US007145552B2

(12) **United States Patent**
Hollingsworth

(10) **Patent No.: US 7,145,552 B2**
(45) **Date of Patent: Dec. 5, 2006**

(54) **ELECTRIC FIELD PROXIMITY KEYBOARDS AND DETECTION SYSTEMS**

(75) Inventor: **Tommy D. Hollingsworth**, Leander, TX (US)

(73) Assignee: **Solectron Corporation**, Milpitas, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 420 days.

(21) Appl. No.: **10/691,099**

(22) Filed: **Oct. 22, 2003**

(65) **Prior Publication Data**

US 2005/0088416 A1 Apr. 28, 2005

(51) **Int. Cl.**
G09G 5/00 (2006.01)

(52) **U.S. Cl.** **345/168**; 345/173; 345/179; 341/22

(58) **Field of Classification Search** 345/168, 345/156, 173, 179; 341/22–23; 178/18.01, 178/18.03

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,971,013 A	7/1976	Challoner et al.	
4,369,432 A *	1/1983	Mikami	341/120
4,394,643 A	7/1983	Williams	
4,680,430 A *	7/1987	Yoshikawa et al.	345/174
5,260,521 A	11/1993	Knowles	
5,324,895 A	6/1994	Inamori et al.	
5,572,205 A	11/1996	Caldwell et al.	
5,586,042 A	12/1996	Pisau et al.	
5,594,222 A	1/1997	Caldwell	
5,673,041 A	9/1997	Chatigny et al.	
6,452,514 B1	9/2002	Philipp	
6,861,961 B1 *	3/2005	Sandbach et al.	341/22
2002/0130848 A1	9/2002	Sims	

OTHER PUBLICATIONS

Jim Midolo, The Advent of Programmable Electronic Keyboards, ECN, Dec. 2001, p. 13, EAO Switch Corp, US.

Touch Sensitive, Touch Sensitive Technology Overview, pp. 15-16, Jun. 2002, EAO, US.

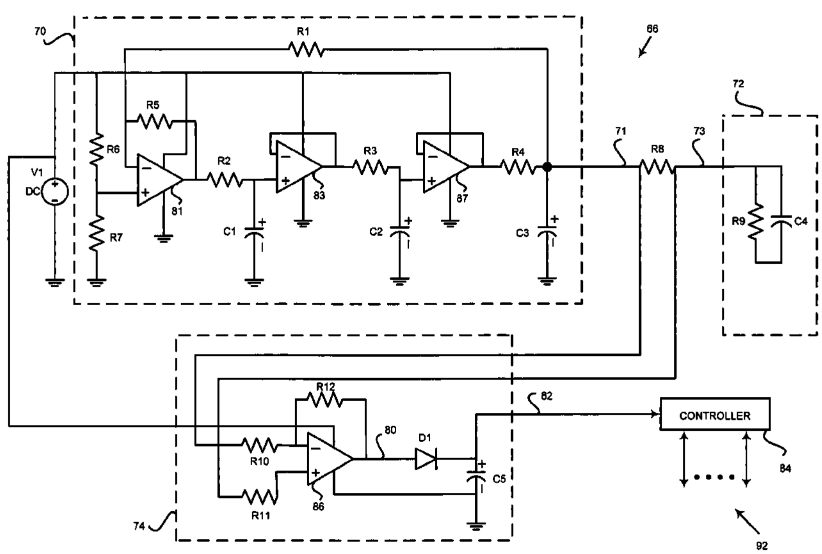
* cited by examiner

Primary Examiner—Richard Hjerpe
Assistant Examiner—Kimnhung Nguyen
(74) *Attorney, Agent, or Firm*—Robert Moll

(57) **ABSTRACT**

The invention is related to an electric field proximity detection system suitable for use as a touch sensitive keyboard or to be used in close proximity without direct contact. In an embodiment of a circuit useful in the system, an AC signal is coupled to a single electrode functioning as an antenna radiating an electric field through a high impedance circuit. A conductive object in close proximity disturbs the field causing a voltage change across nodes of the high impedance circuit that is compared by a detector circuit that generates a DC output indicating an object is close to the electrode. In another embodiment, the circuit couples to an analog multiplexer to control a plurality of electrodes. In another embodiment, a row and column address scheme couples a plurality of electrodes and increases resolution without substantially increasing complexity. The circuits may be integrated in a semiconductor to reduce size and cost. The electric field proximity detection system extends to applications related to object detection such as remote sensing, motion detection and remote controls.

