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(54) **TEST SYSTEM WITH TEST TRAYS AND AUTOMATED TEST TRAY HANDLING**

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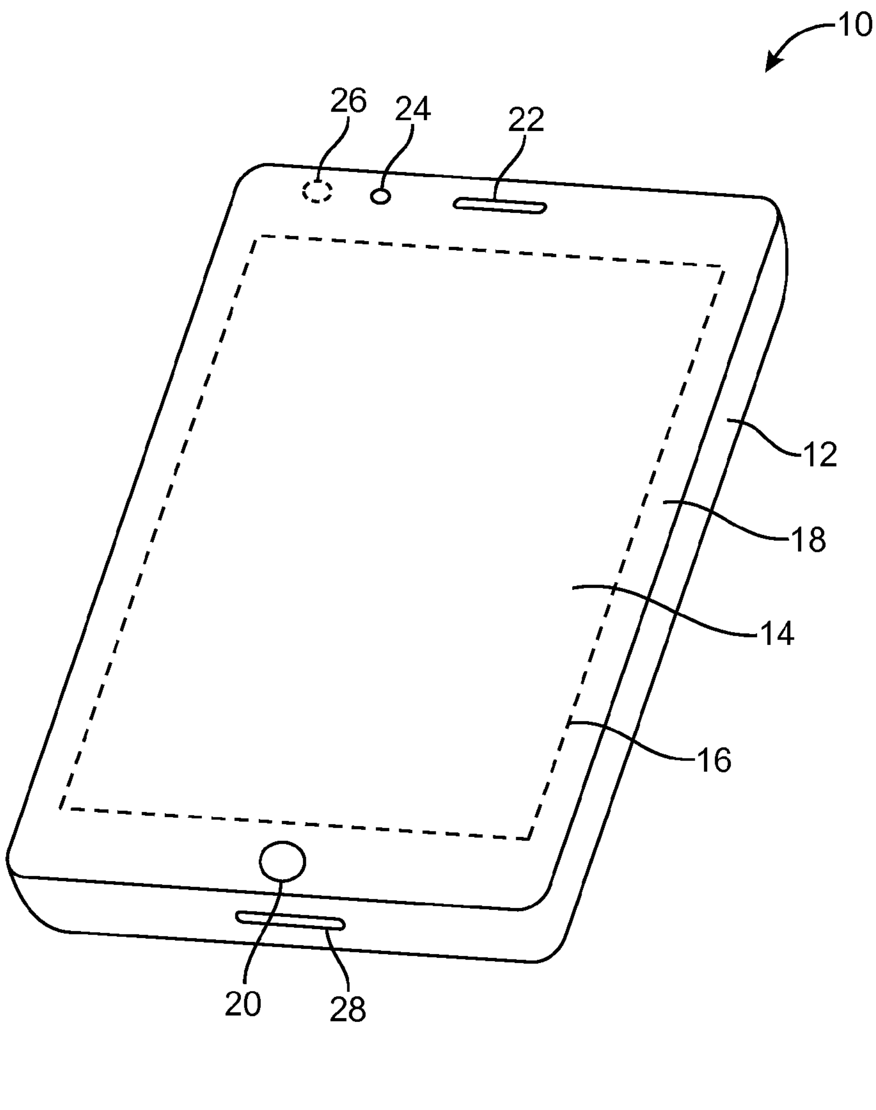
G01R 31/02 (2006.01)

(52) **U.S. Cl.**
USPC **324/756.01**

(57) **ABSTRACT**

A test system may be provided in which devices under test are loaded into test trays. Each test tray may include clamps for retaining a device under test within the test tray. The test tray may be configured to transmit test tray identification information to facilitate tracking of the device under test associated with the test tray. The test tray may include engagement features configured to receive corresponding engagement features on a computer-controlled loading arm. The loading arm may be used to move the test tray and associated device under test to a test fixture for testing. A contact extending structure may be retained in the test tray and may be configured to mate with the device under test. Contact pads on the contact extending structure may be mated with corresponding contacts on the test fixture to form an electrical connection between the device under test and the test fixture.



