

AN-0004	Insulation Resistance Measurement
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Init. JR	

SCOPE

When measuring Insulation Resistance (IR) with the Danbridge DB620-series Megohmmeters there are several issues to consider when comparing to resistance measurement with a common Multimeter. This application note is intended to address some of these. For using the Danbridge Megohmmeters in sorting machines please see "AN-0003 Using Danbridge Megohmmeters in Sorting Machines".

GENERAL

In its simplest form an IR test is performed by applying a DC voltage over the isolation barrier and measure the corresponding DC current, often referred to as "leakage current" (which should not be confused with the leakage current measured applying an AC test voltage). The IR is then calculated from:

$$IR = \frac{U_{HT}}{I_{Leak}} \quad [1]$$

Fig. 1 shows the two basic set-ups when measuring IR. In the first set-up the voltage ("High Voltage" or "High Tension") is applied as a positive voltage with respect to ground potential. The current is measured as the current that flows into a measure circuit with its ground reference connected to ground potential. This set-up is used when both electrodes of the test object (here a capacitor) are electrically floating. In many cases one of the electrodes is connected to ground potential. This could be the case for shielded cables, power transformers, electric motors etc. If the first set-up were used with the current measure circuit connected to the grounded electrode, the leakage current would flow into the ground connection rather than into the measure circuit. The only way to perform the measurement is to shift the electrical potential of the measure circuit ground away from earth ground potential. In the Danbridge DB620 Megohmmeter this is done internally by connecting the output of the HT Supply to earth ground through a relay. When the test voltage is output from the HT supply this forces the internal measure ground of the instrument to a negative potential equal to the test voltage.

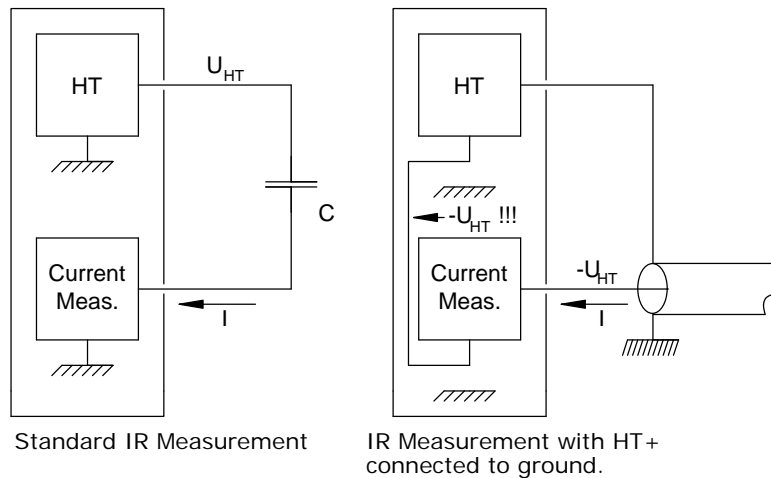


Fig. 1: The two basic set-ups for IR Testing.

CONNECTING DB620-SERIES MEGOHMMETERS.

When connecting the DB62X Megohmmeters to the DUT there are a few issues to address to ensure safety, noise free measurement, and minimum disturbance of the surroundings and long term stability of the instrument.

The first rule is NEVER to connect the shield of the "HT" output with the shield of "I in". The shield of HT out is connected to chassis ground, the shield of "I in" to "Guard" which is used to divert leakage currents from the current input. Often standard resistors used to verify the instrument have their shields connected together through the box they are housed in. In this case the shield of the HT cable must be interrupted in a similar way as shown in fig. 2 of the connections to a jig.

Also the cabling must be carefully considered. The general rule is to avoid electrical loops that can pick up magnetic noise fields (hum) and add self-inductance. Also, the effects of flashovers (sparks) either within the DUT or resulting from mechanical handling problems have to be considered. If a flashover occurs the wires to the DUT act as antennas for the electrical transient. This could lead to disturbances or failures in the Megohmmeter or in electronic equipment in the vicinity of it. The problem is aggravated by loops in the wiring from two reasons:

- 1: The loop acts as an antenna for a magnetic transient influencing the surroundings.
- 2: Together with stray capacitance in the wiring the self-inductance from the loop forms an oscillating circuit that could amplify the voltage transient.