19 Claims, 7 Drawing Sheets



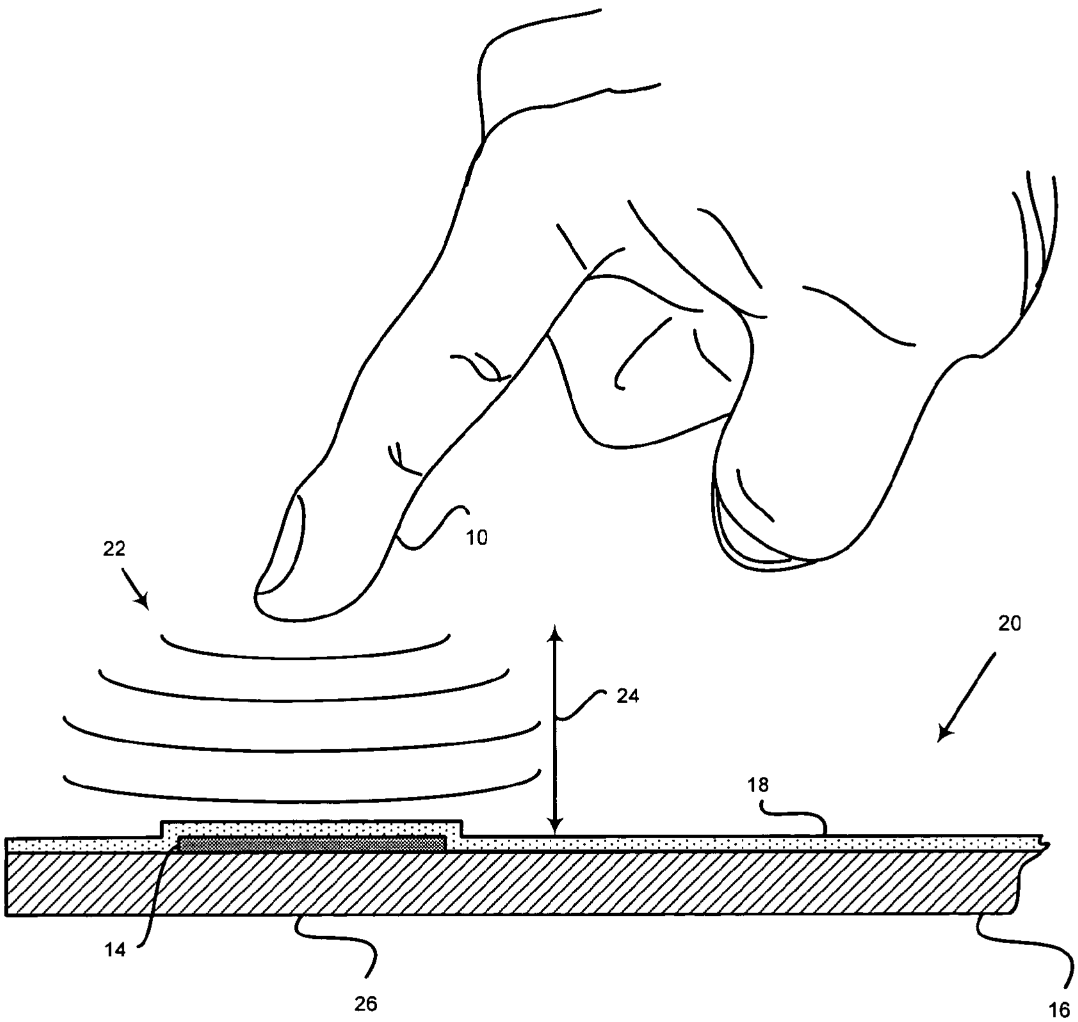


FIGURE 1

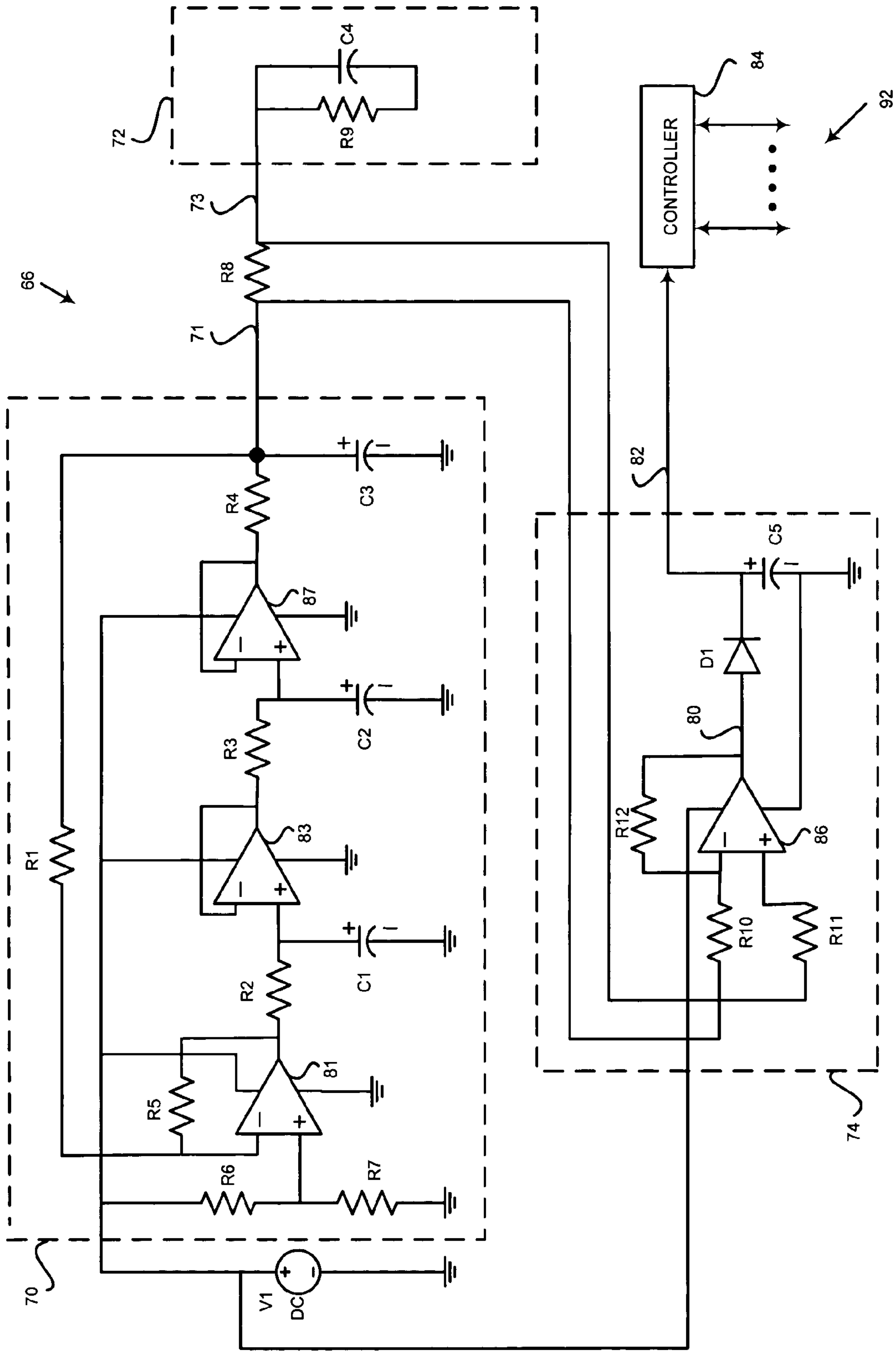

66
70
71
72
73
74
80
81
82
83
84
86
87
92
CONTROLLER
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
C1
C2
C3
C4
C5
D1
V1
DC

