overridden, for example, to extend time durations before an apparatus is turned-off or to immediately turn-off an apparatus when a user is no longer present.

The sensor of the invention may be useful in various applications, for example in kitchen appliances, light switches, headsets, and other electronic consumer devices. For example, a coffee machine incorporating a sensor of the invention may be programmed to power-down after a time period of, say, 30 minutes, where the coffee machine has been left on inadvertently. This will beneficially conserve energy use and minimise the possibility of damage and/or accidents caused by the coffee machine or glass container(s) overheating.

Aspects of the QT102 chip referred to above, and which incorporates an embodiment of the invention, will now be described in the following numbered sections.

The numbered sections may be considered to relate generally to features of the QT102 chip as follows: Section 1—Overview (including 1.1 Introduction, 1.2 Electrode Drive, 1.3 Sensitivity, 1.3.1 Introduction, 1.3.2 Increasing Sensitivity, 1.3.3 Decreasing Sensitivity, 1.4 Recalibration Timeout, 1.5 Forced Sensor Recalibration, 1.6 Drift Compensation, 1.7 Response Time, 1.8 Spread Spectrum). Section 2—Wiring and Parts (including 2.1 Application Note, 2.2 Cs Sample Capacitor, 2.3 Rs Resistor, 2.4 Power Supply, PCB Layout, 2.5 Wiring). Section 3—Operation (including 3.1 Acquisition Modes, 3.1.1 Introduction, 3.1.2 OUT Pin ‘On’ (Fast Mode), 3.1.3 OUT Pin ‘Off’ (Low Power Mode), 3.2 Signal Processing, 3.2.1 Detect Integrator, 3.2.2 Detect Threshold, 3.3 Output Polarity Selection, 3.4 Output Drive, 3.5 Auto Off Delay, 3.5.1 Introduction, 3.5.2 Auto Off—Predefined Delay, 3.5.3 Auto Off—User-programmed Delay, 3.5.4 Auto Off—Overriding the Auto Off Delay, 3.5.5 Configuring the User-programmed Auto-off Delay, 3.6 Examples of Typical Applications). Section 4—Specifications (including 4.1 Absolute Maximum Specifications, 4.2 Recommended Operating Conditions, 4.3 AC Specifications, 4.4 Signal Processing, 4.5 DC Specifications, 4.6 Mechanical Dimensions, 4.7 Moisture Sensitivity Level (MSL)).

1 Overview

1.1 Introduction

The QT102 is a single key device featuring a touch on/touch off (toggle) output with a programmable auto switch-off capability.

The QT102 is a digital burst mode charge-transfer (QT) sensor designed specifically for touch controls; it includes hardware and signal processing functions to provide stable sensing under a wide variety of changing conditions. In examples, low cost, non-critical components are employed for configuring operation.

The QT102 employs bursts of charge-transfer cycles to acquire its signal. Burst mode permits power consumption in the microampere range, dramatically reduces radio frequency (RF) emissions, lowers susceptibility to electromagnetic interference (EMI), and yet permits good response time. Internally the signals are digitally processed to reject impulse noise, using a ‘consensus’ filter which in this example requires four consecutive confirmations of a detection before the output is activated.

The QT switches and charge measurement hardware functions are all internal to the QT102.

1.2 Electrode Drive

FIG. **1** schematically shows the sense electrode connections (SNS, SNSK) for the QT102.

For improved noise immunity, it may be helpful if the electrode is only connected to the SNSK pin.

In examples the sample capacitor Cs may be much larger than the load capacitance (Cx). E.g. typical values for Cx are 5 to 20 pF while Cs is usually 1 or 2 to 50 nF. (Note: Cx is not a physical discrete component on the PCB, it is the capacitance of the touch electrode and wiring. It is shown in FIG. **1** to aid understanding of the equivalent circuit.)

Increasing amounts of Cx destroy gain, therefore it is important to limit the amount of load capacitance on both SNS terminals. This can be done, for example, by minimizing trace lengths and widths and keeping these traces away from power or ground traces or copper pours.

The traces and any components associated with SNS and SNSK will become touch sensitive and so may need to be considered to help in limiting the touch-sensitive area to the desired location.

A series resistor, Rs, may be placed in line with SNSK to the electrode to suppress electrostatic discharge (ESD) and Electromagnetic Compatibility (EMC) effects.

