A New Class of Non Loading Voltmeters FOR Contacting and Contactless Measurements

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Introduction

Voltmeters are used to measure voltages in electronic circuits, data acquisition systems and static electricity applications. By necessity, all Voltmeters have high input impedance, but in some applications which require minimum loading, exceptionally high input impedance is required. In electrostatic voltage applications, no loading can be tolerated and for these cases a class of Voltmeters which make no contact with the measured object are employed. However, a new class of Voltmeters, as described below, is now available. Members of this class provide exceptionally high input resistance and low input capacitance so they can be used both in conventional and static charge measurement applications.

A new class of Voltmeter is now available, providing circuitry to null its input capacitance and eliminate loading caused by its input resistance. This device can be used as a contacting voltmeter when the probe contacts the element under test. It can equally well be used as a non contacting voltmeter because it can sense the voltage on a nearby object by contacting the object's electric field rather than the object itself. It provides safe contact of the most ESD sensitive devices, non loading measurements and can sense the static voltage of very small objects.

Classes of Voltmeters

A conventional Voltmeter, as used for most electronic measurements, utilizes a buffer amplifier, an analog-to-digital converter and a display. This type of Voltmeter employs two contacting passive probes and has an input impedance of 10^5 to 10^8 Ω. This type serves many applications quite well and is the most common type of Voltmeter in use today. These devices measure voltages of several milliVolts to several kV.

In some high impedance applications, a conventional Voltmeter loads down the circuit appreciably - making measurements unacceptable. Higher Voltmeter impedance is required for these applications. Examples include very high gain amplifiers and systems, including biological sensors which measure very small objects which are easily loaded down by conventional meters. In these cases, it is necessary to employ a meter with a very high (>>1 GΩ) input impedance. Some applications, like magneto resistive head measurements, are very demanding because of the potential of damage occurring to the head by contact due to a voltage transient from the Voltmeter itself or from an electrostatic discharge (ESD) event occurring upon contact.

The input resistance and input capacitance of a conventional Voltmeter rapidly drains the charge from the object under study. As an example, there can be a need to measure the surface voltage on a semiconductor chip package. Commonly, charge levels of a few nanoCoulombs can be stored on a capacitance of ~several picoFarads. Using a probe with a capacitance of 1 pF would drastically effect the measurement by transferring much of the charge from the test object upon contact. Furthermore, a probe input resistance of 10^9 Ω would drain the charge from the system in just milliseconds, making the measurement useless.

Figure 1 The Trek 820 Infinitron® Voltmeter

Conventionally, static charge measurements are made with non contacting probes which are placed in close proximity to the object under study. Such electrostatic Voltmeters employ special probes which use vibrating reeds or choppers. For a summary of these electrostatic Voltmeters and probes, see Trek Application Note 3002 (available for download from the Technical Library section of the Trek web site, www.trekinc.com). Because these probes make no contact with the object under test, they have extremely high (>>10^{12} Ω) input resistance and low capacitance (<<1 pF). These devices are used to measure voltages in the range of several Volts to kilovolts and they measure the average voltage over a "spot size" of approximately 0.5-2 cm^2. In some applications, such as electro photography, smaller spot size measurement and the measurement of lower voltages would be quite useful and can be accomplished using the new class of Voltmeters.

There is a class of applications which are not currently well served and involve measuring voltages on extremely sensitive devices. In these cases, the static charge on the stray capacitance associated with just the measurement leads can represent enough energy to destroy the device under test. One example of such a device is the magneto-resistive head used in hard disk drives. Such a device requires careful handling and often operates at <1 Volt which is below the sensitivity of most non-contacting Voltmeters. Other applications involve measuring the voltage on very small objects, such as packaged and unpackaged ICs moving through the production line.

Due to the diversity of applications, there is a need for a contacting/non-contacting Voltmeter which has an extremely high input resistance (>10^{16} Ω) and an extremely low input capacitance (<10^{-15} F). As a side benefit, such a device would load the element under test so minimally that the meter would respond to contact with the electric field adjacent to the object, thus producing the same measurement as physical contact with the object itself, effectively becoming a non-contacting Voltmeter.

New Technology Operation Description

The Trek Model 800 and Model 820 have been designed to provide this level of performance. These two units employ bootstrap technology to virtually eliminate the loading effect caused by conventional contacting Voltmeters. The circuit layout has been done to minimize the effects of input lead capacitance and of electrical pickup from external sources (like power line voltage). In addition, the units provide compensation circuitry for offset issues, which will be described next.

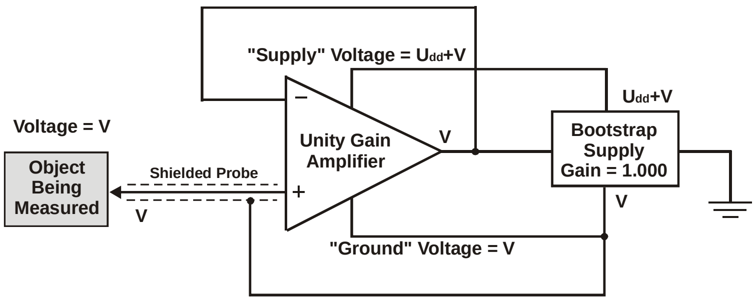

Figure 2. Bootstrap configuration of the Voltmeter.