FIGURE 2

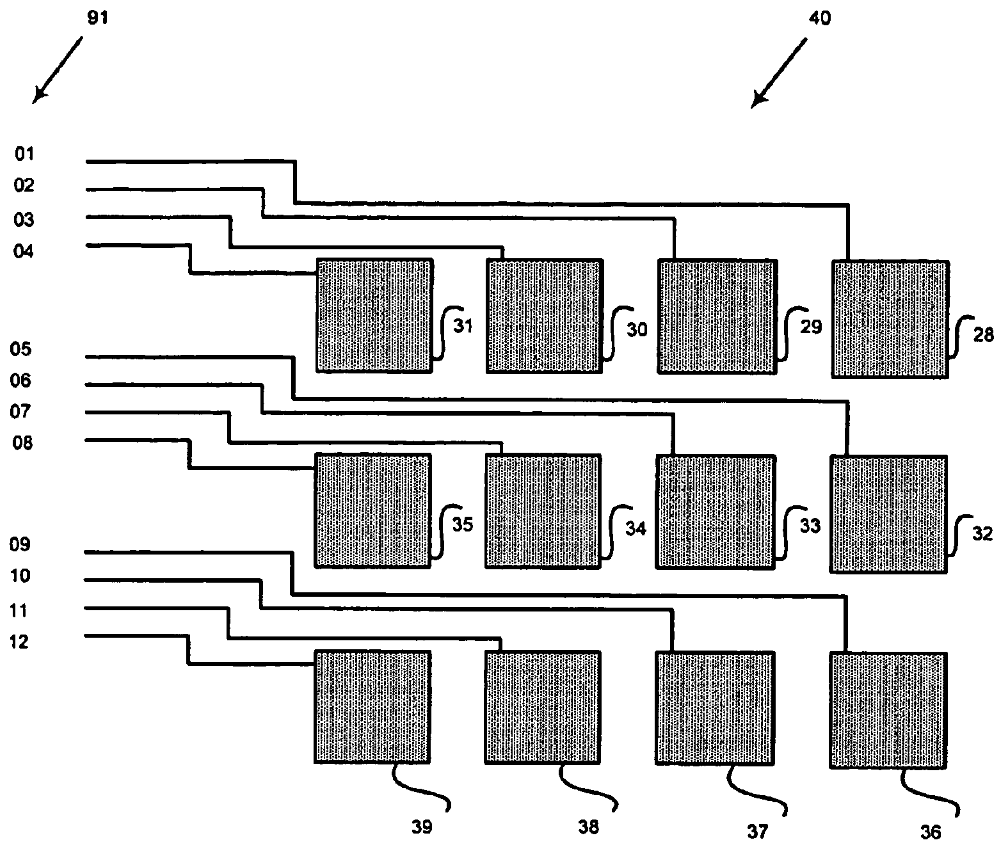

91
40
01
02
03
04
31
30
29
28
05
06
07
08
35
34
33
32
09
10
11
12
39
38
37
36

FIGURE 3

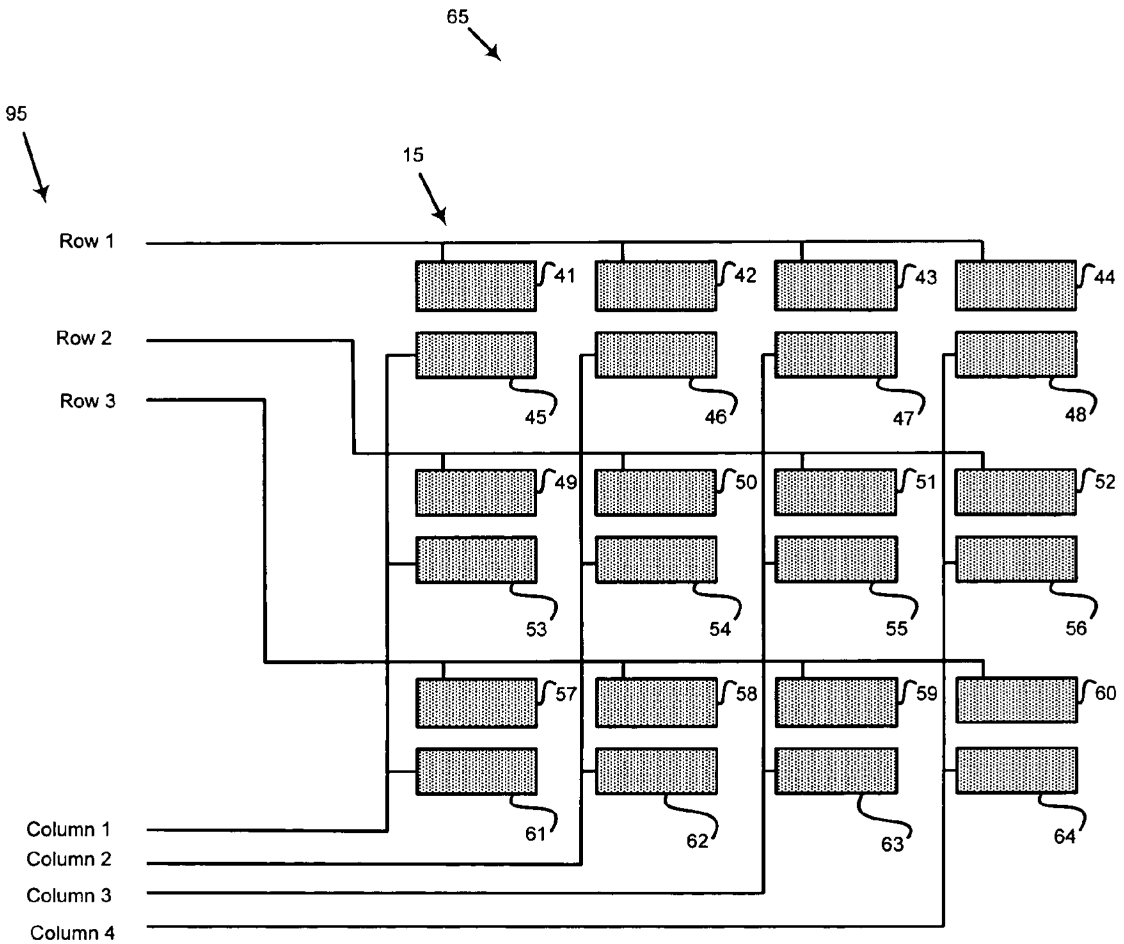

65
95
15
Row 1
Row 2
Row 3
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
Column 1
Column 2
Column 3
Column 4