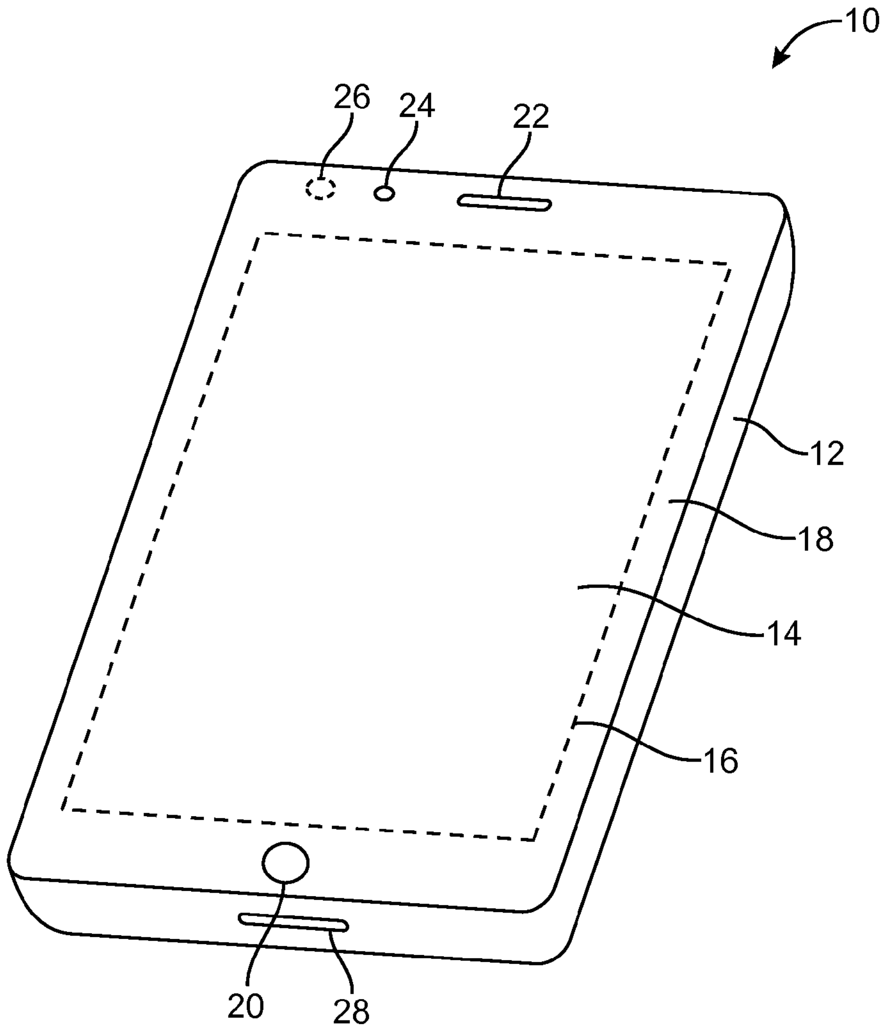


FIG. 1

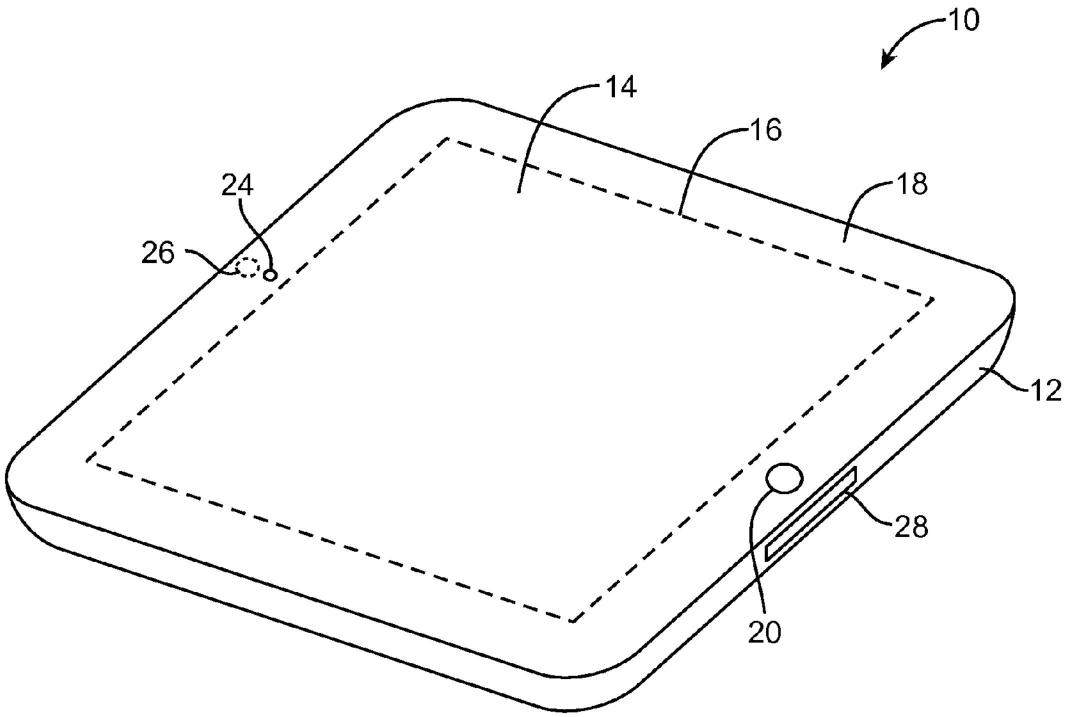


FIG. 2

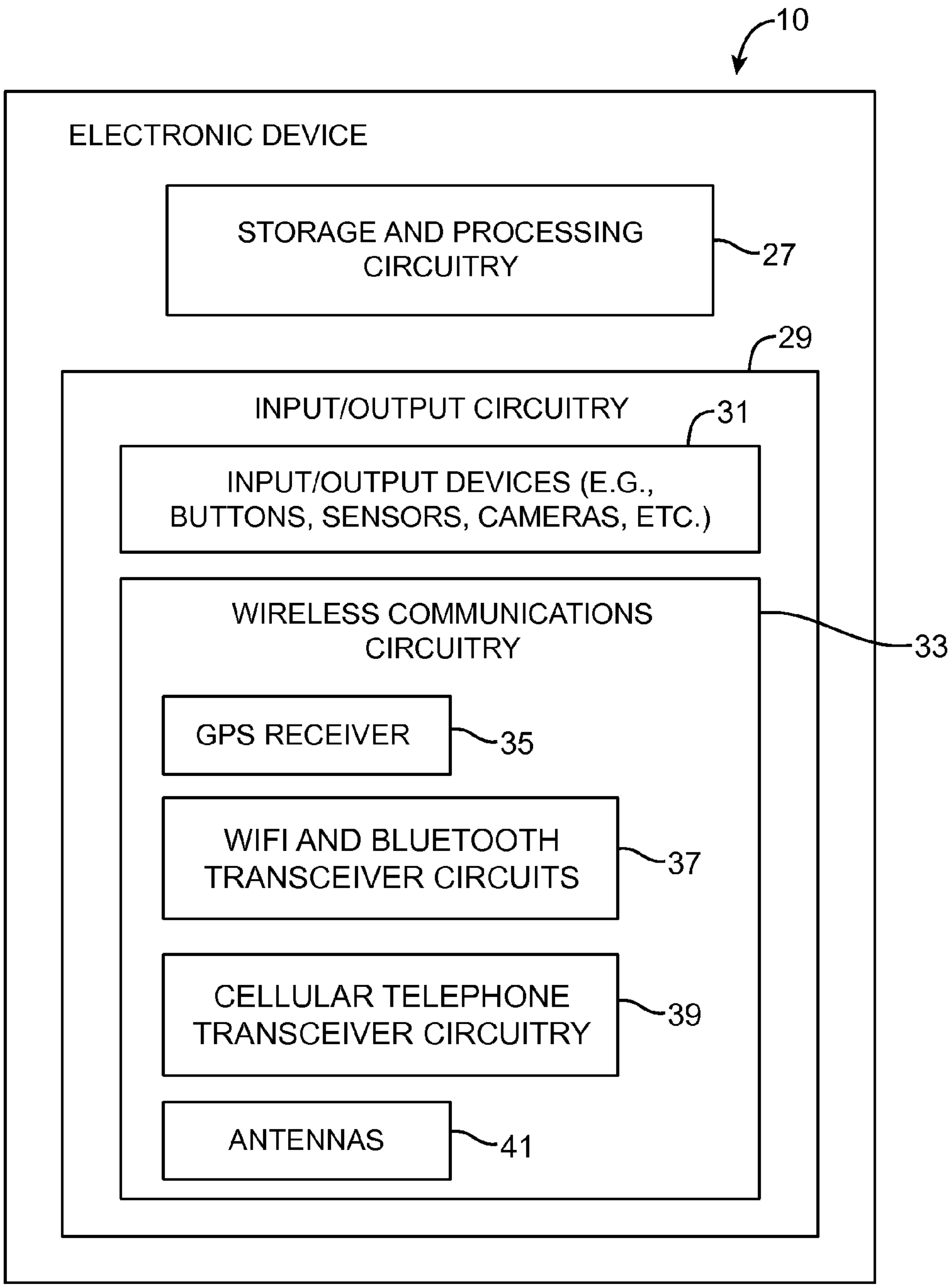
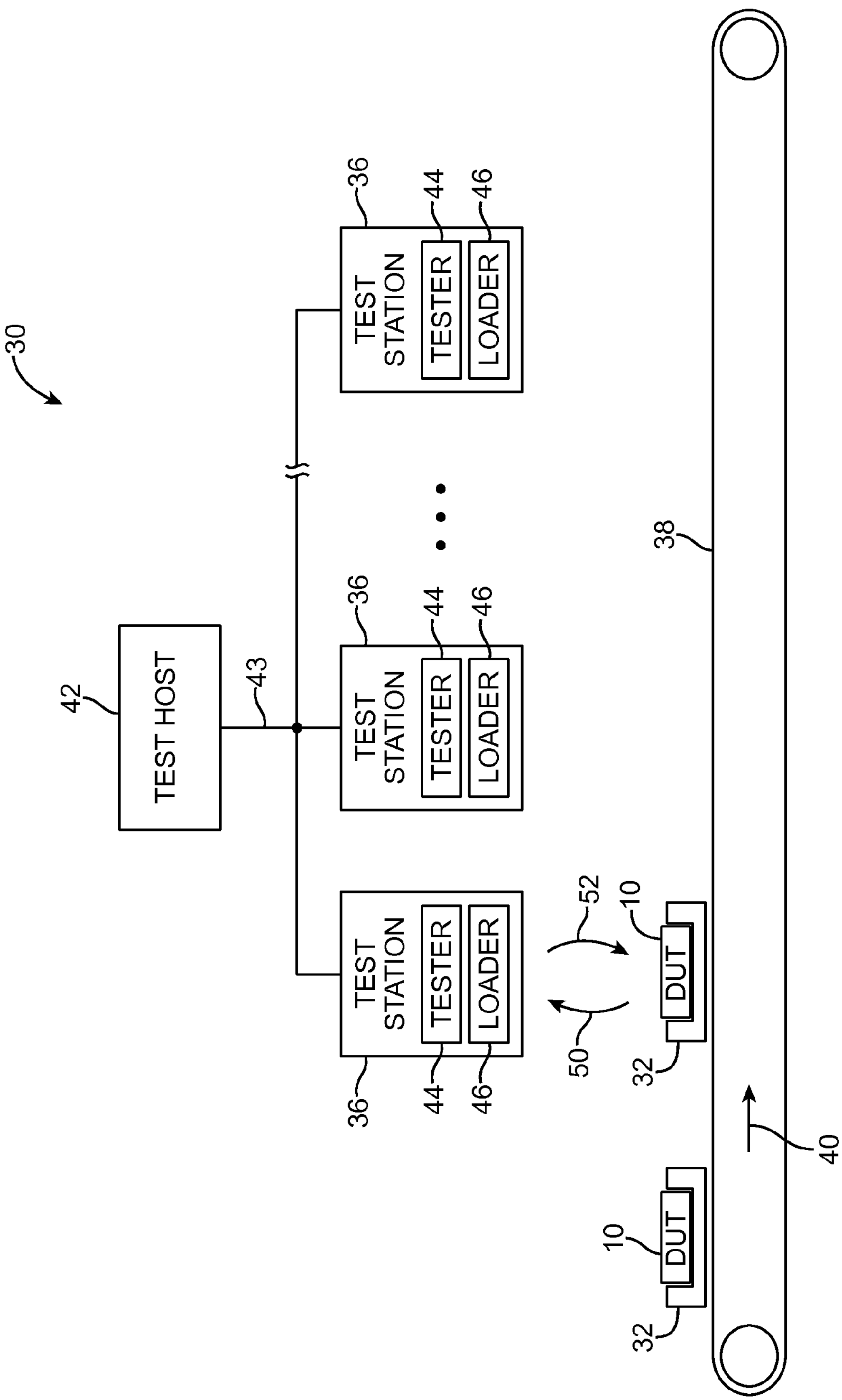

10
ELECTRONIC DEVICE
STORAGE AND PROCESSING CIRCUITRY
27
29
INPUT/OUTPUT CIRCUITRY
31
INPUT/OUTPUT DEVICES (E.G., BUTTONS, SENSORS, CAMERAS, ETC.)
WIRELESS COMMUNICATIONS CIRCUITRY
33
GPS RECEIVER
35
WIFI AND BLUETOOTH TRANSCEIVER CIRCUITS
37
CELLULAR TELEPHONE TRANSCEIVER CIRCUITRY
39
ANTENNAS
41

FIG. 3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TEST HOST
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TEST STATION
TESTER
LOADER
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44
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DUT
10
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50
52
38
40