1.3 Sensitivity

1.3.1 Introduction

The sensitivity of the QT102 is a function of such things as:

- the value of Cs
- electrode size and capacitance
- electrode shape and orientation
- the composition and aspect of the object to be sensed
- the thickness and composition of any overlaying panel material
- the degree of ground coupling of both sensor and object

1.3.2 Increasing Sensitivity

In some cases it may be desirable to increase sensitivity; for example, when using the sensor with very thick panels having a low dielectric constant. Sensitivity can often be increased by using a larger electrode or reducing panel thickness. Increasing electrode size can have diminishing returns, as high values of Cx will reduce sensor gain.

The value of Cs also has an effect on sensitivity, and this can be increased in value with the trade-off of slower response time and more power. Increasing the electrode’s surface area will not substantially increase touch sensitivity if its diameter is already significantly larger in surface area than the object being detected. Panel material can also be changed to one having a higher dielectric constant, which will better help to propagate the field.

Ground planes around and under the electrode and its SNSK trace may lead to high Cx loading and destroy gain. Thus in some cases the possible signal-to-noise ratio benefits of ground areas may be more than negated by the decreased gain from the circuit, and so ground areas around electrodes may be discouraged in some circumstances. Metal areas near the electrode may reduce the field strength and increase Cx loading and so it may be helpful if these are avoided if possible. It may be helpful to keep ground away from the electrodes and traces.

1.4 Recalibration Timeout

If an object or material obstructs the sense electrode the signal may rise enough to create a detection, preventing further operation. To help reduce the risk of this, the sensor includes a timer which monitors detections. If a detection exceeds the timer setting (known as the Max On-duration) the sensor performs a full recalibration. This does not toggle the output state but ensures that the QT102 will detect a new touch correctly. The timer is set to activate this feature after ~30 seconds. This will vary slightly with Cs.

1.5 Forced Sensor Recalibration

The QT102 has no recalibration pin; a forced recalibration is accomplished when the device is powered up, after the recalibration timeout or when the auto-off override is released.

However, supply drain is low so it is a simple matter to treat the entire IC as a controllable load; driving the QT102's VDD pin directly from another logic gate or a microcontroller port will serve as both power and 'forced recal(ibration)'. The source resistance of most CMOS gates and microcontrollers are low enough to provide direct power without problems.

1.6 Drift Compensation

Signal drift can occur because of changes in Cx and Cs over time. It may be helpful if drift is compensated for, otherwise false detections, nondetections, and sensitivity shifts may follow.

Drift compensation is schematically shown in FIG. **2**. Drift compensation is performed by making a reference level track the raw signal at a slow rate, but only while there is no detection in effect. It may be helpful if the rate of adjustment is performed relatively slowly, otherwise there may be a risk that legitimate detections may be ignored. The QT102 drift compensates using a slew-rate limited change to the reference level; the threshold and hysteresis values are slaved to this reference.

Once an object is sensed, the drift compensation mechanism ceases since the signal is legitimately high, and therefore should not cause the reference level to change (as indicated in FIG. **2** during the period between the vertical dotted lines).

The QT102's drift compensation is 'asymmetric'; the reference level drift-compensates in one direction faster than it does in the other. Specifically, it compensates faster for decreasing signals than for increasing signals. It may be helpful if increasing signals are not compensated for quickly, since an approaching finger could be compensated for partially or entirely before approaching the sense electrode.

However, an obstruction over the sense pad, for which the sensor has already made full allowance, could suddenly be removed leaving the sensor with an artificially elevated reference level and thus become insensitive to touch. In this latter case, the sensor will compensate for the object's removal more quickly, for example in only a few seconds.

With relatively large values of Cs and small values of Cx, drift compensation will appear to operate more slowly than with the converse. Note that the positive and negative drift compensation rates are different.

1.7 Response Time

The QT102's response time is dependent on burst length, which in turn is dependent on Cs and Cx. With increasing Cs, response time slows, while increasing levels of Cx reduce response time.

1.8 Spread Spectrum

The QT102 modulates its internal oscillator by ±7.5 percent during the measurement burst. This spreads the generated noise over a wider band reducing emission levels. This also reduces susceptibility since there is no longer a single fundamental burst frequency.

2 Wiring and Parts

FIG. **3** schematically shows a basic circuit configuration for an implementation of an embodiment of the invention.

2.1 Application Note

Although not directly relevant for embodiments of the invention, for completeness, reference may be made to Application Note AN-KD02 ("Secrets of a Successful QTouch™ Design), included herein in its entirety by reference, and downloadable from the Quantum Research Group website, for information on example construction and design methods. Go to http://www.qprox.com, click the Support tab and then Application Notes.