The stray capacitance of the shielded cables should not be ignored either. The 1m cables delivered with the instruments have a capacity of approximately 100pF and should not under normal circumstances cause any problems. However, if the test voltage is turned on before contact is made with the DUT, the charge stored on the cable will discharge directly into the DUT. This discharge happens at a potentially very high current and will not be limited from the current limit of the Megohmmeter. The longer the cables, the more energy is stored in it and the worse is the potential damage caused by it. Even if the cables are connected to the DUT before the test voltage is turned on, a bad or unstable connection can lead to high-current flashes during the (attempted) charging of DUT. The best way to protect against flashovers is to place wire wound resistors as close as possible to the DUT. In this way the transients resulting from the flashovers are damped near the source. The resistors have values of 10 - 1000 ohm and a power rating of 2 - 3W (see last page of this application note).

When measuring high value resistances it is important that the "I in" coax cable (and a resistor housing or jig if present) is fully discharged. Charge can be stored in the cable due to dielectric absorption. Also, it is important to ensure the cabling is mechanically stable to prevent electrical charge to be moved due to pressure and bending of the cables. Follow this procedure:

1. Make zero adjust with "I in" open (no cable)
2. Connect the cable (and the current input side of the resistor if applicable) to "I in".
3. Wait 5 to 10 min before connecting the HT cable and make the measurement.

After this more measurements can be made without the wait. It is a good idea to store the input cables with a short circuit mounted to prevent any charge to build up.

In summary the following rules apply:

- NEVER CONNECT THE HT SHIELD WITH THE "I in" SHIELD.
- MAKE ZERO ADJUST WITH "I in" OPEN.
- USE SHORT CABLES.
- AVOID OR MINIMISE LOOPS IN THE SIGNAL PATH.
- ENSURE A GOOD ELECTRICAL AND MECHANICAL CONNECTION BETWEEN CABLES/PROBES AND THE DUT.
- **NEVER** TURN ON THE TEST VOLTAGE BEFORE GOOD CONNECTION TO THE DUT IS ENSURED.
- USE PROTECTIVE RESISTORS IN THE WIRING NEAR THE DUT.

In the following some typical measure set-ups are described.

IR MEASUREMENT USING A TEST JIG

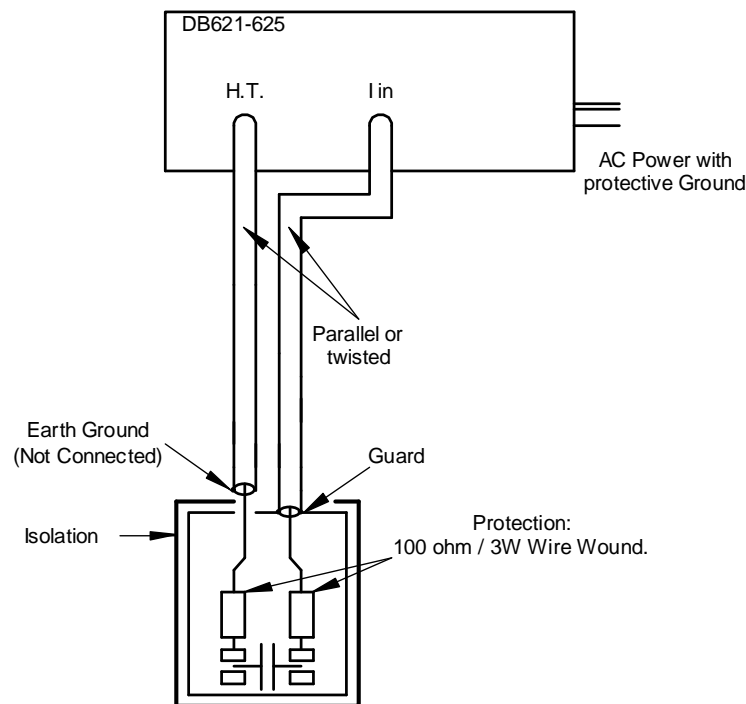


Fig. 2: DB621/22/23/25 IR Measurement using a test jig.