FIG. 4

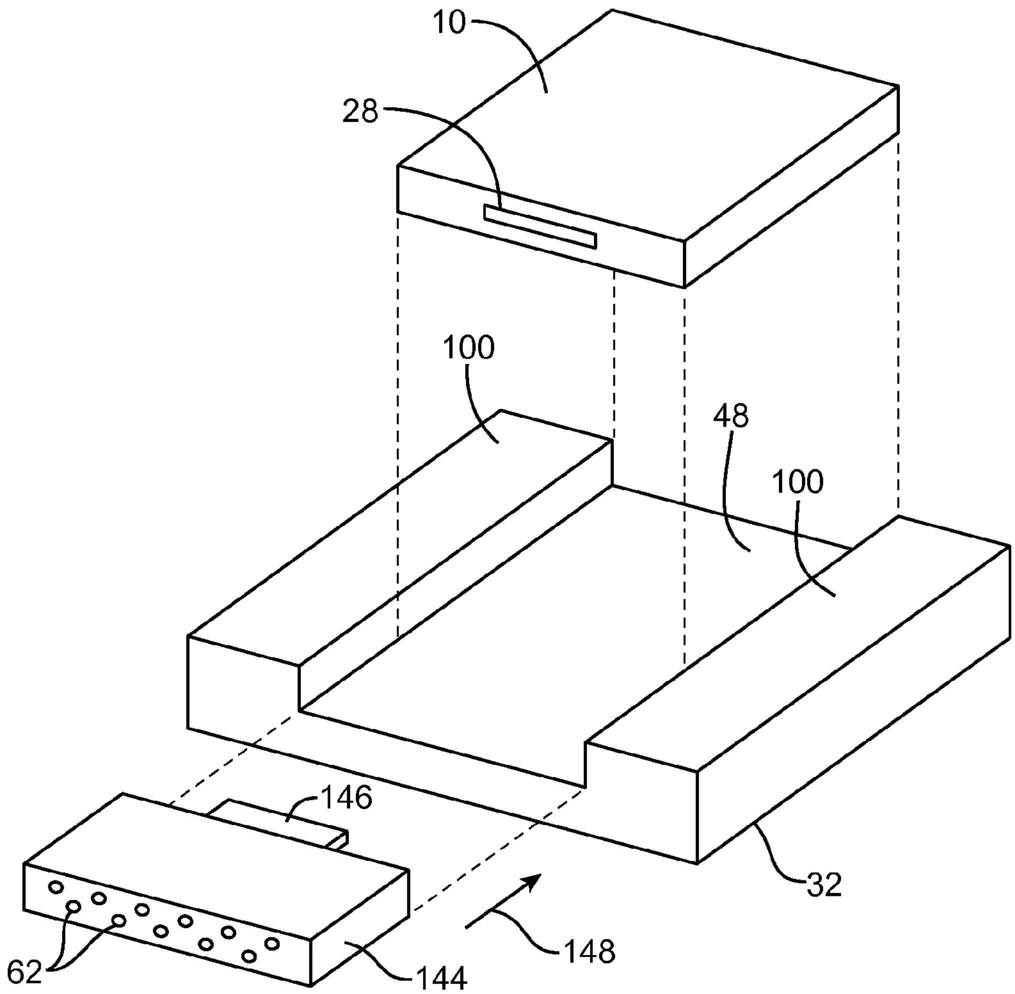

FIG. 5

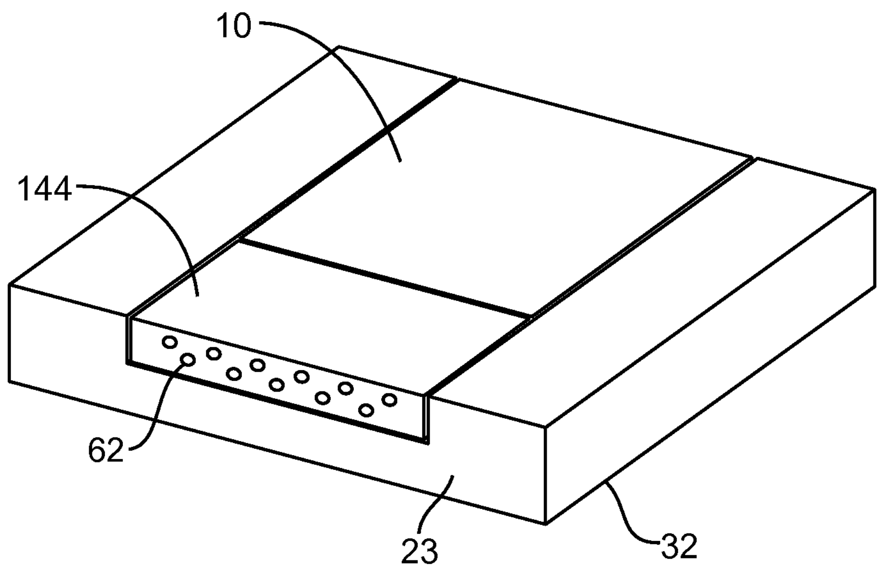

FIG. 6

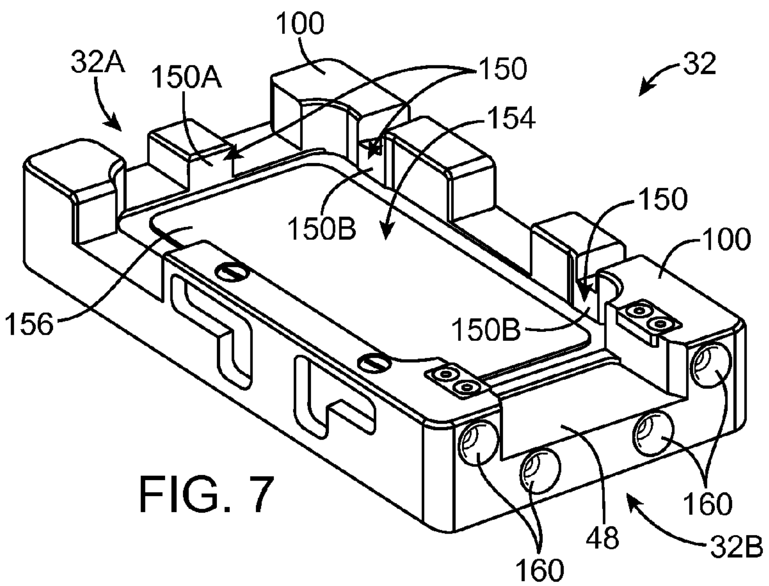

FIG. 7

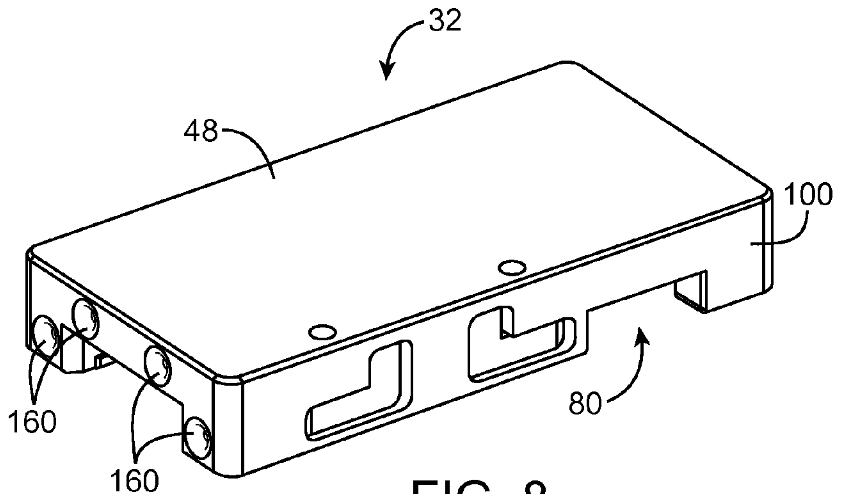

FIG. 8

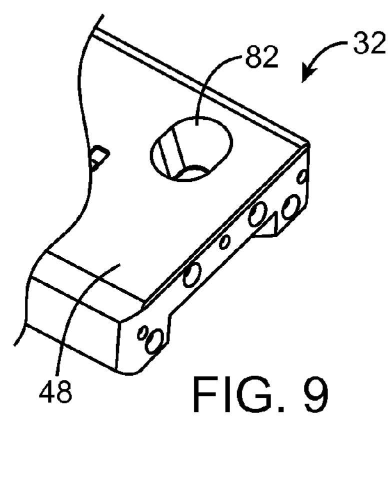

FIG. 9

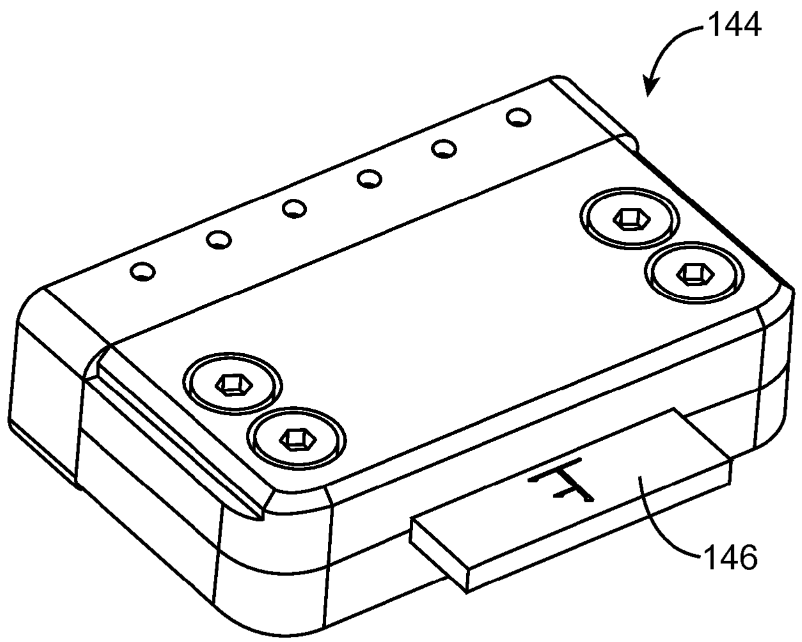

FIG. 10

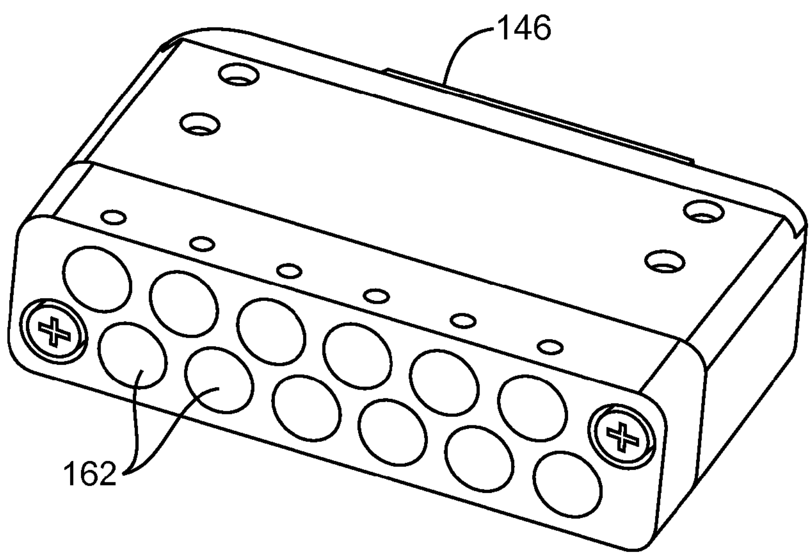

FIG. 11

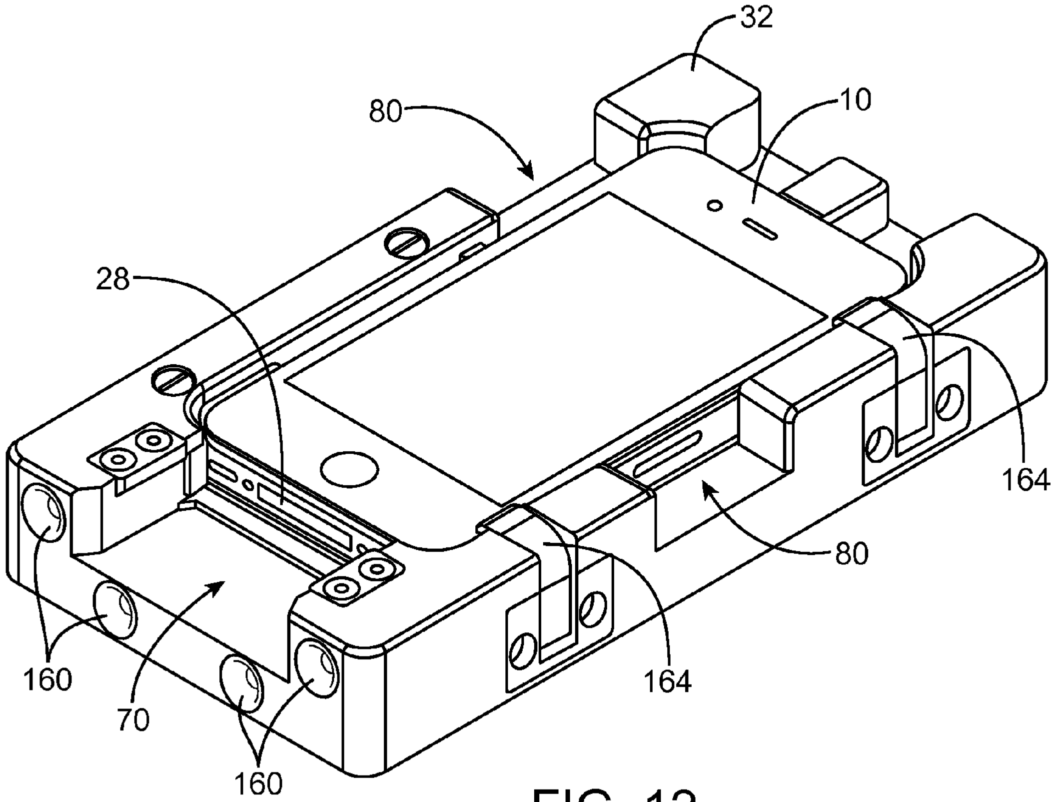

FIG. 12

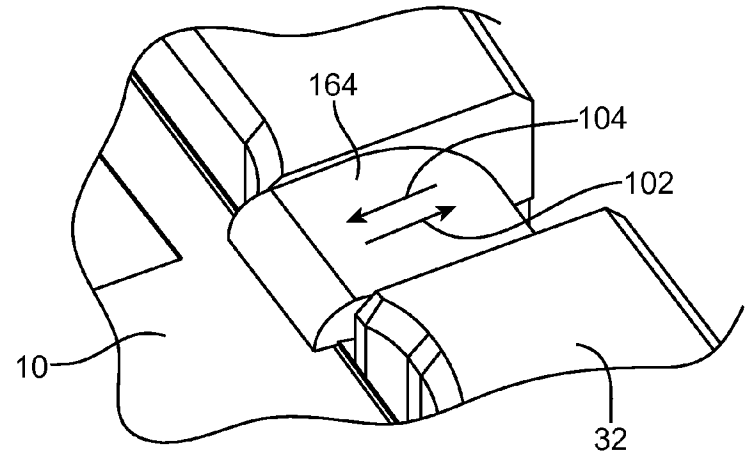

FIG. 13

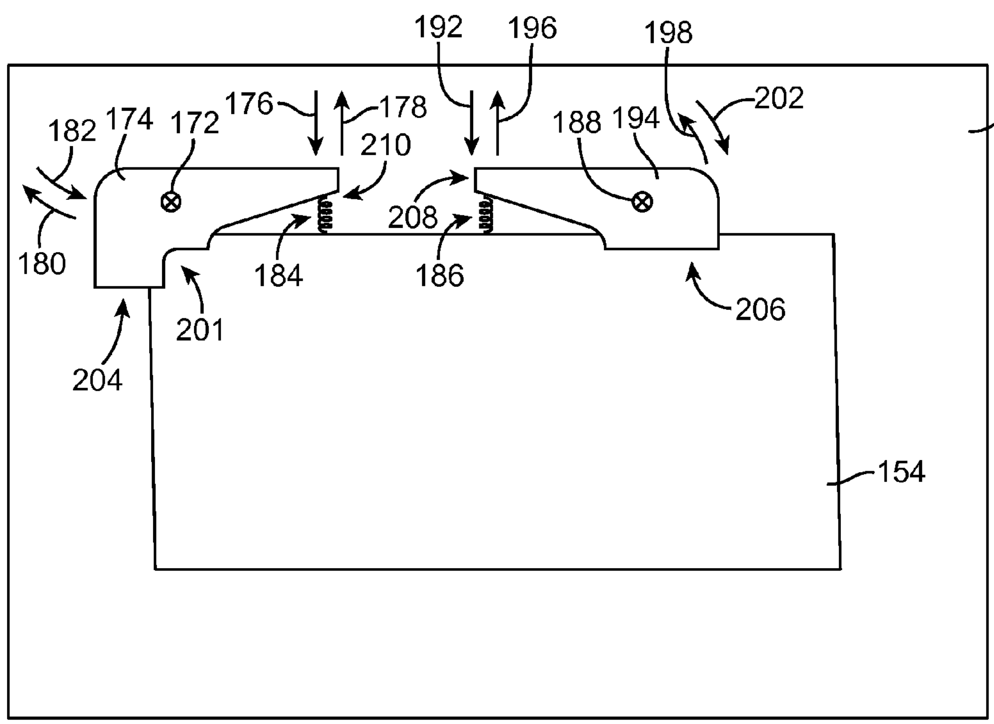
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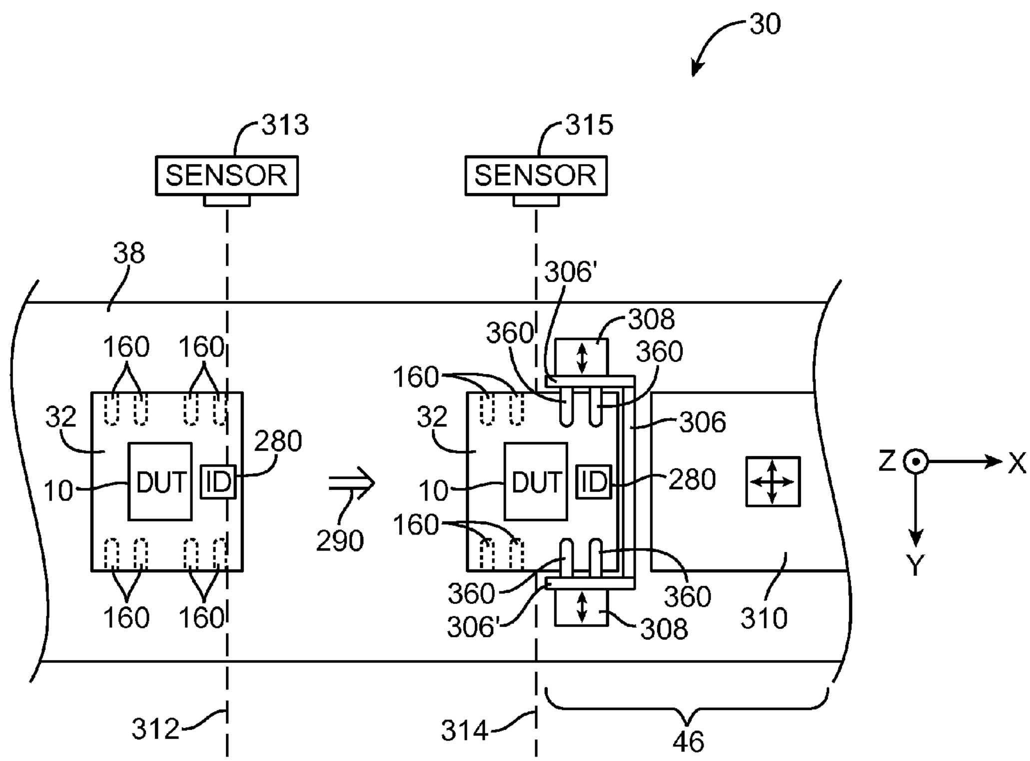