2.2 Cs Sample Capacitor

Cs is the charge sensing sample capacitor. The required Cs value depends on the thickness of the panel and its dielectric constant. Thicker panels require larger values of Cs. Typical values are 1 or 2 nF to 50 nF depending on the sensitivity required; larger values of Cs may demand higher stability and better dielectric to ensure reliable sensing.

The Cs capacitor may be a stable type, such as X7R ceramic or PPS film. For more consistent sensing from unit to unit, 5 percent tolerance capacitors are recommended. X7R ceramic types can be obtained in 5 percent tolerance for little or no extra cost. In applications where high sensitivity (long burst length) is required, the use of PPS capacitors is recommended.

2.3 Rs Resistor

Series resistor Rs is in line with the electrode connection and may be used to limit electrostatic discharge (ESD) currents and to suppress radio frequency interference (RFI). It may be approximately 4.7 kΩ to 33 kΩ, for example.

Although this resistor may be omitted, the device may become susceptible to external noise or RFI. For more details of how to select these resistors see the Application Note AN-KD02 referred to above in Section 2.1.

2.4 Power Supply, PCB Layout

The power supply (between VDD and VSS/system ground) can range between 2.0V and 5.5V for the QT102 implementation. If the power supply is shared with another electronic system, it may be helpful if care is taken to ensure that the supply is free of digital spikes, sags, and surges which can adversely affect the device. The QT102 will track slow changes in VDD, but it may be more affected by rapid voltage fluctuations. Thus it may be helpful if a separate voltage regulator is used just for the QT102 to isolate it from power supply shifts caused by other components.

If desired, the supply can be regulated using a Low Dropout (LDO) regulator. See Application Note AN-KD02 (see Section 2.1) for further information on power supply considerations.

Suggested regulator manufacturers include:

Toko (XC6215 series)
Seiko (S817 series)
BCDSemi (AP2121 series)

Parts placement: The chip may be placed to minimize the SNSK trace length to reduce low frequency pickup, and to reduce Cx which degrades gain. It may be helpful if the Cs and Rs resistors (see FIG. **3**) are placed close to the body of the chip so that the trace between Rs and the SNSK pin is relatively short, thereby reducing the antenna-like ability of this trace to pick up high frequency signals and feed them directly into the chip. A ground plane can be used under the chip and the associated discretes, but it may be helpful if the trace from the Rs resistor and the electrode do not run near ground, to reduce loading.

For improved Electromagnetic compatibility (EMC) performance the circuit may be made entirely with surface mount technology (SMT) components.

Electrode trace routing: It may be helpful to keep the electrode trace (and the electrode itself) away from other signal, power, and ground traces including over or next to ground planes. Adjacent switching signals can induce noise onto the sensing signal; any adjacent trace or ground plane next to, or under, the electrode trace will cause an increase in Cx load and desensitize the device.

Note: a 100 nF (0.1 μF) ceramic bypass capacitor (not shown in FIG. **3**) might be used between VDD and VSS in cases where it is considered appropriate to help avoid latch-up if there are substantial VDD transients; for example, during an ESD (electrostatic discharge) event. It may furthermore be helpful if the bypass capacitor is placed close to the device's power pins.

TABLE 2.1

QT102 Pin Descriptions (referring to the pin numbering shown in FIG. 3)

PIN	NAME	TYPE	DESCRIPTION
1	OUT	O	To switched circuit and output polarity selection resistor (Rop)
2	VSS	P	Ground power pin
3	SNSK	IO	To Cs capacitor and to sense electrode
4	SNS	IO	To Cs capacitor and multiplier configuration resistor (Rm). Rm connected to either VSS or VDD. Refer to Section 3.5 for details.
5	VDD	P	Positive power pin
6	TIME	I	Timeout configuration pin, connected to either VSS, VDD, OUT or an RC network. Refer to Section 3.5 for details.

Type: P - Ground or power; IO - Input and output; OD - Open drain output; O - Output only, push-pull; I - Input only

Regarding FIG. **3**, the following sections provide guidance for some example component values: Section 2.2 for Cs capacitor (Cs); Section 2.3 for Sample resistor (Rs); Section 2.4 for Voltage levels; Section 3.5.2 for Rm; and Section 3.3 for Rop.

3 Operation

3.1 Acquisition Modes

3.1.1 Introduction

The polarity for the OUT pin of the QT102 can be configured to be "active high" or "active low" (see Section 3.3). If configured active high, then 'on' is high and 'off' is low. If configured active low, then 'on' is low and 'off' is high.

The QT102 has more than one acquisition mode with the mode depending on the state of the OUT pin (on or off) and whether a touch is detected. In the following text 'on' is when the output is in its active state (which could be high or low depending on how the polarity for the OUT pin is configured).