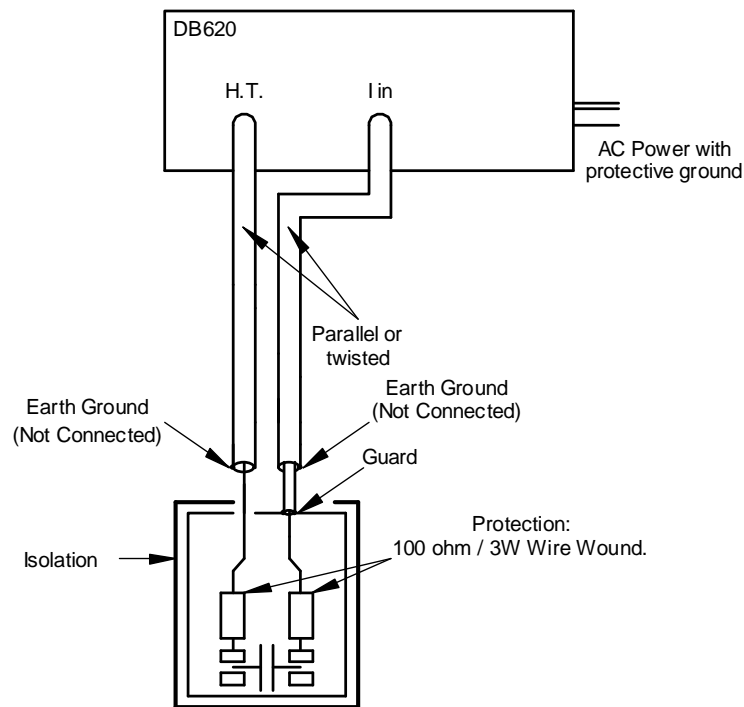


Fig. 3: DB620 (Triax input) IR Measurement using a test jig.

A convenient way to measure leaded electronic components is to use a jig with suitable clamps. The jig cables must be connected as shown in fig. 2 and 3. The jig shield (if any) must be connected to the shield of the "I in" cable. The shield of the "I in" cable is connected to "Guard" which is the internal measure ground. If the jig is shielded it must be isolated from the surroundings.

- NEVER CONNECT THE GUARD TO EARTH GROUND.
- IF USING MODEL DB620 WITH A JIG ALWAYS ENSURE THAT THE INSTRUMENT IS NOT IN "HT on Ground" MODE.

It is always recommended to use protective resistors.

IR MEASUREMENT USING TWEEZERS OR PROBES.