FIG. 14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313
SENSOR
315
SENSOR
38
306'
308
360
360
160
160
160
160
32
32
306
280
DUT
ID
DUT
ID
280
10
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290
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360
306'
308
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160
Z
X
Y
312
314
46

FIG. 15

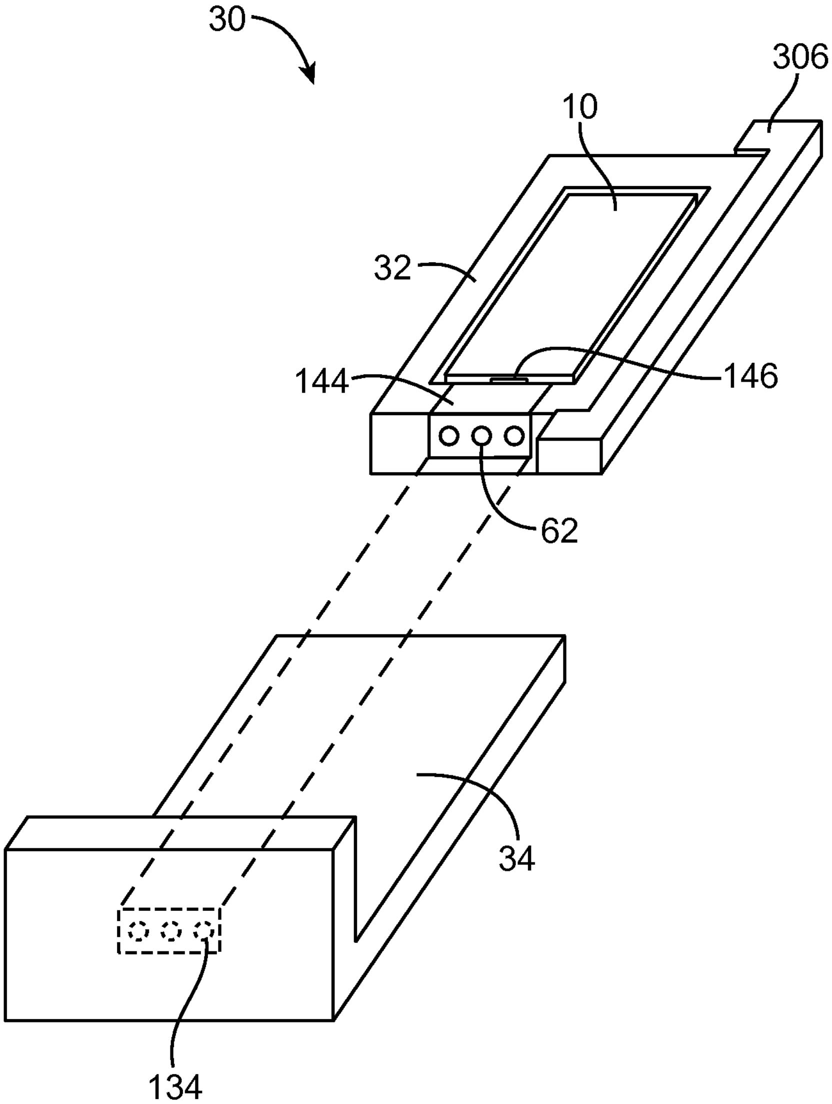

FIG. 16

TEST SYSTEM WITH TEST TRAYS AND AUTOMATED TEST TRAY HANDLING

[0001] This application claims the benefit of provisional patent application No. 61/595,572, filed Feb. 6, 2012, which is hereby incorporated by reference herein in its entirety.