3.1.2 OUT Pin 'On' (Fast Mode)

The QT102 runs in a "Fast mode" when the OUT pin is on. In this mode the device runs at maximum speed at the expense of increased current consumption. The delay between bursts in Fast mode is approximately 2.6 ms. FIG. **4** schematically shows bursts on the SNSK pin during fast mode acquisition.

3.1.3 OUT Pin 'Off' (Low Power Mode)

The QT102 runs in Low Power (LP) mode if the OUT pin is off. In this mode it sleeps for approximately 85 ms at the end of each burst, saving power but slowing response. On detecting a possible key touch, it temporarily switches to Fast mode until either the key touch is confirmed or found to be spurious (via the detect integration process). If the touch is confirmed the QT102 will switch to Fast mode. If a touch is denied the device will revert to normal LP mode operation automatically. FIG. **5** schematically shows bursts on the SNSK pin during a touch detection event. Also schematically represented is the output signal on the OUT pin. A key touch occurs around halfway along the figure. Prior to the key touch, the OUT pin is off (schematically shown here as a low logic level) and the QT102 is running in Low Power mode with sleep periods between bursts. The capacitance measured during the first burst after the key touch is higher and this triggers Fast mode acquisition. Following four burst in which the higher capacitance is seen (see Section 3.2.1), the OUT pin switches to on (schematically shown here as a high logic level) and Fast mode acquisition continues.

3.2 Signal Processing

3.2.1 Detect Integrator

It is desirable to suppress detections generated by electrical noise or from quick brushes with an object. To accomplish this, the QT102 incorporates a 'detect integration' (DI) counter that increments with each detection until a limit is reached, after which the output is activated. If no detection is sensed prior to the final count, the counter is reset immediately to zero. In the QT102, the required count is four. The DI can also be viewed as a 'consensus' filter, that requires four successive detections to create an output.

3.2.2 Detect Threshold

The device detects a touch when the signal has crossed a threshold level. in this example the threshold level is fixed at 10 counts.

3.3 Output Polarity Selection

The output (OUT pin) of the QT102 can be configured to have an active high or active low output by means of the output configuration resistor Rop. The resistor is connected between the output an output configuration voltage Vop, which may be either VSS or VDD as schematically shown in FIG. **6**. For the QT102, if Vop is VSS, the output polarity is configured active high. If Vop is VDD, the output polarity is configured active low

It is noted that some devices, such as Digital Transistors, have an internal biasing network that will naturally pull the OUT pin to its inactive state. If these are being used then the resistor Rop is not required, as schematically shown in FIG. **7**.

3.4 Output Drive

The OUT pin in the QT102 embodiment can sink or source up to 2 mA. When a relatively large value of Cs (e.g. >20 nF) is used, it may be helpful if the OUT pin current is limited to <1 mA to reduce the risk of gain-shifting side effects. These may happen when the load current creates voltage drops on the die and bonding wires; in some cases these small shifts can materially influence the signal level to cause detection instability.

3.5 Auto Off Delay

3.5.1 Introduction

In addition to toggling the output on/off with key touch, the QT102 can automatically switch the output off after a specific time. This feature can be used to save power in situations where the switched device could be left on inadvertently.

The QT102 has:

three predefined delay times (Section 3.5.2)

the ability to set a user-programmed delay (Section 3.5.3)

the ability to override the auto off delay (Section 3.5.4)

The QT102 chip is programmed such that the TIME and SNS pins may be used to configure the auto-off delay t_o and may be connected in one of the ways described in Sections 3.5.2, 3.5.3 and 3.5.4 to provide different functionality.

3.5.2 Auto Off—Predefined Delay

To configure a predefined delay t_o the TIME pin may be wired to a voltage V_t, as schematically indicated in FIG. **8**. Voltage V_t may be VSS, VDD or OUT. These provides nominal values of t_o=15 minutes, 60 minutes or infinity (remains on until toggled off) as indicated in Table 3.2 for an active high output configuration and in Table 3.3 for an active low output configuration.

Furthermore, also as shown in FIG. **8**, a resistor Rm (e.g. a 1 MΩ resistor) may be connected between the SNS pin and the logic level Vm to provide three auto off functions: namely delay multiplication, delay override and delay retriggering. On power-up the logic level at Vm is assessed and a delay multiplication factor is set to ×1 or ×24 accordingly (see Table 3.4). At the end of each acquisition cycle the logic level of Vm is monitored to see if an Auto off delay override is required (see Section 3.5.4).

Setting the delay multiplier to ×24 will decrease the key sensitivity. Thus in some cases it may be appropriate to compensate for this by increasing the value of Cs.