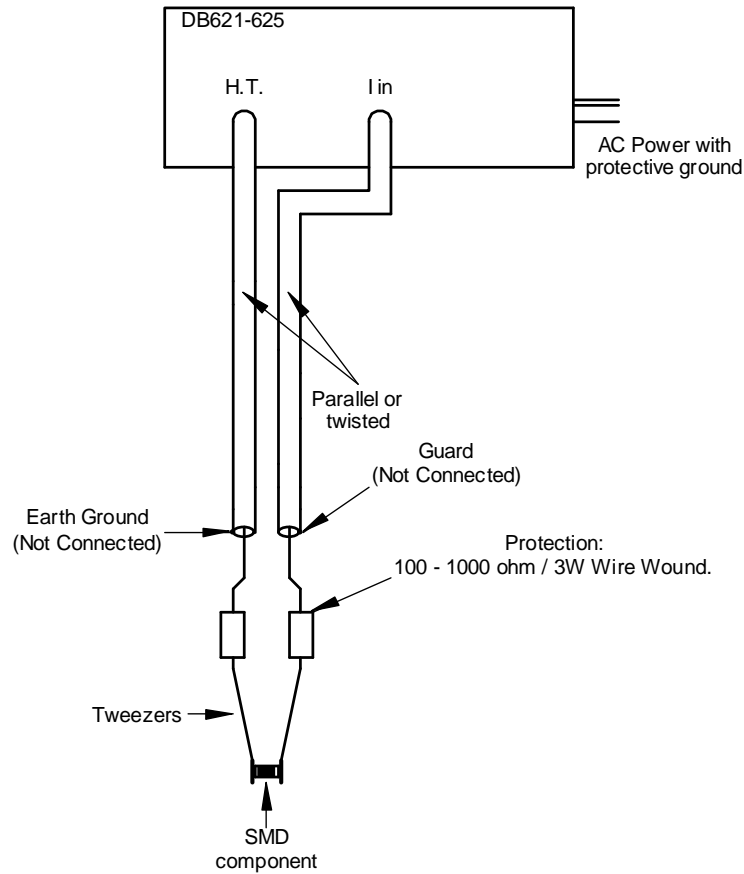


Fig. 4: IR measurement of SMD capacitors using tweezers.

When measuring small electronic devices like SMD capacitors connection is often made with probes or hand tweezers. The tweezers are isolated to protect the operator. Fig. 4 shows the setup without the isolation. When connection is made to the DUT the test voltage is applied (i.e. triggered by means of a foot pedal). The cable shields must be ended without connection and well isolated from the surroundings.

- NEVER CONNECT THE GUARD TO EARTH GROUND.
- IF USING MODEL DB620 WITH TWEEZERS ALWAYS ENSURE THAT THE INSTRUMENT IS NOT IN "HT on Ground" MODE.

Due to the delicacy of handling the devices it is strongly recommended to use protective resistors near the tweezer electrodes.

IR MEASUREMENT USING THE DB620

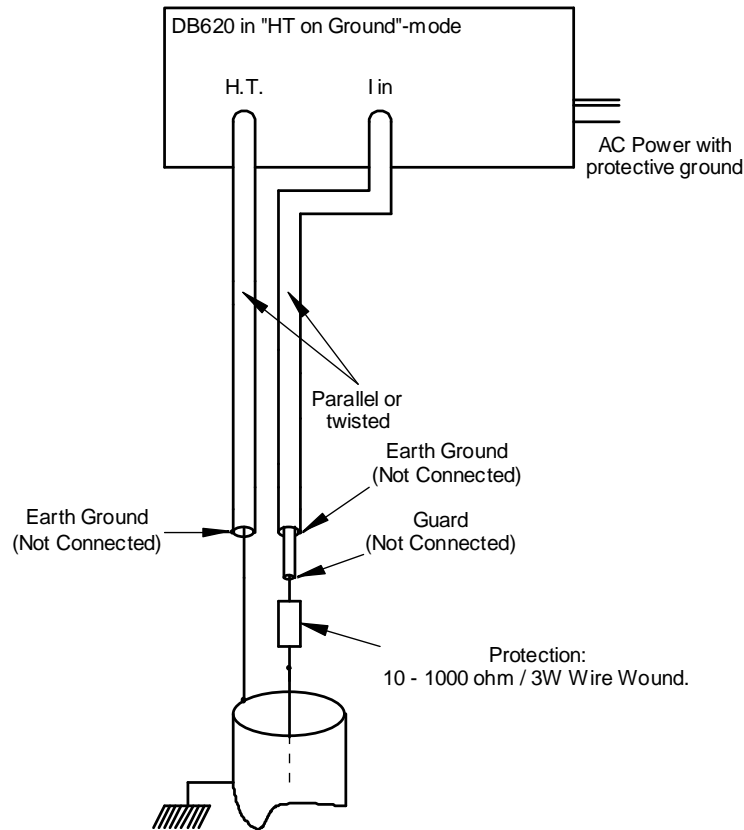


Fig. 5: IR measurement of grounded test object using DB620 in "HT on Ground"-mode.

The DB620 has a 1kV test voltage supply that can be used in both standard and grounded mode. The "I in" connector is a triax type in order to ensure adequate protection when in grounded mode: the inner shield is connected to the internal measure ground (guard), the outer shield is connected to earth ground. When the test voltage is turned on in grounded mode the inner shield reaches a voltage down to -1kV with respect to earth ground. It must therefore be kept away or well isolated from any grounded objects! Fig. 5 shows the set-up.