BACKGROUND

[0002] This relates generally to automation, and more particularly, to automated equipment for use in manufacturing operations such as testing.

[0003] Electronic devices are often tested following assembly to ensure that device performance meets design specifications. For example, a device may be tested at a series of test stations to ensure that components and software in the device are operating satisfactorily. At each test station, an operator may couple a device to test equipment using a cable. Following successful testing at all test stations, a device may be shipped to an end user.

[0004] The process of attaching and detaching test cable connectors can reduce the lifetime of the test cable connectors and can be cumbersome and burdensome to test system operators. If care is not taken, tests may be less accurate and more time consuming than desired. Additionally, excessive contact between a test system operator and a device under test may increase the risk of cosmetic damage to the device under test.

[0005] It would therefore be desirable to be able to provide improved ways of performing manufacturing operations such as testing operations on electronic devices.

SUMMARY

[0006] A test system may be provided in which devices under test are loaded into test trays. Each test tray may include one or more spring-loaded members for retaining a device under test within the test tray.

[0007] A test tray may include a base portion having an opening and one or more side walls having an opening. Openings may be configured to align with input-output devices in the device under test when the device under test is installed in the test tray.

[0008] A test tray may be provided with engagement holes configured to receive corresponding engagement pins on a computer-controlled loading arm. The loading arm may engage with the test tray by inserting the engagement pins into the engagement holes. Once engaged, the loading arm may be used to pick up, hold, and transport the device under test to a desired location in the test system.

[0009] The test system may be a conveyor belt system in which test stations are located along a moving conveyor belt. The test trays and associated devices under test may be fed into the conveyor belt system for testing at the test stations. Each test station may be provided with one or more loading mechanisms. A sensor may be used to detect when a test tray and associated device under test has reached a predetermined location in the conveyor belt system. In response to detecting a test tray at a predetermined location, a computer-controlled loading arm may be actuated to pick up the test tray from the conveyor belt and to bring the test tray and associated device under test to a test station for testing.

[0010] A contact extending structure may be used to form an electrical connection between a device under test in a test tray and a test fixture at a test station. A slot may be formed in the test tray and may be used to retain the contact extending structure within the test tray. The contact extending structure may have a first end configured to mate with the electronic device and a second end having contact pads. The contact pads may be configured to mate with corresponding test fixture contacts at a test station.

[0011] A computer-controlled loading arm may install a test tray and associated device under test in a test fixture for testing by mating the contacts on the contact extending structure with the test fixture contacts at the test station. The contact extending structure may be used to convey test signals between the test fixture and the device under test.

[0012] Each test tray may be provided with a radio-frequency identification tag for transmitting test tray identification information. One or more sensors in the test system may be configured to receive the test tray identification information and to identify the test tray based on the received test tray identification information. The test tray identification information may be used to determine information about the device under test associated with each test tray.

[0013] Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a perspective view of an illustrative electronic device such as a handheld device of the type that may be manufactured using automated equipment in accordance with an embodiment of the present invention.

[0015] FIG. **2** is a perspective view of an illustrative electronic device such as a tablet computer of the type that may be manufactured using automated equipment in accordance with an embodiment of the present invention.

[0016] FIG. **3** is a schematic diagram of an illustrative electronic device with input/output devices and wireless communications circuitry in accordance with an embodiment of the present invention.

[0017] FIG. **4** is a diagram of manufacturing equipment of the type that may be used in manufacturing an electronic device in accordance with an embodiment of the present invention.

[0018] FIG. **5** is an exploded perspective view of an illustrative device under test, pad extender, and test tray in accordance with an embodiment of the present invention.

[0019] FIG. **6** is a perspective view of an illustrative device under test, pad extender, and test tray in accordance with an embodiment of the present invention.

[0020] FIG. **7** is a top perspective view of an illustrative test tray in accordance with an embodiment of the present invention.

[0021] FIG. **8** is a bottom perspective view of an illustrative test tray in accordance with an embodiment of the present invention.

[0022] FIG. **9** is a bottom perspective view of an illustrative test tray with an opening to accommodate tests in accordance with an embodiment of the present invention.

[0023] FIG. **10** is a rear perspective view of an illustrative pad extender for extending contacts in a device under test mounted in a test tray in accordance with an embodiment of the present invention.

[0024] FIG. **11** is a front perspective view of an illustrative pad extender for extending contacts in a device under test mounted in a test tray in accordance with an embodiment of the present invention.

[0025] FIG. **12** is a perspective view of an illustrative test tray in which a device under test has been mounted in accordance with an embodiment of the present invention.

[0026] FIG. **13** is a perspective view of a portion of a test tray having clamps that hold a device under test in accordance with an embodiment of the present invention.

[0027] FIG. **14** is a top view of an illustrative test tray having spring-loaded clamps for retaining devices under test in accordance with an embodiment of the present invention.

[0028] FIG. **15** is a top view of an illustrative test system in which computer-controlled loading arms are used to transfer test trays between test stations and a conveyor belt in accordance with an embodiment of the present invention.

[0029] FIG. **16** is an exploded perspective view of an illustrative test fixture having test fixture contacts that mate with corresponding contacts on a pad extender in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0030] Electronic devices such as electronic device **10** of FIG. **1** may be manufactured using automated manufacturing equipment. The automated manufacturing equipment may include equipment for assembling device components together to form an electronic device. The automated manufacturing equipment may also include testing systems for evaluating whether devices have been properly assembled and are functioning properly.

[0031] Devices such as device **10** of FIG. **1** may be assembled and tested using an automated manufacturing system. The manufacturing system may include one or more stations such as one or more test stations for performing testing operations.

[0032] Devices that are being tested in a test system may sometimes be referred to as devices under test (DUTs). Devices under test may be provided to the test stations using a conveyor belt, using robotic arms, and/or using other loading equipment.

[0033] Test equipment at each test station may be used to perform an associated test on a device. For example, one test station may have equipment for testing a display in the device. Another test station may have equipment for testing an audio component in the device. Yet another test station may have equipment for testing light sensors in the device. Yet another test station may have equipment for testing wireless communications circuitry in the device. Automated equipment in the test system may be used in loading and unloading devices under test, in conveying devices under test between test stations, and in performing tests and maintaining a database of test results.

[0034] Any suitable device may be tested using test equipment. As an example, device **10** of FIG. **1** may be tested using test equipment. Device **10** may be a computer monitor with an integrated computer, a desktop computer, a television, a notebook computer, other portable electronic equipment such as a cellular telephone, a tablet computer, a media player, a wristwatch device, a pendant device, an earpiece device, other compact portable devices, or other electronic equipment. In the configuration shown in FIG. **1**, device **10** is a handheld electronic device such as a cellular telephone, media player, navigation system device, or gaming device.

[0035] As shown in FIG. **1**, device **10** may include a housing such as housing **12**. Housing **12**, which may sometimes be referred to as a case, may be formed of plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, etc.), other suitable materials, or a combination of these materials. In some situations, parts of housing **12** may be formed from dielectric or other low-conductivity material. In other situations, housing **12** or at least some of the structures that make up housing **12** may be formed from metal elements.

[0036] Device **10** may, if desired, have a display such as display **14**. Display **14** may be a touch screen that incorporates capacitive touch electrodes or may be insensitive to touch. Display **14** may include image pixels formed from light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs), plasma cells, electrophoretic display elements, electrowetting display elements, liquid crystal display (LCD) components, or other suitable image pixel structures. A cover glass layer may cover the surface of display **14**. Openings for buttons such as button **20**, openings for speaker ports such as speaker port **22**, and other openings may be formed in the cover layer of display **14**, if desired.

[0037] The central portion of display **14** (i.e., active region **16**) may include active image pixel structures. The surrounding rectangular ring-shaped inactive region (region **18**) may be devoid of active image pixel structures. If desired, the width of inactive region **18** may be minimized (e.g., to produce a borderless display).

[0038] Device **10** may include components such as front-facing camera **24**. Camera **24** may be oriented to acquire images of a user during operation of device **10**. Device **10** may also include a rear facing camera. A rear facing camera may be formed on a back side of device **10** (e.g., on an opposing side of display **14**).

[0039] Device **10** may include sensors in portion **26** of inactive region **18**. These sensors may include, for example, an infrared-light-based proximity sensor that includes an infrared-light emitter and a corresponding light detector to emit and detect reflected light from nearby objects. The sensors in portion **26** may also include an ambient light sensor for detecting the amount of light that is in the ambient environment for device **10**. Other types of sensors may be used in device **10** if desired. The example of FIG. **1** is merely illustrative.

[0040] Device **10** may include input-output ports such as port **28**. Ports such as port **28** may include audio input-output ports, analog input-output ports, digital data input-output ports, or other ports. Each port may have an associated connector. For example, an audio port may have an associated four-contact audio connector, a digital data port may have a connector with two or more pins (contacts), a connector with four or more pins, a connector with thirty pins, or other suitable data port connector.