FIGURE 4

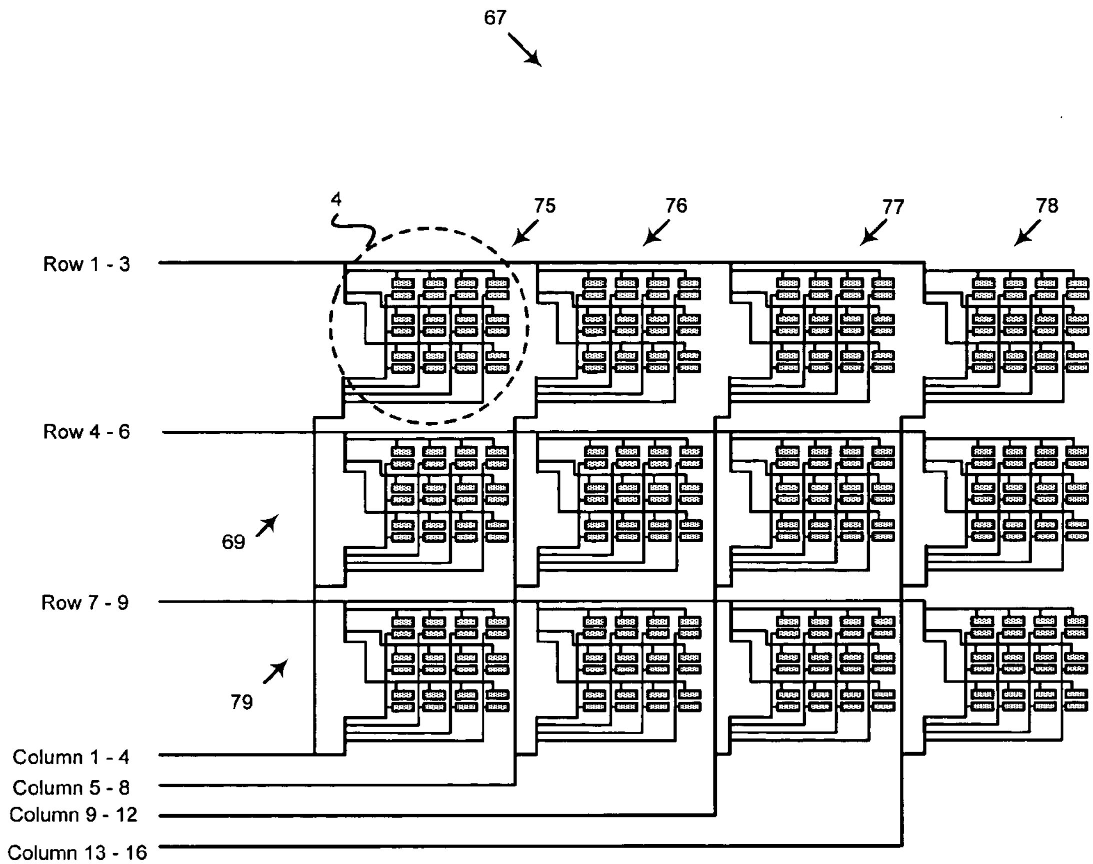

67
4
75
76
77
78
Row 1 - 3
Row 4 - 6
Row 7 - 9
69
79
Column 1 - 4
Column 5 - 8
Column 9 - 12
Column 13 - 16