- ALWAYS BE AWARE OF THE FACT THAT "I in" AND GUARD, NOT THE H.T., ARE CARRYING THE MEASURE VOLTAGE!
- IF USING A TRIAX MEASURE CABLE WITH ALLIGATOR CLIPS BE SHURE THAT THE GUARD CLIP UNDER NO CIRCUMSTANCES CAN COME IN CONTACT WITH PEOPLE OR ANYTHING ELSE!
- NEVER CONNECT THE GUARD TO EARTH GROUND.

It is always recommended to use a protective resistor in the "I in" wire.

(continued)

To protect the DB620 in case of a line power failure the following limitations in DUT Capacity and voltage should not be exceeded:

Capacity	Maximum HV
$C < 1\mu\text{F}$	1000V
$1\mu\text{F} < C < 10\mu\text{F}$	500V
$10\mu\text{F} < C < 100\mu\text{F}$	100V

CABLE TESTING IN SALINE WATER SOLUTION

To ensure the integrity of cable insulation tests are made immersing the cable into a conductive fluid, typically saline water. By using the water as one termination and the inner conductor as the other measurement of the isolation resistance can be made. Connection to the water can be made by using a conductive vessel as shown in Fig. 6. By using DB620 in "HT on Ground"-mode the vessel can be grounded ensuring good safety for the operator.

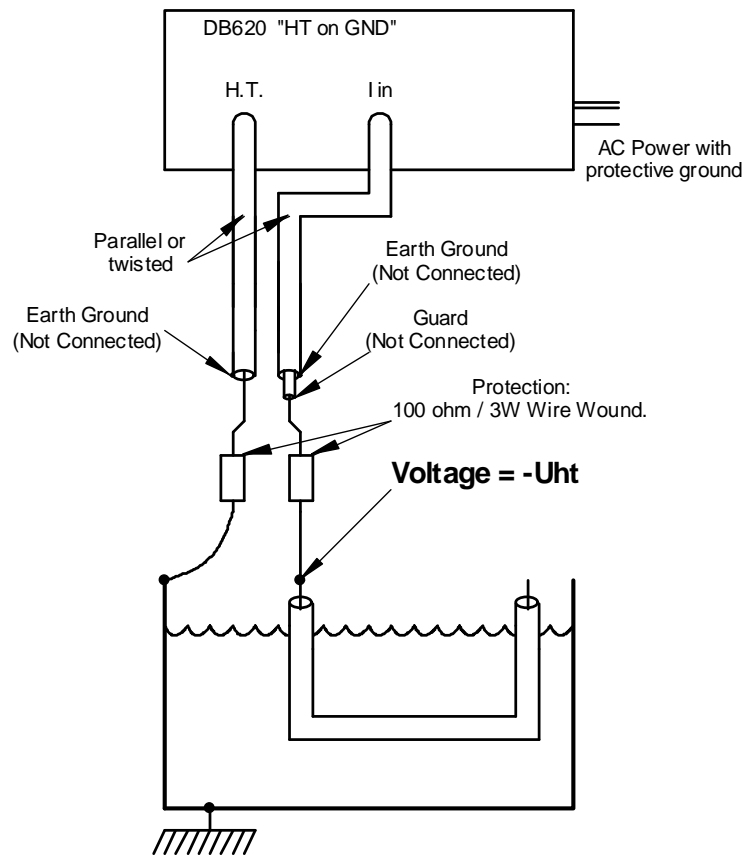


Fig. 6: IR measurement of cable insulation using DB620 in "HT on Ground"-mode.

Fig. 7 shows how to use the DB621/22/23/25 which do not have the feature of "HT on Ground"-mode. Here, the connection to the liquid is the high voltage, so precautions ensuring the isolation of the vessel or electrode must be made.

