Claims

1. A high-impedance connector assembly for a sensor circuit, comprising:
   - a first connector part (receptacle) and a mating second connector part (plug) for carrying a sensitive sensor signal,
   - the connector parts including a signal contact (10) for the sensor signal, one or more guard contacts (12) adjacent to and surrounding said signal contact, and a ground contact (13) spaced further out,
   - an insulating connector body (14) supporting the contacts, made of a high-resistance dielectric,
   - wherein the guard contacts (12) of the connector are arranged such that when the connector parts mate, the guard contacts of the plug and receptacle engage each other, connecting a driven guard shield from one side to the other, and said guard contacts physically and electrically envelop the signal contact (10) so that any leakage current or capacitive coupling between the signal contact and the ground contact must pass through or be intercepted by the guard contacts, effectively maintaining guard shielding across the connector interface.
2. The connector assembly of claim 1, implemented in a coaxial geometry (triaxial connector), wherein:
   - the signal contact is a central pin (male on one side, female on the other),
   - the guard contact is an intermediate cylindrical conductor (a sleeve or shell concentric with the center pin, insulated from it by a tubular dielectric) ,
   - the ground contact is an outer conductor (outer shell of the connector) insulated from the guard contact by a second dielectric layer,
   - such that the mated connector forms a coaxial arrangement of signal conductor surrounded by guard conductor which is further surrounded by ground, thereby extending a continuous triaxial guard shield through the connector with extremely high insulation resistance between the signal and ground .
3. The connector assembly of claim 1, implemented in a multi-pin configuration, wherein the contacts are arranged in a pattern and include at least one signal pin (10) and multiple guard pins (12) positioned adjacent to the signal pin in said pattern, all said guard pins being electrically common and connected to a guard shield driver in the circuit when the connector is mated. The guard pins thus form a ring of guard around the signal pin, substantially reducing any leakage from the signal pin to other pins or

connector surfaces by keeping the electric field around the signal pin at nearly signal potential. For example, in a rectangular 2-row connector, the guard pins may surround the signal pin on all four sides.

4. The connector assembly of claim 3, wherein the plug side guard pins are connected together to an inner shield of a sensor cable or to a guard ring on a sensor module, and the receptacle side guard pins are all tied to the instrument's driven guard net, ensuring that when mated each guard pin pair joins the instrument guard to the sensor-side guard, thereby continuing the guarded environment from the instrument, through the connector, to the sensor.

5. The connector assembly of claim 1, wherein the insulating material (14) separating the signal and guard contacts is chosen for ultra-high volume resistivity and low moisture absorption, such as PTFE or polystyrene , and the connector is constructed so that the creepage distance from the signal contact to any external surface or to the ground contact is maximized (for instance by recessing the signal contact within the guard shell, or by adding barriers in the insulator), thereby providing connector insulation on the order of teraohms and minimizing leakage even under humid or contaminated conditions.

6. An air-quality monitoring system comprising:

    - a sensor front-end circuit with a driven guard shield,
    - a removable sensor or cable that connects to said front-end via a connector assembly as in claim 1,
    - wherein the system's guard shield driver is electrically connected to the guard contact(s) of the connector, and the sensor's guard or shield is connected to the mating guard contact(s),
    - such that the sensitive sensor signal is guarded continuously from the sensor, through the connector, to the measuring circuit without interruption, allowing modular sensors or extension cables to be used while maintaining picoamp-level leakage suppression and measurement accuracy afforded by guard shielding.

Independent Claims

1. Apparatus claim (system)

A sensor-interface apparatus for measuring picoampere-range currents from an air-quality sensing element, comprising:

a) a transimpedance amplifier (TIA) including an operational amplifier having a non-inverting input coupled to circuit common and an inverting input coupled to the sensing element;

b) a feedback network coupled between the operational-amplifier output and the inverting input, the network including:

i. a resistor having a resistance ≥ 1 GΩ, and

ii. a capacitor having a capacitance in a range of 0.1 pF – 10 pF connected in parallel with the resistor;

c) a driven-guard circuit that drives a conductive guard structure disposed on a printed-circuit board (PCB) and on a multi-conductor cable to substantially the same potential as the inverting input, thereby suppressing leakage currents;

d) a high-voltage-immunity structure including:

i. an insulating slot in the PCB positioned between the sensing element node and other conductors, the slot increasing creepage distance, and

ii. a transient-voltage-suppressor (TVS) device having a reverse-stand-off voltage greater than the maximum normal operating voltage and a specified leakage ≤ 100 fA at that voltage, the TVS coupled between the inverting input and circuit common;