FIGURE 5

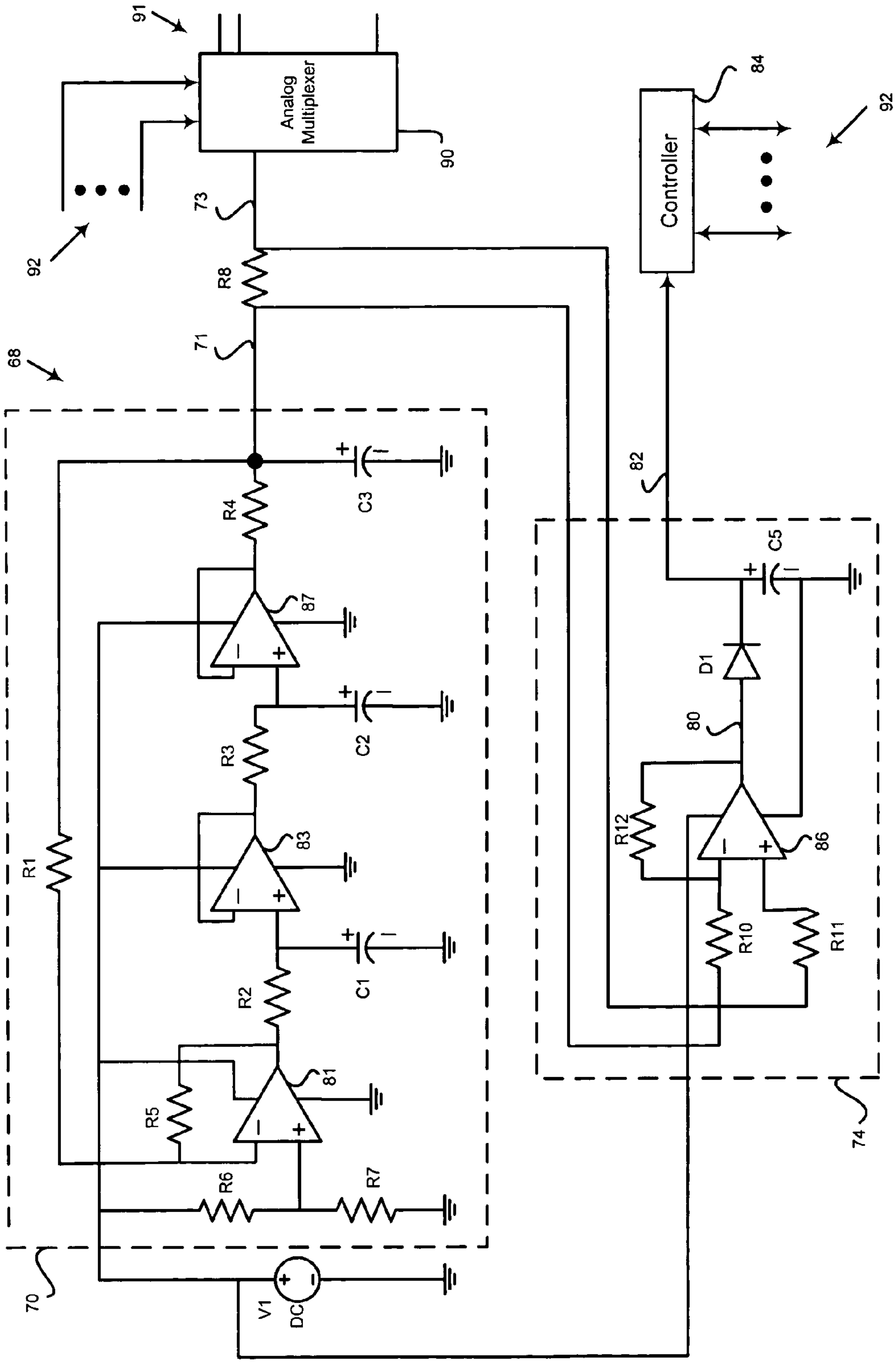

91
Analog Multiplexer
90
84
Controller
92
92
73
R8
71
68
82
C5
D1
80
R12
86
R10
R11
74
R4
C3
87
C2
R3
83
R1
C1
R2
R5
81
R6
R7
70
V1
DC

FIGURE 6

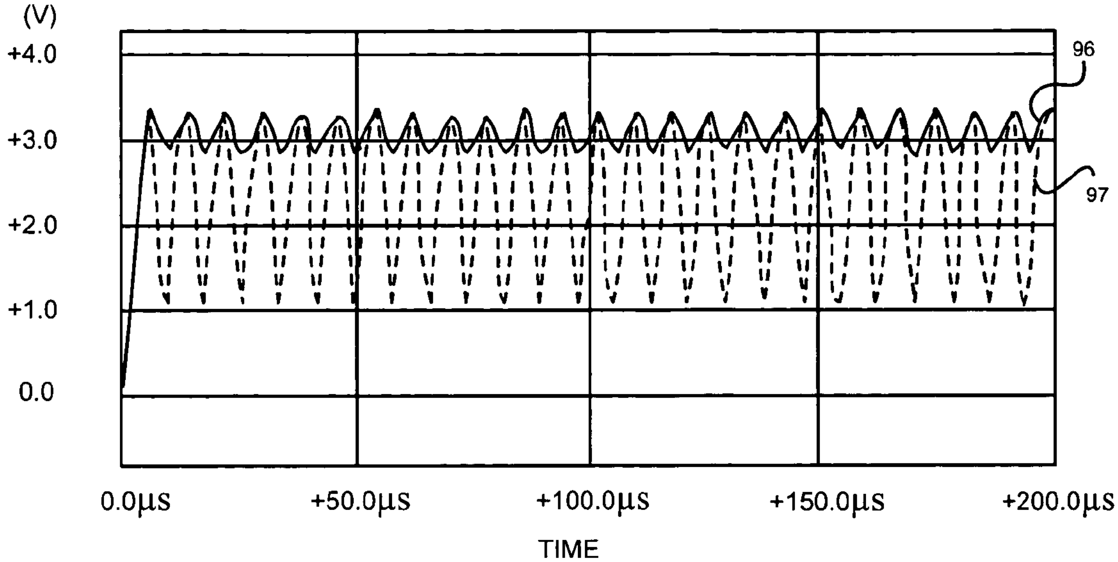


FIGURE 7A

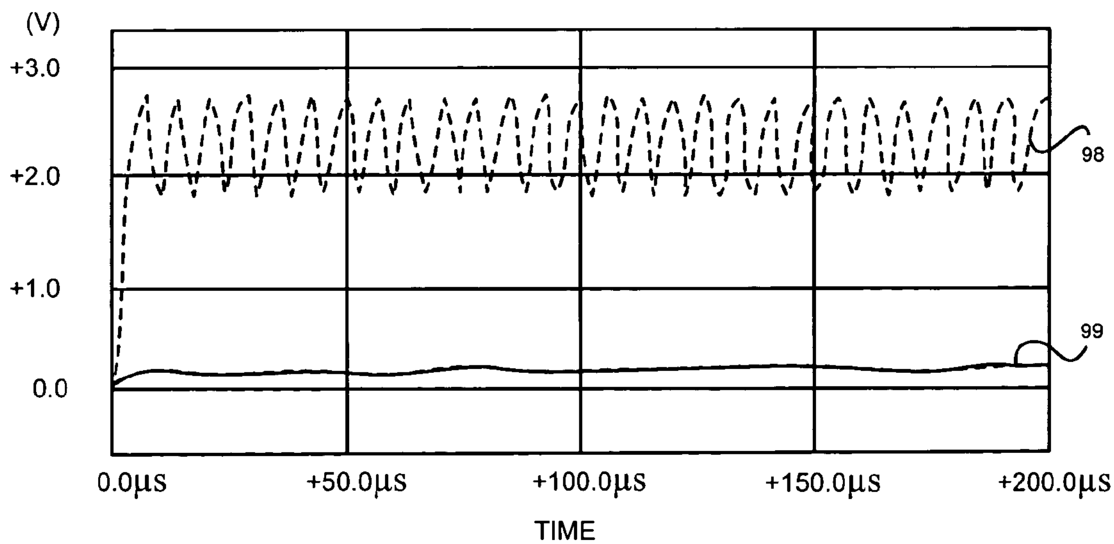


FIGURE 7B

ELECTRIC FIELD PROXIMITY KEYBOARDS AND DETECTION SYSTEMS

BACKGROUND

This invention relates to electric field proximity detection systems and particularly to electric field proximity circuits for touch sensitive or close proximity keyboards.

Many keyboards today are activated by depressing a keypad. A touch sensitive keyboard provides a similar I/O device, but is activated by merely touching rather than depressing each keypad. Touch sensitive keyboards are used in a variety of applications such as handheld computing devices (e.g., PDA), musical instruments, elevator switches, appliances, bank ATMs, and computers. Other types of touch sensitive keyboards can be activated by an object such as a finger or stylus touching the keypads displayed on a computer or terminal. A close proximity keyboard does not require contact, but is activated when an object (e.g., stylus or finger) is detected in close proximity to the keypad. Close proximity means the object is at a distance that should be detected for activation. The close proximity keyboard is especially useful where physical contact would result in undue wear or contamination in a sterile or hazardous environment.