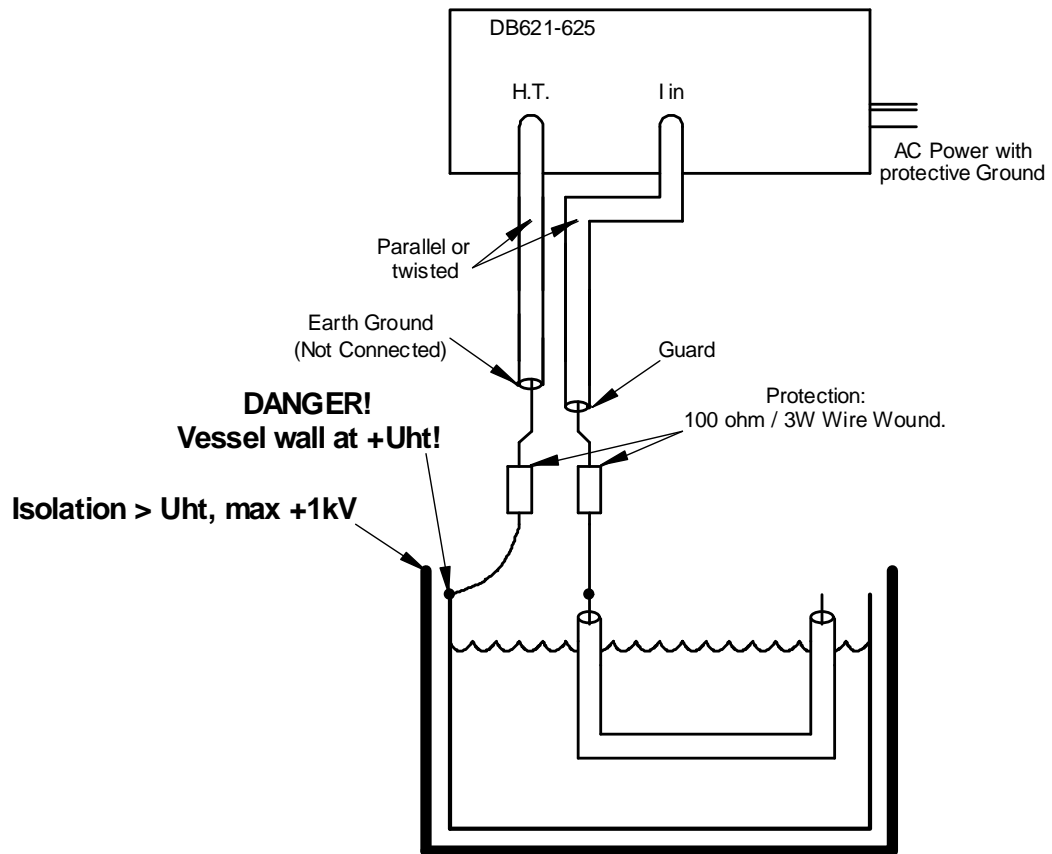


Fig. 7: IR measurement of cable insulation using DB621/22/23/25.

CHARGING AND DISCHARGING LARGE CAPACITIES

In most cases when measuring IR the DUT exhibit an electrical capacitance. This capacitance has to be fully charged before the IR is measured. Fig. 8 shows the voltage and the charge current when charging a capacitor of 6.8 uF to 100V with a HT current limit of 80mA and a total series resistance of 212ohm (12ohm in output resistance and 2 100ohm protective resistors).

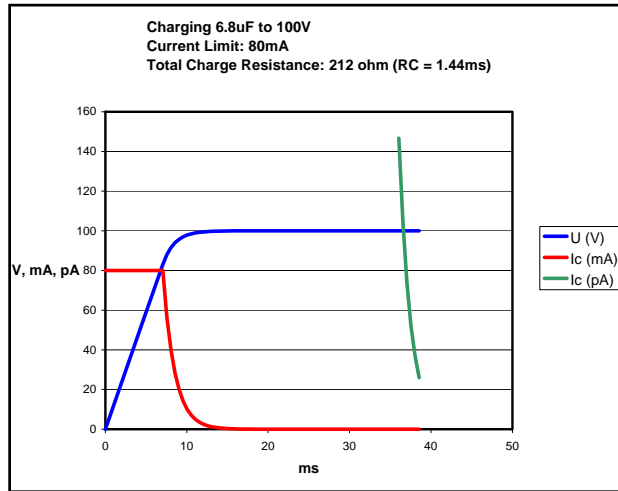


Fig. 8: Charge sequence.