[0041] Sensors such as the sensors associated with region **26** of FIG. **1**, cameras such as camera **24**, audio ports such as speaker port **22**, buttons such as button **20**, and ports such as port **28** may be located on any suitable portion of device housing **12** (e.g., a front housing face such as a display cover glass portion, a rear housing face such as a rear planar housing wall, sidewall structures, etc.).

[0042] FIG. **2** is a perspective view of device **10** in an illustrative configuration in which device **10** has been implemented in the form of a tablet computer. As shown in FIG. **2**, device **10** may include a housing such as housing **12**. Housing **12** may be formed from metal, plastic, fiber-based composite material, glass, ceramic, other materials, or combinations of these materials. Device **10** may have an upper (front) surface that is covered with display **14**. Active portion **16** of display **14** may have a rectangular shape (as an example). Inactive portion **18** of display **14** may have an opening to accommodate button **20**, a window region for camera **24**, and a portion such as portion **26** that is associated with one or more optical sensors such as an infrared-based proximity sensor and/or an ambient light sensor.

[0043] A schematic diagram of an electronic device such as electronic device **10** is shown in FIG. **3**. As shown in FIG. **3**, electronic device **10** may include storage and processing circuitry **27**. Storage and processing circuitry **27** may include storage such as hard disk drive storage, nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processors, power management units, audio codec chips, application specific integrated circuits, etc.

[0044] Storage and processing circuitry **27** may be used to run software on device **10**, such as internet browsing applications, voice-over-internet-protocol (VoIP) telephone call applications, email applications, media playback applications, operating system functions, etc. To support interactions with external equipment, storage and processing circuitry **27** may be used in implementing communications protocols. Communications protocols that may be implemented using storage and processing circuitry **27** include internet protocols, wireless local area network (WLAN) protocols (e.g., IEEE 802.11 protocols—sometimes referred to as WiFi®), protocols for other short-range wireless communications links such as the Bluetooth® protocol, cellular telephone protocols, etc.

[0045] Circuitry **27** may be configured to implement control algorithms that control the use of antennas in device **10**. For example, to support antenna diversity schemes and MIMO schemes or beam forming or other multi-antenna schemes, circuitry **27** may perform signal quality monitoring operations, sensor monitoring operations, and other data gathering operations and may, in response to the gathered data, control which antenna structures within device **10** are being used to receive and process data. As an example, circuitry **27** may control which of two or more antennas is being used to receive incoming radio-frequency signals, may control which of two or more antennas is being used to transmit radio-frequency signals, may control the process of routing incoming data streams over two or more antennas in device **10** in parallel, etc.

[0046] Input/output circuitry **29** may be used to allow data to be supplied to device **10** and to allow data to be provided from device **10** to external devices. Input/output circuitry **29** may include input/output devices **31**. Input/output devices **31** may include touch screens, displays without touch sensor capabilities, buttons, joysticks, click wheels, scrolling wheels, touch pads, key pads, keyboards, microphones, speakers, tone generators, vibrators, cameras, sensors, light-emitting diodes and other status indicators, light sources, audio jacks and other audio port components, data ports, light sensors, motion sensors (accelerometers), capacitance sensors, proximity sensors, etc. A user can control the operation of device **10** by supplying commands through input/output devices **31** and may receive status information and other output from device **10** using the output resources of input/output devices **31**.

[0047] Wireless communications circuitry **33** may include radio-frequency (RF) transceiver circuitry formed from one or more integrated circuits, power amplifier circuitry, low-noise input amplifiers, passive RF components, one or more antennas, transmission lines, and other circuitry for handling RF wireless signals. Wireless signals can also be sent using light (e.g., using infrared communications).

[0048] Wireless communications circuitry **33** may include satellite navigation system receiver circuitry **35**, transceiver circuitry such as transceiver circuitry **37** and **39**, and antenna circuitry such as antenna circuitry **41**. Satellite navigation system receiver circuitry **35** may be used to support satellite navigation services such as United States' Global Positioning System (GPS) (e.g., for receiving satellite positioning signals at 1575 MHz) and/or other satellite navigation systems.

[0049] Transceiver circuitry **37** may handle 2.4 GHz and 5 GHz bands for WiFi® (IEEE 802.11) communications and may handle the 2.4 Bluetooth® communications band. Circuitry **37** may sometimes be referred to as wireless local area network (WLAN) transceiver circuitry (to support WiFi® communications) and Bluetooth® transceiver circuitry. Circuitry **33** may use cellular telephone transceiver circuitry (sometimes referred to as cellular radio) **39** for handling wireless communications in cellular telephone bands such as bands at 850 MHz, 900 MHz, 1800 MHz, 1900 MHz, 2100 MHz, and/or other cellular telephone bands of interest.

[0050] Examples of cellular telephone standards that may be supported by wireless circuitry **33** and device **10** include: the Global System for Mobile Communications (GSM) "2G" cellular telephone standard, the Evolution-Data Optimized (EVDO) cellular telephone standard, the "3G" Universal Mobile Telecommunications System (UMTS) cellular telephone standard, the "3G" Code Division Multiple Access 2000 (CDMA 2000) cellular telephone standard, and the "4G" Long Term Evolution (LTE) cellular telephone standard. Other cellular telephone standards may be used if desired. These cellular telephone standards are merely illustrative.

[0051] Wireless communications circuitry **33** may include circuitry for other short-range and long-range wireless links if desired. For example, wireless communications circuitry **33** may include wireless circuitry for receiving radio and television signals, paging circuits, etc. In WiFi® and Bluetooth® links and other short-range wireless links, wireless signals are typically used to convey data over tens of hundreds of feet. In cellular telephone links and other long-range links, wireless signals are typically used to convey data over thousands of feet or miles.

[0052] Wireless communications circuitry **33** may include one or more antennas **41**. Antennas **41** may be formed using any suitable antenna type. For example, antennas **41** may include antennas with resonating elements that are formed from loop antenna structures, patch antenna structures, inverted-F antenna structures, slot antenna structures, planar inverted-F antenna structures, helical antenna structures, hybrids of these designs, etc. Different types of antennas may be used for different bands and combinations of bands. For example, one type of antenna may be used in forming a local wireless link antenna and another type of antenna may be used in forming a remote wireless link antenna.

[0053] FIG. **4** is a diagram of an illustrative system of the type that may be used for manufacturing operations such as device testing. As shown in FIG. **4**, system **30** may include one or more stations such as test stations **36**. In general, test system **30** may include automated equipment that is used in loading and unloading devices under test, in conveying devices under test between test stations, and in performing tests and maintaining a database of test results. Each test station **36** may, for example, include test equipment **44** for performing one or more tests on device under test **10** and may therefore sometimes be referred to as a device tester or DUT tester. For example, a first type of test station **36** may have equipment for testing a display in device **10**. A second type of test station **36** may have equipment for testing an audio component in device **10**. Yet another type of test station **36** may have equipment for testing light sensors in device **10**. Yet another type of test station **36** may have equipment for testing wireless communications circuitry in device **10**. If desired, test system **30** may include more than one test station of the same type arranged along conveyor belt **38** so that multiple devices under test **10** can be tested in parallel.

[0054] Device under test **10** may, if desired, be installed in a test tray such as tray **32**. Tray **32** may be configured to receive one or more devices under test. For example, tray **32** may have multiple slots, each of which is configured to receive a corresponding device under test. If desired, tray **32** may be configured to receive only a single device under test.

[0055] Device **10** may be installed in test tray **32** manually or using automated equipment. To facilitate manual installation, test tray **32** may include features to facilitate human manipulation. For example, test tray **32** may include features that help an operator open and close clamps or other device holding features in test tray **32**.

[0056] Device under test **10** that is mounted in test tray **32** may be conveyed between test stations **36** using a conveyor belt such as conveyor belt **38** (e.g., a belt that moves in direction **40**). When using a conveyor system such as one or more conveyor belts **38**, each test station **36** may be provided with loading mechanisms (e.g., one or more computer-controlled loaders) **46**. With this type of arrangement, test tray **32** may serve as an interface between device under test **10** and loader **46**. Test tray **32** may, for example, be more robust than device **10**, may have engagement features that are configured to mate with loader **46**, may have an identification number that facilitates tracking, and may have other features that facilitate testing of device **10** by test stations **36**.

[0057] For example, loader **46** in each test station **36** may be provided with one or more computer-controlled positioning arms. The positioning arms in loader **46** may be used in picking up a test tray (i.e., a test tray that is loaded with device under test **10**) from conveyor **38** (arrow **50**), may be used to present test tray **32** to tester **44** at test station **36** to perform desired testing on device under test **10**, and may be used to replace test tray **32** on conveyor **38** following testing (arrow **52**).

[0058] Test stations **36** may provide test results to computing equipment such as test host **42** (e.g., one or more networked computers) for processing. Test host **42** may maintain a database of test results, may be used in sending test commands to test stations **36**, may track individual trays and devices under test as the trays and devices pass through system **30**, and may perform other control operations.

[0059] FIG. **5** is a diagram showing how device under test **10** may be received within test tray **32**. As shown in FIG. **5**, test tray **32** may have a base such as base **48** on which device under test **10** rests. Sidewalls such as sidewalls **100** may be formed on peripheral portions of base **48**, thereby forming a recess such as recess **154** in test tray **32**. Device under test **10** may be installed in test tray **32** by placing device under test **10** within recess **154**. Sidewalls **100** may be formed on one, two, three, or all four sides of device under test **10**. Sidewalls **100** may contain device locating features such as tangential surfaces or notches and may have device retention structures such as clamps, clips, or other structures.

[0060] Device under test **10** may have one or more connector ports such as port **28** (see, e.g., FIG. **1**). A contact extending structure such as contact extending structure **144** may have a mating connector such as plug **146**. Plug **146** may be configured to mate with a connector in port **28** when device under test **10** has been mounted in test tray **32** and when contact extending structure **144** (sometimes referred to as "pad extender" **144**) has been moved towards device under test **10** in direction **148**.