In the past, touch sensitive and close proximity keyboards have used complicated detection systems. Some of these detection systems are described in U.S. Pat. Nos. 6,452,514 B1, 5,572,205, and 5,594,222, and U.S. published patent application Ser. No. 2002/0130848 A1. These patents and application describe use of two spaced apart electrodes or conductive pads such as a transmit electrode and a receiver electrode with a keypad. An object is detected as close to the keypad when it interferes with a signal coupled or transmitted between the two electrodes or pads. U.S. Pat. No. 3,971,013 takes a different approach using a gas panel to detect gas discharge due to contact to the gas panel. Due to the complexity of these detection designs, the costs impact the adoption rates of these types of keyboards.

SUMMARY OF THE INVENTION

The present invention relates to several embodiments of electric field proximity detection systems. The systems are suitable for touch sensitive keyboards and/or close proximity keyboards. In one embodiment, each keypad uses an electrode to radiate an electric field. In others, each keypad has a plurality of electrodes. The electric field is disturbed by touching an associated area (e.g., a keypad) or by a conductive object in close proximity to that area. A circuit that can sense when the electric field is disturbed and sends an output to activate a response and/or to a controller for further analysis and in some cases activation of a response.

In other features, the electric field proximity detection systems use row and column address schemes to multiplex the electrodes. The row and columns can be nested to permit higher resolution. The address schemes generally reduce complexity, and costs by reducing the addresses. The electric field proximity circuits, arrangements of electrodes, and address schemes are not limited to the keyboards and extend to applications related to object detection such as remote sensing, motion detection and remote control. By increasing the resolution using the row and column schemes, the waveform characteristics change accordingly. The controller can store the different loaded state waveforms characteristics for various objects for analysis and identification of the object types, and distance and duration of the object.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an object in close proximity to an electrode associated with a keypad of an electric field proximity keyboard.

FIG. **2** illustrates a circuit for an electrode suitable for use in an electric field proximity keyboard.

FIG. **3** illustrates an electric field proximity keyboard with an address to each electrode.

FIG. **4** illustrates a row and column address scheme for an electric field proximity keyboard.

FIG. **5** illustrates a nesting row and column address scheme for an electric field proximity keyboard.

FIG. **6** illustrates a circuit for a plurality of electrodes suitable for use in an electric field proximity keyboard.

FIG. **7**A compares the waveforms of the AC reference signal with the unloaded electric field signal of an electrode when no object is in close proximity to a keypad.

FIG. **7**B compares the waveforms of the AC reference signal with the loaded electric field signal of an electrode when an object is in close proximity to a keypad.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description includes the best mode of carrying out the invention. The detailed description is made for the purpose of illustrating the general principles of the invention and should not be taken in a limiting sense. The scope of the invention is determined by reference to the claims.

We assign each part, even if structurally identical to another part, a unique reference number wherever that part is shown in the drawing figures. A dashed circle indicates a portion of a figure that is enlarged in another figure. The figure showing the enlarged portion is indicated by a reference number tied to the dashed circle.

FIG. **1** illustrates an electric field proximity keyboard **20** that includes a substrate **16** such as a printed circuit board (PCB) and one or more keypads each with an electrode **14**. Each electrode can be made, for example, by conductive patterns on the PCB and is connected to an AC signal source described further in connection with FIG. **2**. The electrode **14** functions as an antenna radiating an electric field **22** and is located over a non-metallized portion **26** of the substrate **16** to reduce loading of the electric field **22**. A conductive object such as a finger **10** in close proximity to the electrode **14**, for example, at a distance **24**, will disturb, i.e., reduce the intensity of electric field **22**. This is referred to as electric field attenuation or loading. The electrode **14** may be protected from the environment and physical contact by a low loss dielectric layer **18** such as a solder mask or another other dielectric media (not shown) over the layer **18**. Suitable materials include a polycarbonate cover, glass, plastic, wood and other non-conductive materials that do not overly attenuate the electric field **22**.

FIG. **2** illustrates a circuit **66** for a single electrode of an electric field proximity keyboard. Horowitz and Hill, *The Art of Electronics* (Second Edition, 1989) describe electronic circuit design and is incorporated by reference herein. This circuit **66** can be used for an electrode in a keyboard or another electric field proximity detection system although other arrangements are possible as will be described below. It should be also understood that any circuit lines that cross each other are not electrically connected unless the intersection is covered by a solid dot. The circuit **66** includes an electrode circuit **72** (i.e., modeling the electrode **14**), an oscillator circuit **70** that includes multi-stage feedback oscillator amplifiers **81**, **83**, and **87**, and RC low pass filters such as the following resistor and capacitors: R**2**-C**1**, R**3**-C**2**, and R**4**-C**3**. The oscillator circuit **70** produces an AC signal, for example, a 64 KHz signal, at a first node **71**. A high impedance circuit such as a resistor R**8** (e.g., 2k ohms to 100 M ohms) isolates the AC signal from the electrode circuit **72** illustrated as a variable impedance parallel RC circuit with a resistor R**9** and a capacitor C**4**.

The detector circuit will detect the loading of the electrode when an object such as a human finger **10** is in close proximity or in contact with the electrode by comparing the voltage difference of the AC signal source with the electric field voltage at the electrode **14**. More specifically, when there is no conductive object near the electrode **14**, the electrode circuit **72** is in an unloaded state. In this state, resistor R**9** has a high resistance of 1 M ohm or more and capacitor C**4** has a low capacitance such as 1–10 picofarads and the voltage at a second node **73** is substantially identical to the voltage at the first node **71**. Thus, resistor R**9** and capacitor C**4** represent the impedance of the body (specifically the finger **10**) as it approaches the electrode **14**.

When a conductive object is close to electrode **14**, the electrode circuit **72** is loaded and grounded and the resistor R**9** goes as low as 1k ohm, while the capacitance of capacitor C**4** increases to 100 picofarads or more and the voltage at second node **73** is attenuated in an amount dependent on the distance **24** of the conductive object such as a finger **10** to the electrode **14** in FIG. **1**. Voltage waveforms for unloaded and loaded states is discussed in connection with FIGS. **7**A and **7**B.