TABLE 3.2

Predefined Auto-off Delay (Active High Output)

Vt	Auto-off delay (t_o)
VSS	Infinity (remain on until toggled to off)
VDD	15 minutes
OUT	60 minutes

TABLE 3.3

Predefined Auto-off Delay (Active Low Output)

Vt	Auto-off delay (t_o)
VSS	15 minutes
VDD	Infinity (remain on until toggled to off)
OUT	60 minutes

TABLE 3.4

Auto-off Delay Multiplier

Vm	Auto-off delay multiplier
VSS	$t_o * 1$
VDD	$t_o * 24$

3.5.3 Auto Off—User-Programmed Delay

If a user-programmed delay is desired, a resistor Rt and capacitor Ct can be used to set an auto-off delay (see Table 3.5 and FIG. **9**). The delay time is dependent on the RC time constant (Rt*Ct) the output polarity (i.e. whether active high or active low), and the supply voltage. Section 3.5.5 gives more details of how to configure the QT102 to have auto-off delay times ranging from 1 minute to up to 24 hours.

TABLE 3.5

Programmable Auto Off Delay

Output type	Auto Off Delay (seconds)
Active high	(Rt * Ct * 15)/42
Active low	(Rt * Ct * 15)/14.3

Notes: The RC divisor values K (42 and 14.3) may be obtained from FIGS. **13** and **14**. In this example the values are for a supply voltage VDD=3.5 volts. For the parameterization shown in Table 3.5, Rt is in kΩ and Ct is in nF.

3.5.4 Auto Off—Overriding the Auto Off Delay

In normal operation the QT102 output is turned off automatically after the auto-off delay. However, in some applications it may be useful to extend the auto-off delay ('sustain' function), or to switch the output off immediately ('cancel' function). This can be achieved by pulsing the voltage on the delay multiplier resistor Rm as schematically shown in FIG. **10** (positive-going pulse from VSS to VDD for delay multiplier ×1 configuration) and FIG. **11** (negative-going pulse from VDD to VDD for delay multiplier ×24 configuration). The pulse duration tp may determine whether a retrigger of the auto-off delay or a switch of the output to off is desired. To help ensure the pulse is detected it may be present for a time greater than the burst length as shown in Table 3.6.

TABLE 3.6

Time Delay Pulse

Pulse Duration	Action
tr > burst time + 10 ms (typical value 25 ms)	Retrigger (reload auto-off delay counter)
tp > burst time + 50 ms (typical value 65 ms)	Switch output to off state and inhibit further touch detection until Vm returns to original state

While Vm is held in the override state (i.e. the duration of the pulse) the QT102 inhibits bursts and waits for Vm to return to its original state (at the end of the pulse). When Vm returns to its original state the QT102 performs a sensor recalibration before continuing in its current output state.

FIG. **12** schematically shows override pulses being applied to a QT102 with delay multiplier set to ×1 (i.e. Vm normally at VSS with positive going pulses). The QT102 OUT signal is shown at the top of the Figure. Vm is shown in the middle. Acquisition bursts on SNSK are shown at the bottom. Each short pulse P on Vm causes a sensor recalibration C and a restart of the auto-off timer. During the long pulse applied to Vm (i.e. where $tp>t_{off}$), the output is switched off at O. When the pulse finishes, the output remains switched off and a sensor recalibration C is performed.

3.5.5 Configuring the User-Programmed Auto-Off Delay

As described in Section 3.5.3 the QT102 can be configured to give auto-off delays ranging from minutes to hours by means of a simple CR network and the delay multiplier input.

With the delay multiplier set at ×1 the auto-off delay is calculated as follows:

$$\text{Delay value}=\text{integer value of}(Rt*Ct/K)*15\text{ seconds.}$$

$$(\text{i.e. } Rt*Ct=\text{Delay value(in seconds)}*K/15$$

Note: Rt is in kΩ, Ct is in nF.

In some applications improved operation may be achieved if the value of Rt*Ct is between 4 and 240. Values outside this range may be interpreted as the hard wired options TIME linked to OUT and TIME linked to 'off' respectively, causing the QT102 to use the relevant predefined auto-off delays (see Tables 3.2 and 3.3).

FIGS. **13** and **14** show typical values of K versus supply voltage for a QT102 with active high or active low output.