[0061] Following insertion of device under test **10** into test tray **32** and following insertion of plug connector **146** of pad extender **144** into connector **28** of device under test **10**, test tray **32** of FIG. **5** may appear as shown in FIG. **6**. Pad extender **144** may contain signal paths that connect pins in connector **28** to corresponding contacts **62** on pad extender **144**. Contacts **62** may be configured to mate with corresponding contacts coupled to tester **44** at test station **36** and/or test host **42** during testing in system **30**. If desired, pad extender **144** may be configured such that contacts **62** are flush with end surface **23** of test tray **32** when pad extender is connected to device under test **10** as shown in FIG. **6**.

[0062] Because device under test **10** is connected to test contacts **62** in test tray **32** using pad extender **144** associated with test tray **32**, it is not necessary to repeatedly connect and disconnect device under test **10** from cabling at each test station **36**. Rather, connections between device under test **10** and the test equipment at each test station **36** by may be formed by coupling contacts **62** in pad extender **144** to corresponding contacts at each test station **36**. By minimizing the number of times that cables need to be connected and disconnected from each device under test, the life of tester cables and connectors may be extended.

[0063] The use of test tray **32** may allow device under test **10** to be placed accurately within test stations **36** (e.g., with an accuracy of +/−0.1 mm or better, as an example). Test tray **32** may shield device under test **10** from scratches and other damage during testing. In general, device under test **10** may be received within test tray **32** in either an upwards facing configuration in which display **14** faces outwards (e.g., in which display **14** faces away from test tray **32**) or in which display **14** faced downwards (e.g., in which display **14** faces towards test tray **32**).

[0064] FIG. **7** is a perspective view of one suitable embodiment of test tray **32**. As shown in FIG. **7**, tray **32** may be provided with engagement features such as holes **160**. Engagement features such as holes **160** may be formed on one, two, three, or all four sides of test tray **32** and may be configured to mate with corresponding engagement features on automated loading equipment such as loaders **46** at test stations **36** (FIG. **4**). For example, holes **160** may be formed on opposing ends of test tray **32** such as ends **32**A and **32**B of test tray **32**. The example of FIG. **7** in which engagement features **160** have been implemented in the form of holes is merely illustrative. Engagement features **160** may be implemented in the form of slots, notches, dimples, openings, recesses, protrusions, or other features that allow test equipment such as computer-controlled loading equipment to engage with test tray **32**.

[0065] Automated loading equipment such as loaders **46** may have engagement pins that are configured to engage simultaneously with ends **32**A and **32**B, allowing loader **46** to pick up, hold, and transport device **10** to a desired location (e.g., to a test station such as test station **36** of FIG. **4**). In the example of FIG. **7**, test tray **32** is shown with four engagement holes on each end. This is, however, merely illustrative. If desired, tray **32** may include less than four engagement holes, more than four engagement holes, more than six engagement holes, more than 10 engagement holes, etc.

[0066] Tray **32** may be formed using non-marring material such as acetyl plastic, Delrin® (a polyoxymethylene plastic), other plastics, or other suitable non-marring materials. The use of non-marring materials may help avoid scratches or other damage to device under test **10** when device under test **10** is placed within test tray **32**. If desired, a layer of material **156** may be formed on portions of test tray **32** such base portion **48**. As an example, material **156** may be formed using the same material that is used to form tray **32**. As another example, material **156** may be formed using elastomeric material such as rubberized foam. Material **156** may, in general, be formed using any suitable non-marring material.

[0067] Test tray **32** may be provided with guide structures configured to accurately position device under test **10** in a desired location within recessed portion **154** of tray **32**. As shown in FIG. **7**, guide structures such as guide surfaces **150** may be used as reference points for determining the location of a device under test relative to test tray **32** and/or test station **36**. For example, a device under test may be positioned in a known location relative to test tray **32** by registering the device under test against guide surfaces **150**. A guide structure on the end of tray **32** may have an exposed end guide surface such as guide surface **150**A. Guide structures on the side of tray **32** may have exposed side guide surfaces such as guide surfaces **150**B. Guide surfaces such as guide surfaces **150**A and **150**B may sometimes be referred to as datums.

[0068] FIG. **8** is a bottom perspective view of one suitable embodiment of test tray **32**. As shown in FIG. **8**, holes, openings, or gaps such as gaps **80** may be formed in sidewalls **100** of test tray **32**. Gaps **80** in sidewalls **100** may allow portions of device **10** to be untouched by test tray **32**. For example, structures such as buttons, switches, ports (e.g., a subscriber identity module (SIM) card port to authorize cellular telephone service), and other input/output devices may be formed in a housing sidewall of device **10**. If desired, gaps **80** may be formed in portions of sidewalls **100** that are adjacent to (e.g., aligned with) these structures. This type of configuration may ensure that structures such as buttons or switches in device **10** are not unintentionally actuated or otherwise unnecessarily touched by test tray **32**. This is, however, merely illustrative. If desired, sidewalls **100** of test tray **32** may be free of gaps.

[0069] Test tray **32** may have one or more openings in base **48** to facilitate test measurements on device under test **10** during testing. For example, as shown in the bottom perspective view of FIG. **9**, openings such as opening **82** may be formed in base **48** and may be configured to align with one or more input-output devices in device under test **10** when device **10** is installed in tray **32**. Test equipment at a test station may communicate with a component in device **10** via opening **82**. In the example of FIG. **9**, opening **82** has an inverted cone shape to facilitate testing of a camera in device **10** (e.g., a light signal from a test light source may be transmitted through opening **82** to reach a camera in device **10**, or a light-emitting diode flash from a camera in device **10** may emit light through opening **82** to reach a light sensor at a test station). Other examples of components in device **10** that may be tested using openings such as opening **82** in test tray **32** include ambient light sensors, light-based proximity sensors, capacitive sensors, light-emitting diodes (e.g., for status indicators), display components, magnetic sensors, or other electrical components.

[0070] When device **10** is installed in test tray **32**, some components in device **10** may face away from test tray **32** (e.g., components formed on a front side of device **10**) and some components in device **10** may face towards test tray **32** (e.g., components formed on a back side of device **10**). If desired, openings such as openings **82** may only be formed in portions of base **48** that are aligned with components in device **10** that face towards test tray **32**.

[0071] FIG. **10** is a perspective view of pad extender **144** showing how connector **146** may protrude from one end of pad extender **144**. FIG. **11** is a perspective view of pad extender **144** showing how contacts **62** may be formed on an opposing end of pad extender **144**.

[0072] FIG. **12** is a perspective view of test tray **32** after device under test **10** has been inserted into test tray **32**. As shown in FIG. **12**, test tray **32** may have clamps **164** for holding device under test **10** within test tray **32**. The inner surfaces of clamps **164** may serve as guide surfaces **150** (FIG. **7**) or, if desired, may be separate structures adjacent to guide surfaces **150**.

[0073] Test tray **32** may have one or more notches or slots such as slot **170**. Slot **170** may be configured to receive pad extender **144**. If desired, pad extender **144** may be retained within slot **170** when device **10** is installed in test tray **32** (e.g., when connector **146** of pad extender **144** is connected to connector port **28** in device **10**) and when device **10** is not installed in test tray **32** (e.g., when test tray **32** is empty).

[0074] FIG. **13** is a perspective view showing how clamps **164** may have portions that extend over a top surface of device under test **10**. Clamps **164** may be spring-loaded to facilitate installation of device under test **10** in test tray **32**. For example, springs or other biasing structures may be used to bias the upper portions of clamps **164** towards device **10**. When it is desired to load device **10** into test tray **32**, clamps **164** may be pulled in direction **102** and device **10** may be placed on base **48**. Following placement of device **10** on base **48**, clamps **164** may be released and clamps **164** may be forced towards device **10** (e.g., in direction **104**) to secure device **10** to test tray **32**.

[0075] In addition to securing a device under test to a test tray, some clamps may serve the additional purpose of accurately positioning a device under test within a test tray. FIG. **14** is a top view of an illustrative test tray in which spring-loaded members may be used to both secure and accurately position a device under test within a test tray. As shown in FIG. **14**, spring-loaded members such as spring-loaded corner clamp **174** and spring-loaded side clamp **194** may be located at the periphery of recess **154** (e.g., may be mounted in sidewall portions **100** of FIG. **7**).

[0076] Clamps such as corner clamp **174** may be located at one or more corners of test tray **32** and may be used to accurately position a device under test within the test tray. For example, clamp **174** may be used to press device **10** against alignment features in test tray **32** (e.g., may be used to press device **10** against two of three datums within test tray **32** such as guide surfaces **150**). Corner clamp **174** may have a lip or protruding portion such as portion **201** that extends partially over a top surface of device **10** when device **10** is inserted in test tray **32**. Clamp **174** may be configured to rotate about pivot point **172**. A biasing structure such as spring **184** may be used to bias end portion **210** of clamp **174** in direction **178** (e.g., away from recess **154**). Because clamp **174** rotates about point **172**, the biasing force exerted on end portion **210** of clamp **174** may in turn provide a biasing force on opposing end portion **204** in direction **182**. When portion **210** of clamp **174** is pressed in direction **176**, clamp **174** will pivot about pivot point **172** and portion **204** of clamp **174** will move outwards in direction **180** to accommodate insertion of device under test **10** in recessed portion **154** of test tray **32**. After inserting device under test **10** into test tray **32**, end portion **210** of clamp **174** may be released and corner portion **204** may be forced towards device **10** in direction **182**.

[0077] Clamps such as side clamp **194** may be located on one or more sides of test tray **32**. If desired, clamp **194** may have a lip or protruding portion that extends partially over a top surface of device **10** when device **10** is inserted in test tray **32**. Side clamp **194** may pivot about pivot point **188**. A biasing structure such as spring **186** may be used to bias end portion **208** of clamp **194** in direction **196** (e.g., away from recess **154**). Because clamp **194** rotates about pivot point **188**, the biasing force exerted on end portion **208** of clamp **194** may in turn provide a biasing force on opposing end portion **206** of clamp **194** in direction **202**. When portion **208** of clamp **194** is pressed in direction **192**, clamp **194** will pivot about pivot point **188** and portion **206** of clamp **194** will move outwards in direction **198** to accommodate insertion of device under test **10** in recessed portion **154** of test tray **32**. After inserting device under test **10** into test tray **32**, portion **208** may be released and end portion **206** may be forced towards device **10** in direction **202**.