The detector circuit **74** indicates when an object is close to the electrode. When a conductive object is close to electrode **14** (FIG. **1**) modeled by electrode circuit **72**, the detector circuit **74** senses a voltage drop at second node **73** with respect to the reference voltage at first node **71**. A differential operational amplifier **86** uses the voltage at first node **71** as its inverting input and the voltage at second node **73** as its noninverting input. In an alternative, the second node **73** can be the inverting input and the first node **71** the noninverting input. The output **80** is coupled to a diode D_1 for conversion to a DC output **82** indicating an object is in close proximity. A sample hold capacitor C_5 connected to diode D_1 reduces noise in DC output **82**. The closer the object to the electrode **14**, the larger electric field attenuation as indicated by a drop in the DC output **82**. The DC output **82** is coupled to a controller **84** with addresses **92**. One suitable programmable integrated circuit for the controller **84** is the Microchip PIC16F77 made by Microchip Technology, Inc. in San Jose, Calif., which performs logic to analyze DC output **82** as described below.

FIG. **3** illustrates an electric field proximity keyboard **40** having twelve keypads associated with twelve electrodes **28**, **29**, **30**, **31**, **32**, **33**, **34**, **35**, **36**, **37**, **38** and **39** that connect to corresponding I/O addresses **01**, **02**, **03**, **04**, **05**, **06**, **07**, **08**, **09**, **10**, **11**, and **12** that are inputs to an analog multiplexer **90** discussed in connection with FIG. **6**.

FIG. **4** illustrates a row and column address scheme for an electric field proximity keyboard **65**. The AC signal described earlier can be multiplexed to a pair of electrodes associated with each keypad using the address scheme. Each electrode of the pair radiates its own electric field. Thus, if one electrode fails, the other electrode can still independently radiate and sense disturbance of its own electric field. For example, keypad **15** has an electrode **41** connected to an address represented by row **1** and an electrode **45** connected to an address represented by column **1**. The product of the rows and columns (m×n) will equal the total number of keypads, while the sum of the rows and columns (m+n) will equal the number of addresses. FIG. **4** illustrates the scheme with 12 keypads made up of three rows and four columns and seven addresses. As shown, the AC signal is coupled to the electrodes **41**, **42**, **43**, and **44** on row **1**, to the electrodes **49**, **50**, **51**, and **52** on row **2**, and to the electrodes **57**, **58**, **59**, and **60** on row **3**. The AC signal is coupled to electrodes **45**, **53** and **61** on column **1**, to electrodes **46**, **54** and **62** on column **2**, to electrodes **47**, **55** and **63** on column **3**, and to electrodes **48**, **56**, and **64** on column **4**. An individual keypad **15** can be viewed as a 1×1 electrode pair of row electrode **41** and column electrode **45**. In contrast to the keyboard **40** shown in FIG. **3**, where the number of I/O addresses equal the number of keypads, this addressing scheme scales increasingly well as the number of keypads increases. For example, I/O addresses made up nine rows and 16 columns will form an array of (9×16) 144 electrode pairs with only (9+16) 25 I/O addresses. This reduces the complexity of the addressing scheme, manufacturing costs and has advantages as discussed in connection with FIG. **6**.

In another embodiment shown in FIG. **5**, the address scheme can be used on a keypad such as keypad **75** on an electric field proximity keyboard **67** by nesting the row and column addresses to form a larger array of electrodes. For example, the electric field keyboard **67** is defined by an array of keypads with three rows (m_1=3) and four columns (n_1=4) such as the keypads **75**, **76**, **77**, and **78**, where each of the keypads such as keypad **75** is further defined by an array with three rows (m_2=3) and four columns (n_2=4) of electrode pairs. The electric field proximity keyboard **67** includes a total of **12** (m_1×n_1) keypads and a total of (m_2×n_2) **12** electrode pairs associated with each keypad such as keypad **75**. Thus, the address scheme has a total of 144 (m_1×n_1)×(m_2×n_2) electrode pairs but only 25 (m_1×m_2)+(n_1×n_2) I/O addresses.

Still referring to FIG. **5**, the first row of keypads such as keypads **75**, **76**, **77**, and **78** are activated by their associated electrodes coupled to address rows **1**, **2**, and **3**. The second and third rows of keypads are activated by their associated electrodes coupled to address rows **4**, **5**, and **6**, and **7**, **8**, and **9**, respectively. The first column of keypads **75**, **69**, and **79** are activated by their associated electrodes coupled to column addresses **1**, **2**, **3**, and **4**. Likewise, the second, third and fourth column of keypads are activated by their associated electrodes coupled to column addresses **5**, **6**, **7**, and **8**, column addresses **9**, **10**, **11**, and **12**, and column addresses **13**, **14**, **15**, and **16**, respectively. The increase in electrodes per keypad increases resolution of the detected object and keeps the design simple. FIG. **4** shows an enlarged view of an electrode array for a single keypad **75**.

By increasing the number of electrodes associated with each keypad, a larger number of smaller and overlapping electric fields can be generated and sensed so that together the electrodes for a given area (e.g., keypad) act like a phased array antenna or a multi-aperture antenna to closely resolve the approaching object. The resulting signals sent to the microcontroller can be analyzed as to the shape and conductivity of the object in close proximity to the keypad to validate or invalidate the object as activating the keypad. The shape and pattern of electrodes to be used include common planar antenna structures that can be printed onto the PCB such as rectangular, circular, spiral, looped, serpentine and inter-digital structures.

FIG. **6** illustrates a circuit **68** for an electric field proximity keyboard with an AC signal source coupled through a high impedance circuit such as resistor R**8** at the second node **73** to the output of the analog multiplexer **90** such as the 64-channel 491AMUX1-64 multiplexer manufactured by Quad Tron, Inc. in Feasterville, Pa. Horowitz and Hill, *The Art of Electronics* (Second Edition, 1989) describe analog multiplexers and is incorporated by reference herein. The plurality of analog multiplexer inputs are the I/O addresses to the electrodes. A plurality of multiplexers can be also connected in parallel to increase I/O addresses, that is, the channel capacity. The AC signal is selected and connected to each of the plurality of I/O addresses **91** that are the inputs of the analog multiplexer for a predetermined time and a control command **92** of the controller **84** selects the I/O address to connect. The controller **84** switches the AC signal to each of the I/O addresses **91** that interface with the electrodes associated with the keypads. The controller **84** is programmed as is known in this field to compensate for background noise, to determine the distance and time duration the object must be from the electrode to be in close proximity, and to compare the object to known signatures (e.g., shapes and conductivity). The functions on the circuits can be miniaturized in a semiconductor substrate in a known manner in an integrated circuit to reduce the size and the cost of manufacturing the circuits.