Example Using the Formula to Calculate Rt and Ct

Requirements/Operating Parameters:

Active high output (Vop connected to VSS)

Auto-off delay 45 minutes

VDD=3.5 v

Proceed as Follows:

1. Calculate Auto-off delay in seconds 45*60=2700

2. Obtain K from FIG. **13** (active high): K=42 for VDD=3.5 v

3. Calculate Rt*Ct=2700*42/15=7560

4. Select a value for Ct (or conversely Rt). E.g. Ct=47 nF

5. Calculate Rt (or conversely Ct)=7560/47=160 kΩ

As an alternative to calculation, Rt and Ct values may be selected from pre-calculated curves such as shown in FIGS. **15** and **16**. FIGS. **15** and **16** show charts of typical curves of auto-off delay against resistor and capacitor values for active high (FIG. **15**) and active low (FIG. **16**) outputs at various values of VDD and for delay multiplier=×1.

Example Using Plot Shown in FIG. **15** or **16** to Calculate Rt and Ct

Requirements/Operating Parameters:

Active low output (Vop connected to VSS)

Auto-off delay 10 hours

VDD=4V

Proceed as Follows:

1. Calculate Auto-off delay in seconds 10×60×60=36000. This value is outside of the range of the charts so use the ×24 multiplier (connect Rm to VDD).

Note: this will decrease the key sensitivity, so in some circumstances it may be helpful to increase the value of Cs.

2. Find 36000/24=1500 on the 4V chart in FIG. **16**

3. Read across to see appropriate Rt/Ct combinations. This example shows the following Rt/Ct combinations to be appropriate: 100 nF/10 kΩ, 47 nF/27 kΩ, 22 nF/60 kΩ and 10 nF/130 kg.

Of course the Auto-off delay times given here are nominal and will vary slightly from chip to chip and with capacitor and resistor tolerance.

3.6 Examples of Typical Applications

FIG. **17** shows a first example application of a QT102 chip in accordance with an embodiment of the invention. Here the QT102 is in an active low configuration and is shown driving a PNP transistor with an auto off time of 500 s×24 (3.33 hours)

The auto off time for the circuit configuration shown in FIG. **16** may be obtained from the VDD=3V chart in FIG. **16**. Setting the delay multiplier to ×24 will decrease the key sensitivity, so it may be helpful in some cases to increase the value of Cs.

FIG. **17** shows a second example application of a QT102 chip in accordance with an embodiment of the invention. Here the QT102 is in an active high configuration and is shown driving high impedance with an auto off time of 135 s×1 (2.25 minutes).

The auto off time for the circuit configuration shown in FIG. **18** may be obtained from the VDD=5V chart in FIG. **15**.

4. Example Specifications for an Example QT102 Chip

A chip incorporating an embodiment of the invention may have the following specifications.

4.1 Suggested Maximum Operating Specifications

Operating temperature:	−40° C. to +85° C.
Storage temperature:	−55° C. to +125° C.
VDD:	0 to +6.5 V
Maximum continuous pin current, any control or drive pin:	±20 mA
Short circuit duration to VSS, any pin:	infinite
Short circuit duration to VDD, any pin:	infinite
Voltage forced onto any pin:	−0.6 to (VDD + 0.6) Volts

4.2 Recommended Typical Operating Conditions

VDD:	+2.0 to 5.5 V
Short-term supply ripple + noise:	±5 mV
Long-term supply stability:	±100 mV
Cs value:	1 or 2 nF to 50 nF
Cx value:	5 to 20 pF

4.3 AC Specifications

VDD=3.0V, Cs=10 nF, Cx=5 pF, Ta=recommended range, unless otherwise noted

Parameter	Description	Min	Typ	Max	Units	Notes
T_{RC}	Recalibration time		250		ms	Cs and Cx dependent
T_{PC}	Charge duration		2		µs	±7.5% spread spectrum variation
T_{PT}	Transfer duration		2		µs	±7.5% spread spectrum variation
T_{G1}	Time between end of burst and start of the next (Fast mode)		2.6		ms	
T_{G2}	Time between end of burst and start of the next (LP mode)		85		ms	Increases with reducing VDD
T_{BL}	Burst length		20		ms	VDD, Cs and Cx dependent. See Section 2.2 for capacitor selection.
T_R	Response time			100	ms	

4.4 Signal Processing

Description	Min	Typ	Max	Units	Notes
Threshold differential		10		counts	
Hysteresis		2		counts	
Consensus filter length		4		samples	
Recalibration timer duration		40		secs	Will vary with VDD