In the first 7ms the voltage increase is linear due to the current limit. The linear charge time can be estimated from:

$$T_{Ch} = C \cdot \frac{U_{HT}}{I_{Limit}} \quad [2]$$

After the linear charge the current is limited by the series resistance and follows an exponential curve. In Fig. 8 the current is also shown in pA scale (green). However, for most isolators the charge time is not given by charging the capacity but from the effect of "dielectric absorption" (often referred to as "soaking"). It can be described with the equivalent shown in Fig. 9. Cds will typically have a value of 0.1 - 1% of C and the time constant of Rda and Cda will be app. 1 - 10 sec.

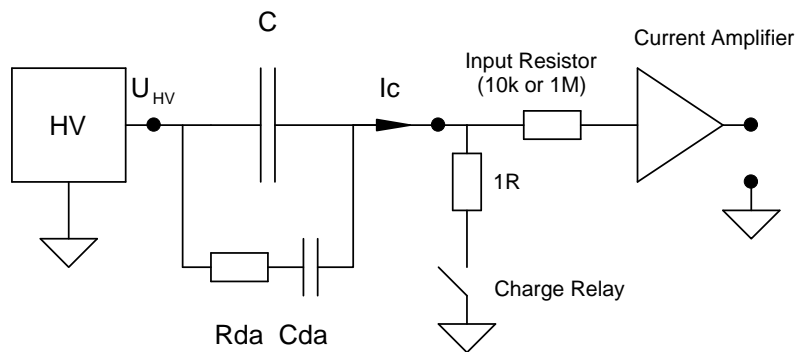


Fig. 9: Dielectric absorption.

This is why it is often required to apply the voltage for say 60 seconds before the measurement is made. The time from the capacity is charged until the measurement is made is often called dwell time. In some cases the dwell time is longer in order to ensure that no ionization in air or another isolator builds up resulting in arcing and flashover.

After the measurement the capacity has to be discharged. In the Danbridge Megohmmeter models with output voltages lower than 1kV this is done by switching the output to a 10kohm / 11W wire wound resistor. For voltages over 300V the total energy that can be absorbed by the resistor is 500J. The stored energy in a capacitor is calculated from:

$$E_c = \frac{1}{2} \cdot C \cdot U^2 \quad [3]$$

At 500V this limits the capacity that can be discharged by the internal resistor to 4mF. The discharge time can be found from:

$$t_{disch} = R_{disch} \cdot C \cdot \ln \frac{U_{start}}{U_{finish}} \quad [4]$$

Example: $R_{disch} = 10\text{kohm}$, $C = 4\text{mF}$, $U_{start} = 500\text{V}$, $U_{finish} = 5\text{V}$: $t_{disch} = 180 \text{ sec.} = 3 \text{ min.}$!

In the model DB625 5kV the internal discharge resistor is 100kohm / 35W. For voltages over 1500V the energy that can be absorbed by the resistor is 1500J. At 5000V this limits the capacity that can be discharged by the internal resistor to 120uF. For a capacity of this value the discharge time from 5000V to 5V is 80 seconds.

If larger energies than specified here have to be discharged or if the discharge time must be shortened it must be done with an external resistor.

WARNING: AFTER DISCHARGE THE CAPACITOR CAN REGAIN 1/10 OF THE TEST VOLTAGE DUE TO DIELECTRIC ABSORPTION IF LEFT WITH OPEN LEADS!

CONTROLLING MEASURE VOLTAGE RAMP

In some cases a requirement for controlling the ramp of the measure voltage applies. This can be done by using the fixed current limits build in to the HT supply. By charging a capacitor which is not part of the IR measure circuit the ramp is defined by the ramp control capacitor C_{ctrl} and the current limit. Fig. 10 shows the circuit.