FIG. **7**A compares the waveform of the AC signal from the oscillator circuit with the electric field signal of an electrode with no object (e.g., finger) in close proximity. In this unloaded state, the electric field voltage is not attenuated and the voltage at the first node **71** and the second node **73** (FIG. **2**) are substantially identical and can be represented by waveform **97** (dashed line). The DC output **82** from the detector D**1** is represented by the waveform **96** (solid line). The small peak-to-peak ripple is due to the sample and hold charge capacitor C**5** in the circuit that reduces noise and ripple.

FIG. **7**B compares the waveform of the AC signal at node **71** versus the electric field signal of an electrode when the object is in close proximity to the electrode **14** (FIG. **1**). In this loaded state, the electric field voltage at the second node **73** is attenuated as depicted by the waveform **99** (solid line), and the AC signal at the first node **71** is also affected as represented by the waveform **98** (dash line). The DC output **82** follows waveform **99** due to the attenuation and the change in DC output **82** is analyzed in the controller **84** shown in FIG. **6** and identifies the change as an object touching or in close proximity to the electrode **14**.

What is claimed:

1. An electric field proximity keyboard on a substrate, comprising:

a plurality of keypads each having an electrode radiating an electric field;

a circuit including as follows:

a high impedance circuit having a first node and a second node;

an AC signal source coupled to the first node;

an analog multiplexer having an output coupled to the second node, and having a plurality of inputs wherein each input is coupled to one electrode;

a detector circuit generating a DC output based on the voltage difference across the first node and the second node; and

a controller coupled to the DC output and the analog multiplexer wherein the controller issues control commands to the analog multiplexer to selectively couple each electrode to the second node for a predetermined time period and to determine whether the DC output indicates a disturbance in the electric field from an object in close proximity or touching the keypad and wherein the object in close proximity or touching each keypad disturbs the electric field attenuating the voltage at the second node and the voltage difference between the first and second nodes indicates the distance of the object to each keypad.

2. The keyboard of claim **1**, wherein the plurality of keypads are arranged in a m×n array with m rows and n columns, wherein each keypad includes an electrode pair including a row electrode coupled to a row address and a column electrode coupled to a column address, wherein the quantity of keypads is increased by m×n while the I/O addresses are determined by m+n.

3. The keyboard of claim **2**, wherein the circuit is integrated with the controller in a semiconductor IC.

4. The keyboard of claim **1**, wherein each keypad includes a plurality of electrode pairs arranged in a m×n array, wherein, m rows and n columns of the electrode pairs are associated with each keypad, wherein each electrode pair includes a row electrode coupled to a row address and a column electrode coupled to a column address, wherein the sensitivity and resolution of each keypad is increased by m×n times.

5. The keyboard of claim **4**, wherein the circuit is integrated with the controller in a semiconductor IC.

6. The keyboard of claim **1**, wherein the circuit is integrated with the controller in a semiconductor IC.

7. The keyboard of claim **1**, wherein the controller is programmed to store, adjust and compensate for the shape, size, conductivity, proximity of the object with respect to the plurality of electrodes and environmental conditions.

8. The keyboard of claim, **7** wherein the circuit is integrated with the controller in a semiconductor IC.

9. An electric field proximity keyboard on a substrate, comprising:

a keypad having an electrode radiating an electric field;

a circuit including as follows:

a high impedance circuit having a first node and a second node;

an AC signal source, wherein the AC signal source is coupled to the first node and the electrode is coupled to the second node;

a detector circuit generating a DC output based on the voltage difference across the first node and the second node; and

a controller coupled to the DC output wherein the controller determines whether the DC output indicates a disturbance in the electric field from an object in close proximity or touching the keypad and wherein the object in close proximity or touching the keypad disturbs the electric field attenuating the voltage at the second node and the voltage difference between the first and second nodes indicates the distance of the object to the keypad.

10. The keyboard of claim **9**, wherein one or more of the AC signal source, high impedance circuit, and the detector circuit are integrated with the controller on a single semiconductor.

11. The keyboard of claim **9**, wherein the controller is programmed to store, adjust and compensate for the shape, size, conductivity, proximity of the object with respect to the electrode and environmental conditions.

12. An electric field proximity keyboard on a substrate, comprising:

a plurality of keypads each having as follows:

an electrode radiating an electric field;

a circuit including as follows:

a high impedance circuit having a first node and a second node;

an AC signal source coupled to the first node;

a detector circuit generating a DC output based on the voltage difference across the first node and the second node;

an analog multiplexer having an output coupled to the second node, and having a plurality of inputs wherein each input is coupled to one electrode; and

a controller coupled to the DC output and the analog multiplexer, wherein the controller issues control commands to the analog multiplexer to selectively couple the electrode to the second node for a predetermined time period and to determine whether the DC output indicates a disturbance in the electric field from an object in close proximity or touching the keypad, wherein the plurality of keypads is arranged in a m×n array with m rows and n columns, wherein each keypad include an electrode pair including a row electrode coupled to a row address and a column electrode coupled to a column address, wherein the quantity of keypads is increased by m×n while the I/O addresses are determined by m+n.

13. The keyboard of claim **12**, wherein each keypad includes a plurality of electrode pairs arranged in a m×n array, wherein each electrode pair includes a row electrode coupled to a row address and a column electrode coupled to a column address, wherein the sensitivity and resolution of each keypad is increased by m×n times.

14. The keyboard of claim **13**, wherein the controller is programmed to store, adjust and compensate for the shape, size, conductivity, proximity of the object with respect to the plurality of electrodes pairs and environmental conditions.

15. The keyboard of claim **14**, wherein the circuit is integrated with the controller in a semiconductor IC.

16. The keyboard of claim **13**, wherein the circuit is integrated with the controller in a semiconductor IC.

17. The keyboard of claim **12**, wherein the controller is programmed to store, adjust and compensate for the shape, size, conductivity, proximity of the object with respect to the electrode pairs and environmental conditions.

18. The keyboard of claim **17**, wherein the circuit is integrated with the controller in a semiconductor IC.

19. The keyboard of claim **12**, wherein the circuit is integrated with the controller in a semiconductor IC.

* * * * *