4.5 DC Specifications

VDD=3.0V, Cs=10 nF, Cx=5 pF, Ta=recommended range, unless otherwise noted

Parameter	Description	Min	Typ	Max	Units	Notes
V_{DD}	Supply voltage	2		5/5.5	V	
I_{DD}	Supply current	5		60	μA	Depending on supply and run mode
Iddl	Supply current, LP Mode		23		μA	2 V
			37			3 V
			90			5 V
V_{DDS}	Supply turn-on slope	100			V/s	Required for proper start-up
V_{IL}	Low input logic level			0.8	V	
V_{HL}	High input logic level	2.2			V	
V_{OL}	Low output voltage			0.6	V	OUT, 4 mA sink
V_{OH}	High output voltage	VDD − 0.7			V	OUT, 1 mA source
I_{IL}	Input leakage current			±1	μA	
Cx	Load capacitance range	0		100	pF	
A_R	Acquisition resolution		9	14	bits	

4.6 Mechanical Dimensions

In one example embodiment a chip implementing the above-described QT102 chip functionality may be provided in an SOT23-6 package type. Referring to FIG. **19**, the chip may thus have the following dimensions.

Package type: SOT23-6						
	Millimeters			Inches		
Symbol	Min	Max	Notes	Min	Max	Notes
M	2.8	3.10		0.110	0.122	
W	2.6	3.0		0.102	0.118	
Aa	1.5	1.75		0.059	0.069	
H	0.9	1.3		0.035	0.051	
h	0.0	0.15		0	0.006	
D	—	—	0.95 BSC	—	—	0.038 BSC
L	0.35	0.5		0.014	0.02	
E	0.35	0.55		0.014	0.022	
e	0.09	0.2		0.004	0.008	
Φ	0°	10°		0°	10°	

A QT102 chip provided in an SOT23-6 package type may have a pin arrangement as schematically indicated in FIG. **20**.

4.7 Moisture Sensitivity Level (MSL)

A chip implementing the above-described QT102 chip functionality may be rated as follows:

MSL Rating	Peak Body Temperature	Specifications
MSL1	260° C.	IPC/JEDEC J-STD-020C

Thus, in accordance with an embodiment of the invention, the QT102 charge-transfer (QT) touch sensor is a self-contained digital IC capable of detecting near-proximity or touch. It may project a touch or proximity field through any dielectric like glass, plastic, stone, ceramic, and even most kinds of wood. It can also turn small metal-bearing objects into intrinsic sensors, making them responsive to proximity or touch. This capability, coupled with its ability to self calibrate, can lead to entirely new product concepts. It may be implemented in human interfaces, like control panels, appliances, toys, lighting controls, or anywhere a mechanical switch or button may be found.

The QT102 example embodiment may be seen as a single key chip combining a touch-on/touch-off toggle mode with timeout and timing override functions, oriented towards power control of small appliances and battery-operated products, for example. With a small low-cost SOT-23 package, this device can suit almost any product needing a power switch or other toggle-mode controlled function.

An environmentally friendly ('green') feature of the QT102 is the timeout function, which can turn off power after a specified time delay ranging from minutes to hours. Furthermore, external 'sustain' and 'cancel' functions permit designs where the timeout needs to be extended further or terminated early. A user's interaction with a product might trigger a 'sustain' input, prolonging the time to shutoff. A safety sensor, such as a tip-over switch on a space heater, can feed the 'cancel' function to terminate early.

The QT102 embodiment of the invention features automatic self-calibration, drift compensation, and spread-spectrum burst modulation. The device can in some cases bring inexpensive, easy-to-implement capacitive touch sensing to all kinds of appliances and equipment, from toys to coffee makers. The small, low cost SOT-23 package lets this unique combination of features reside in almost any product.

The QT102 chip embodying an example of the invention may be summarised as having the following operational features/application parameters:

Number of keys: One touch on/touch off (toggle mode), plus hardware programmable auto switch-off/switch-off delay and external cancel

Technology: Spread-spectrum charge-transfer (direct mode)

Example key outline sizes: 6 mm×6 mm or larger (generally panel thickness dependent); widely different sizes and shapes possible

Example electrode design: Solid or ring electrode shapes

PCB Layers required: One

Example electrode materials: Etched copper, silver, carbon, Indium Tin Oxide (ITO), Orgacon®

Example electrode substrates: PCB, FPCB, plastic films, glass

Example panel materials: Plastic, glass, composites, painted surfaces (including relatively low particle density metallic paints)

Example panel thickness: Up to 50 mm glass, 20 mm plastic (generally electrode size dependent)

Key sensitivity: Settable via external capacitor

Interface: Digital output, active high or active low (hardware configurable)

Moisture tolerance: Good

Power: 2V~5.5V; drawing, for example, 23 μA at 2V

Example package: SOT23-6 (3×3 mm) RoHS compliant

Signal processing: Self-calibration, auto drift compensation, noise filtering

Example Applications: Power switch replacement in countertop appliances, irons, battery powered toys, heaters, lighting controls, automotive interior lighting, commercial and industrial equipment such as soldering stations and cooking equipment

The above-described sensors may be used in apparatus or devices with one touch key or the sensing element of the sensor of an embodiment of the invention may comprise more than one key, for example two, three, or more keys.