[0078] FIG. **15** is a top view of an illustrative conveyor belt **38** showing how test trays **32** might be used in a test system such as conveyor belt system **30**. Each test tray may contain a radio-frequency identification (RFID) tag such as tray ID tag **280** (e.g., a tag that wirelessly transmits tray identification information such as a tray serial number to RFID reading equipment). Conveyor belt system **30** may have one or more built in sensors such as RFID reader **313** that may be used to monitor incoming test trays **32** for RFIDs. If the RFID reader at a test station determines that the tray ID for a test tray matches previously received instructions, the test station may initiate loading mechanisms (e.g., loader **46**) to load the test tray into the test station. The serial number or other identification information associated with test tray **32** may be used in determining whether or not a device requires testing at a given test station, may be used in determining whether or not a device under test has successfully passed a given test, and/or may be used in determining other information about a device that is installed in test tray **32**.

[0079] One or more loaders **46** may be associated with each test station. As shown in FIG. **15**, loader **46** may include loading arm **306** and loading arm positioner **310**. Positioner **310** may be a computer-controlled actuator such as a motor-driven or air-driven actuator and may be configured to move loading arm **306** along three axes (e.g., along X, Y, and Z axes). Loading arm **306** may have engagement arm members **306'**. Each engagement arm member **306'** may have loading arm engagement features such as engagement pins **360** that are configured to mate with corresponding engagement holes **160** in test tray **32**. Engagement arm members may be controlled using air-driven or motor-drive actuators such as actuators **308**. Actuators **308** may be configured to move engagement arm members **306'** in a direction that is parallel to axis Y.

[0080] Initially, device under test **10** and test tray **32** may be located on the left hand side of conveyor belt **38**. As conveyor belt **38** moves in direction **290**, test tray **32** may approach location **312**. A sensor such as RFID reader **313** may be positioned along conveyor belt **38** and may be configured to identify a serial number with test tray **32** as it passes location **312**. Based on the identified serial number, test host **42** (FIG. **4**) may be used to determine whether or not the device under test associated with that test tray needs to be tested at a given test station. As test tray **32** approaches loader **46**, a sensor such as sensor **315** may be used to detect the presence of test tray **32** at location **314**. Sensor **315** may (as an example) be a laser-based distance sensor. If desired, a single sensor may be used to both detect and identify test trays **32**. The example of FIG. **15** in which separate sensors are used for identification and detection of test tray **32** is merely illustrative.

[0081] In response to detection of test tray **32** by sensor **315**, loading arm **306** may automatically be moved by loading arm actuator **310** into the position shown in FIG. **15**. As conveyor belt **38** continues to move in direction **290**, device under test **10** and test tray **32** may be received within loading arm **306**. If desired, one or more sensors may be used to inform a controlling computer such as host **42** (FIG. **4**) when a test tray is properly received within loading arm **306**.

[0082] Engagement pins **360** (sometimes referred to as protrusions) may be used to engage with test tray **32** so that loader arm **306** may pick up test tray **32** from conveyor belt **38** and transfer test tray **32** to a desired location (e.g., test station **36**). Initially, engagement pins **360** may be held in a retracted position by actuators **308**. After conveyor belt **38** has moved tray **32** into a position within arm **306**, actuators **308** may be used to extend pins **360** into holes **160**. If desired, actuator **308** may be configured to move pins **360** towards test tray **32** by moving engagement arm members **306'** inward. The example in which actuator **308** moves only engagement pins **360** to engage with holes **160** is merely illustrative. Once loader arm **306** has engaged with test tray **32**, loader arm **306** may deliver test tray **32** and device under test **10** to a test fixture at the test station associated with loader arm **306**. In some configurations, loader arm **306** may unload test tray **32** at the test station by disengaging pins **360** from holes **160**. In other configurations, loader **306** may remain engaged with test tray **32** while device under test **10** is tested at a test station.

[0083] Following testing at a given test station, loading arm **306** may return test tray **32** to conveyor belt **38**. If desired, a first loading arm may be used in picking up test tray **32** from conveyor belt **38** and a second loading arm may be used to return test tray **32** to conveyor belt **38**. Test tray **32** may have a first and second sets of engagement holes **160** so that first and second loading arms may simultaneously engage with test tray **32** (e.g., so that test tray **32** may be transferred between loading arms).

[0084] Each test station **36** (FIG. **4**) at which device under test **10** is tested may have an associated test fixture configured to receive test tray **32** and associated device under test **10**. FIG. **16** is an exploded perspective view of test system **30** showing how test tray **32** may be received by a test fixture such as test fixture **34**. After loading arm has **306** engaged with test tray **32**, loading arm **306** may present test tray **32** and device under test **10** to test fixture **34** at a test station for testing. Test fixture **34** may have contacts such as test fixture contacts **134**. Contacts **134** (sometimes referred to as contact pads or contact pins) may be configured to mate with contacts **62** on pad extender **144**. By bringing pad extender contacts **62** into contact with test fixture contacts **134**, an electrical connection may be formed between device under test **10** and test fixture **34**. Test signals may be conveyed between test fixture **34** and device under test **10** via pad extender **144**.

[0085] Device under test **10** may be tested at multiple test stations. If desired, each test station may have a test fixture with an associated set of test fixture contacts **134**. Pad extender **144** may be configured to mate with corresponding test fixture contacts **134** at each test station.

[0086] The foregoing is merely illustrative of the principles of this invention and various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention. The foregoing embodiments may be implemented individually or in any combination.

What is claimed is:

1. Test apparatus for testing an electronic device, comprising:

a test tray configured to receive the electronic device, wherein the test tray includes a plurality of test tray engagement features configured to receive corresponding loader engagement features on a computer-controlled loader; and

a contact extending structure having first and second ends, wherein the first end comprises a connector configured to mate with the electronic device, and wherein the second end comprises a plurality of contact pads configured to mate with contacts at a test station.

2. The test apparatus defined in claim **1**, wherein the test tray further includes at least one spring-loaded member configured to retain the electronic device within the test tray.

3. The test apparatus defined in claim **1**, wherein the test tray comprises a base and at least one side wall, wherein the at least one side wall comprises at least one opening, and wherein the opening aligns with an input-output device in the electronic device when the electronic device is received within the test tray.

4. The test apparatus defined in claim **1**, wherein the test tray comprises a base and at least one side wall, wherein the base comprises at least one opening, and wherein the opening aligns with an input-output device in the electronic device when the electronic device is received within the test tray.

5. The test apparatus defined in claim **1**, wherein the test tray comprises a slot configured to receive the contact extending structure.

6. The test apparatus defined in claim **1**, wherein the plurality of test tray engagement features comprises a plurality of recesses in the test tray.

7. The test apparatus defined in claim **1**, wherein the test tray comprises a radio-frequency identification tag configured to transmit test tray identification information.

8. A test system for testing a device under test, comprising:

a test tray configured to receive the device under test, wherein the test tray comprises a radio-frequency identification tag configured to transmit test tray identification information;

a sensor configured to receive the test tray identification information;

a test fixture configured to receive the test tray; and

computer-controlled loading equipment configured to engage with the test tray and to move the test tray towards the text fixture for testing.

9. The test system defined in claim **8**, wherein the test fixture comprises a plurality of test fixture contacts, the test system further comprising:

a contact extending structure having first and second ends, wherein the first end comprises a connector configured to mate with the device under test and wherein the second end comprises a plurality of contact pads configured to mate with the plurality of test fixture contacts.

10. The test system defined in claim **8**, wherein the test tray comprises test tray engagement features, wherein the computer-controlled loading equipment comprises a loading arm having loading arm engagement features, and wherein the loading arm is configured to hold and move the test tray by engaging the loading arm engagement features with the test tray engagement features.

11. The test system defined in claim **8**, wherein the test tray comprises a plurality of recesses, wherein the computer-controlled loading equipment comprises a loading arm having a plurality of protrusions, and wherein the loading arm is configured to hold and move the test tray by inserting each protrusion in the plurality of protrusions in an associated recess in the plurality of recesses.

12. The test system defined in claim **8**, wherein the test tray comprises at least one spring-loaded member configured to retain the device under test within the test tray.

13. The test system defined in claim **8**, wherein the computer-controlled loading equipment comprises a loading arm and an actuator and wherein the actuator is configured to actuate the loading arm to engage with the test tray in response to the sensor receiving the test tray identification information.

14. A method of testing a device under test, comprising:

installing the device under test into a test tray;

connecting a contact extending structure to a connector port in the device under test;

while the device under test is installed in the test tray and while the contact extending structure is connected to the connector port, feeding the test tray into a conveyor belt system; and

with a computer-controlled loading arm, installing the test tray in a test fixture for testing.

15. The method defined in claim **14**, further comprising:

with the test tray, transmitting test tray identification information; and

with a sensor, receiving the test tray identification information.

16. The method defined in claim **14**, further comprising:

with a sensor, detecting the test tray at a predetermined location in the conveyor belt system; and

in response to detecting the test tray at the predetermined location, automatically actuating the computer-controlled loading arm to pick up the test tray.

17. The method defined in claim **16**, wherein the computer-controlled loading arm comprises a plurality of pins, wherein the test tray comprises a plurality of holes, and wherein automatically actuating the computer-controlled loading arm to pick up the test tray comprises inserting each pin in the plurality of pins into an associated hole in the plurality of holes.

18. The method defined in claim **14** wherein the contact extending structure comprises a plurality of contact pads, wherein the test fixture comprises a plurality of test fixture contacts, and wherein installing the test tray in the test fixture comprises electrically connecting the plurality of contact pads to the plurality of test fixture contacts.

19. The method defined in claim **14**, further comprising:

after installing the test tray in the test fixture, performing testing on the device under test.

20. The method defined in claim **19**, wherein performing testing on the device under test comprises:

with the contact extending structure, conveying test signals between the test fixture and the device under test.

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