e) a DC-DC power-conversion stage providing at least one supply rail for the operational amplifier, the stage arranged on the PCB outside the guard structure and referenced to circuit common only at a single point so that switching ripple currents are prevented from flowing within the guard structure;

f) a digital controller configured to:

i. periodically disable or modulate the driven-guard circuit,

ii. acquire the resulting change, if any, in the TIA output, and

iii. flag a guard-integrity fault when the change exceeds a prescribed threshold;

g) a non-volatile memory storing a humidity-to-offset calibration map that correlates ambient relative-humidity values with corresponding baseline current offsets, and wherein the controller is further configured to:

i. measure ambient humidity,

ii. retrieve a baseline-offset value from the map, and

iii. numerically compensate the TIA output using the retrieved value; and

h) a detachable connector assembly carrying separate conductors for the sensing element signal, the driven guard, and circuit common such that the driven-guard potential is maintained across the connector interface.

2. Method claim

A method for operating the apparatus of claim 1, comprising:

a) energising the driven-guard circuit to minimise leakage;

b) sampling the TIA output to obtain a raw sensor-current measurement;

c) determining ambient relative humidity;

d) retrieving, from the non-volatile memory, a stored baseline-offset value corresponding to the determined humidity;

e) subtracting the baseline-offset value from the raw sensor-current measurement to obtain a humidity-compensated current value;

f) periodically executing a guard-integrity self-test by disabling the driven-guard circuit for a predetermined interval, monitoring the TIA output for a deviation greater than a threshold, and setting an error flag when the deviation exceeds the threshold; and

g) outputting the humidity-compensated current value together with any guard-integrity error status.

3. Computer-readable-medium claim

A non-transitory computer-readable medium storing instructions that, when executed by the digital controller of the apparatus of claim 1, cause the controller to perform steps (a) through (g) of claim 2.

Dependent Claims

4. The apparatus of claim 1 wherein the resistor is a hermetically sealed thick-film resistor having distributed capacitance ≤ 0.2 pF per 100 MΩ segment and is physically surrounded on all sides by the driven guard.

5. The apparatus of claim 1 wherein the capacitor is an NP0/C0G dielectric capacitor having insulation resistance ≥ 10 TΩ at 25 °C.

6. The apparatus of claim 1 wherein the insulating slot provides a creepage distance increase of at least 5 mm compared with an un-slotted PCB.

7. The apparatus of claim 1 wherein the TVS device exhibits a leakage current ≤ 10 fA at 25 °C and ≤ 100 fA over the operating-temperature range −20 °C to +60 °C.

8. The apparatus of claim 1 wherein the DC-DC stage is a charge-pump converter operating at a switching frequency ≥ 1 MHz and is enclosed within a ground-referenced copper shield can that is electrically isolated from the guard structure except at a single star-ground point.

9. The apparatus of claim 1 wherein the driven guard is provided on both outer layers of a multi-layer PCB and connected by via-stitching at intervals ≤ 2 mm to minimise guard impedance.

10. The apparatus of claim 1 wherein the multi-conductor cable is a triaxial cable whose inner shield is driven by the driven-guard circuit and whose outer shield is connected to circuit common.

11. The apparatus of claim 1 wherein the connector assembly comprises a three-lug triaxial bayonet connector mating with the triaxial cable.

12. The apparatus of claim 1 wherein the controller executes the guard-integrity self-test at intervals selectable between 10 s and 10 min.

13. The apparatus of claim 1 wherein the baseline-offset calibration map is generated by factory characterisation at ≥ 5 discrete humidity points spanning 10 %–90 % RH.

14. The apparatus of claim 1 further comprising a temperature sensor, and wherein the calibration map is two-dimensional, storing baseline-offset values as a function of both humidity and temperature.

15. The method of claim 2 wherein step (f) further comprises logging the deviation magnitude and trend over time to predict impending guard degradation.

16. The method of claim 2 wherein step (g) further comprises transmitting the humidity-compensated current value and guard-integrity status over a wireless interface to a remote monitoring device.

17. The apparatus of claim 1 wherein the operational amplifier includes an integrated guard-buffer output pin that directly drives the guard structure without external buffering.

18. The apparatus of claim 1 wherein the feedback network includes a second selectable resistor-capacitor pair providing an alternative time constant for accelerated warm-up calibration.

19. The apparatus of claim 1 wherein the digital controller is configured to re-enable the driven guard immediately upon detecting a deviation exceeding the guard-integrity threshold.

20. The apparatus of claim 1 wherein the sensor-interface apparatus is housed within an environmental chamber that channels airflow through the sensing element while isolating the TIA and guard-shielded PCB from direct exposure to ambient particulate contaminants.