The invention claimed is:

1. A sensor for determining the presence of an object comprising:

a sensing element;

a capacitance measurement circuit operable to measure the capacitance of the sensing element; and

a control circuit operable to determine whether the object is in proximity with the sensor based on a measurement of the capacitance of the sensing element, the control circuit further being operable to provide an output signal to control a function of an apparatus when it is determined that the object has not been in proximity with the sensor for a predetermined time duration, wherein the control circuit includes a time input terminal and the predetermined time duration is selectable from the number of different predefined time durations according to a voltage applied to the time input terminal, and wherein the control circuit includes a delay multiplier terminal and is configured so that a selected one of the number of different predefined time durations is multiplied by a multiplication factor according to a voltage applied to the delay multiplier terminal to provide the predetermined time duration.

2. The sensor of claim **1**, wherein the capacitance measurement circuit is configured to operate in one of more than one acquisition modes depending on the output signal.

3. The sensor of claim **2**, wherein a one of the more than one acquisition modes is a low-power mode.

4. The sensor of claim **2**, wherein a one of the more than one acquisition modes is a fast mode.

5. The sensor of claim **1**, wherein the capacitance measurement circuit and the control circuit are comprised in a general purpose microcontroller under firmware control.

6. The sensor of claim **1**, wherein the capacitance measurement circuit and the control circuit are comprised within a six-pin integrated circuit chip package.

7. An apparatus comprising a sensor according to claim **1**.

8. The sensor of claim **1**, wherein the control circuit is configured such that the provision of the output signal to control a function of an apparatus after the predetermined time duration may be overridden so the output signal is not provided when it is determined that an object has not been in proximity with the sensor for a predetermined time duration.

9. The sensor of claim **8**, wherein the control circuit is operable to receive an override pulse and on receipt of the override pulse to retrigger the predetermined time duration to so as to extend the time before the output signal to control a function of an apparatus is provided.

10. The sensor of claim **1**, wherein the control circuit is configured such that the provision of the output signal to control a function of an apparatus after the predetermined time duration may be overridden so the output signal is provided before it is determined that an object has not been in proximity with the sensor for a predetermined time duration.

11. The sensor of claim **10**, wherein the control circuit is operable to receive an override pulse and on receipt of the override pulse to provide the output signal to control a function of an apparatus.

12. The sensor of claim **1**, wherein the sensor is configured to perform a recalibration when the sensor is powered up, when an object is determined to be in proximity with the sensor for more than a timer setting, and/or when an override is released.

13. The sensor of claim **1**, wherein the control circuit is configured such that the output signal is toggled between a high state and a low state when an object is determined to be in proximity with the sensor.

14. The sensor of claim **1**, wherein the function of the apparatus controlled by the output signal is a switch-off function.

15. The sensor of claim **1**, wherein the capacitance measurement circuit employs bursts of charge-transfer cycles to acquire measurements.

16. A sensor for determining the presence of an object comprising:

a sensing element;

a capacitance measurement circuit operable to measure the capacitance of the sensing element; and

a control circuit operable to determine whether an object is in proximity with the sensor based on a measurement of the capacitance of the sensing element, the control circuit further being operable to provide an output signal to control a function of an apparatus when it is determined that an object has not been proximity with the sensor for a predetermined time duration, wherein the control circuit is configured so that the predetermined time duration is programmable by a user to provide a user-selected time duration, and wherein the control circuit includes a delay multiplier terminal and is configured so that the user-selected time duration is multiplied by a multiplication factor according to a voltage applied to the delay multiplier terminal to provide the predetermined time duration.

17. The sensor of claim **16**, further comprising a resistor-capacitor (RC) network coupled to the control circuit and wherein the predetermined time duration depends on a time constant of the RC network.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 7,952,366 B2	Page 1 of 1
APPLICATION NO.	: 12/179769	
DATED	: May 31, 2011	
INVENTOR(S)	: Philip et al.	

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 13, Line 30 delete “nF/130 kg” and insert -- nF/130 kΩ --.

Signed and Sealed this
Twelfth Day of November, 2013

Teresa Stanek Rea

Teresa Stanek Rea
Deputy Director of the United States Patent and Trademark Office