Bootstrap technology involves raising the ground and supply voltages of the input amplifier to the same voltage as the input to the meter. As shown in Figure 2, the output of the unity gain amplifier is equal to the voltage on the object under test. This voltage is applied to the power supply circuit (Bootstrap Supply) which creates reference voltages U_{dd}+V and V. These are the conventional rails (in normal operation these values are U_{dd} and 0 V) for the unity gain amplifier but elevated by the value of the input voltage.

As the probe approaches the object to be measured, that object induces its voltage on the probe tip. By the time the probe actually contacts the object being tested, there is no voltage difference between either the object and the probe tip or the object and the probe shield. This dramatically reduces the effects of resistive or capacitive loading of the object under test by the Voltmeter as well as eliminating the possibility of an ESD event.

Figure 3. The probe contains the front end buffer amplifier

Due to the variety of applications that exist for non-loading non-invasive technology, the unit has been designed in two different formats. The Model 800 can measure voltages up to ±100 V and the Model 820 covers a larger range of ±2000 V.

Active Probe - An important part of the high performance of the bootstrapping system has been to locate the front end amplifier in the probe body. See Figure 2. This eliminates the prospects of AC and DC pickup in the probe cable and minimizes any loading effects that would arise from the unbuffered lead capacitance. The probe is shown in Figure 3.

Because the Model 820 operates with voltages to ±2 kV, this could represent a safety issue. For that reason, a grounded guard electrode is provided for the Model 820. This increases the capacitance of the circuit in return for a safety factor. For that reason, the effective input capacitance of the 820 is higher than that of the 800, although it is still very low, $<5\times10^{-13}$ F. In contrast, the Model 800 with no safety electrode has an effective input capacitance of $<10^{-15}$ F. The difference in specifications is reasonable because it is foreseen that the two units will serve different application requirements, the Model 820 with the lower input capacitance serving more demanding lower voltage applications.

Extremely low input capacitance and high input resistance precision circuits are adversely affected by the input offset voltage and the input bias current associated with the input amplifier. These factors have been compensated for in this family of special ultra high impedance Voltmeters.

Input Offset Voltage Correction– This is a potential source of a small DC voltage error which both units must correct for. A push button on the front panel and on the probe allows the user to put the unit into a mode to automatically correct for the input voltage. This circuit drives any charge off of the physical input capacitance while the probe is connected to a zeroing pad on the Voltmeter body. After the zeroing operation is performed, the unit is restored to normal operation and will read zero for a zero volt input.

Input Bias Current Correction – The input unity gain amplifier used for both of the Voltmeters has an input bias current ~2 fA (femtoAmp). This is a very small value and for the case of the Model 820, it is small enough to be acceptable. The input bias current will charge the input capacitance linearly over time and will represent a small voltage ramp added to the reading. This value is <6 V/minute. Furthermore, the offset voltage is eliminated with each input voltage correction performed by the operator.

In the case of the Model 800, an additional circuit is provided to cancel out this tiny current, making the voltage drift described above un-measureable. When the Model 800 performs a null operation, it measures its input bias current and applies an equal but opposite current to its input, thus canceling out this drift. Internal circuitry tracks the accuracy of this current.

Instrument Performance

Model	Range	Bandwidth Sm/Lrg Sig	Step Response	Voltage Display Resolution	Voltage Drift	Input Capacitance	Input Resistance
800	±100 V	10 kHz / 100 Hz	<3.5 ms for 100 V step	0.1 V	<500 mV/hr.	$<10^{-15}$ F	$>10^{16}$ Ω
820	±2000 V	5 kHz / 200 Hz	<750 us for 1 kV step	1 V	<6V/min	$<5\times10^{-13}$ F	$>3\times10^{13}$ Ω

Applications

- Accurate reading of electrostatic voltages on ESD-sensitive semiconductor die, packaged parts and MR Heads. Prevention of charge build-up and safe dissipation of that charge is the only way to control ESD. The Trek 800 series cannot cause ESD damage to the component it is measuring.
- Measuring a surface charge distribution in electro-photographic measurements. With the tip designed for the non-contacting measurements, the Model 820 can measure charge uniformity. The unit provides finer spacial resolution than conventional electrostatic voltmeters. The zeroing function improves measurement.
- Voltage monitoring on ESD sensitive devices: Mainly in semiconductor industry, devices fail due to ESD during handling and processing. Model 820 contacting measurement technology helps in measuring voltage precisely on ESD sensitive devices. Voltage measurement on Semiconductor chips, MR Head sensors are some examples.

- Measuring the potential on cells in biological applications without perturbing the organism under study.

- Other applications include:

    - Measuring electrostatic potential on powders in chemical, pharmaceutical, ceramic and other applications
    - Electrostatic painting/coating
    - Electrostatic potential distributions on film, polymers, and paper
    - Test and measurement, instrumentation
    - Material evaluation and quality control
    - Military, automotive, aerospace
    - R&D applications

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