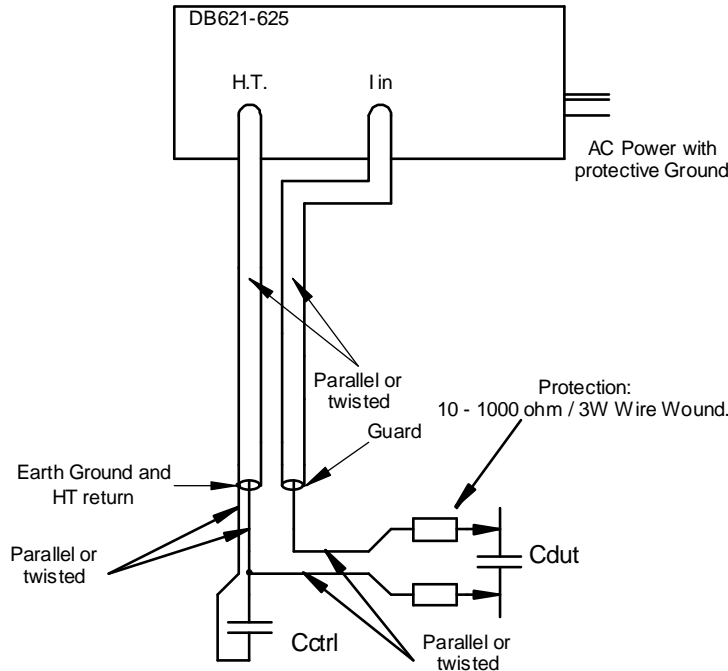


Fig. 10: Controlling Measure Voltage Ramp.

The ramp can be estimated from:

$$\frac{dU_{HT}}{dt} = \frac{I_{Limit}}{C_{filter} + C_{ctrl} + C_{DUT}} \quad [5]$$

where C_{filter} is the capacitance of the HT output filter, C_{ctrl} is the Ramp Control Capacitor and C_{DUT} is the capacitance of the device under test.

Example: The required ramp is 500V/s: set the current limit to 2mA and use a control capacitor that ensures a total capacitance of 4uF.

The fixed current limits of the Danbridge Megohmmeters are primarily designed to ensure safety and protection of the instrument. This means that they shut down faster than they recover giving rise to an (audible) oscillation. However, since the ramp control capacitance is normally much higher than the capacitance of the DUT, this should not cause problems. The current limit circuit is designed to give higher current at short circuit than at the maximum voltage. The ramp should therefore always be verified with other instrumentation like a storage oscilloscope with at HT probe or eq.

- ALWAYS USE THE HT SHIELD CONNECTION AS RETURN PATH OF THE CHARGE CURRENT!
- ALWAYS USE PROTECTIVE RESISTORS NEAR THE DUT!
- NEVER CONNECT THE GUARD TO EARTH GROUND.



RANGE SELECTION

Over the years Danbridge Megohmmeters have been delivered with 3-range and 4 range Current Measurement boards:

600-series:

3-range Current Measurement Boards:	1	1 pA - 10 nA
	2	2 nA - 1 uA
	3	0.2 uA – 1 mA

600- and 620-series:

4-range Current Measurement Boards:	1	1 pA - 10 nA
	2	2 nA - 100 nA
	3	20 nA - 10 uA
	4	2 uA - 1 mA

The correct range is established from measuring the leakage current on several known good and known bad components at the specified voltage and charge/dwell/soak time. The range to choose is the most sensitive range that do not lead to overflow at the upper limit of the leakage current. The upper limit is established from the measure voltage divided with the minimum insulation resistance: $I_{limit} = U_{ht} / IR_{,min}$.

Example: $U_{HT} = 100V$, $IR_{min} = 25Gohm \Rightarrow I_{leak,max} = 4nA$: Select Range 1.

ACCURACY

The Danbridge Megohmmeters have a stated accuracy of 2% in Resistance Mode, but this requires in some cases ideal test conditions in terms of external noise and measure setup. The resolution on the current measurement of 1pA means an uncertainty of 10% if the current is 10pA. Thus, the measure (leakage) current must be larger than 100pA if the accuracy should be maintained. If the expected Insulation Resistance is 1Tohm, the measure voltage must be larger than 100V: $100V / 1Tohm = 100pA$.

Danbridge order numbers for wire wound resistors:

10 ohm	5%	2W	4621000
100 ohm	5%	3W	4632700
1 kohm	5%	3W	4632500