STP01

Soil Temperature Profile Sensor

USER MANUAL

STP01 manual version 0606

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Hukseflux
Thermal Sensors

Warning:

Putting more than 15 volt across the heater of STP01 may result in permanent damage to the sensor.

Contents

List of symbols

Thermal diffusivity	a	m^2/s
Distance from the heater	r	m
Heating cycle time	H	s
Heating power per meter	Q	W/m
Thermal conductivity	λ	W/mK
Voltage output	U	V
Sensitivity of the thermocouple	E_T	V/K
Time	t	s
Temperature	T	K
Differential temperature	ΔT	K
Electrical resistance	R_e	Ω
Electrical resistance per meter	R_{em}	Ω/m

Subscripts

Property of thermocouple sensor	tc
Properties of the heater	heat
Property of the Pt-100	P
Property of the cold joints	c
Property before heating, at t = 0	0

Introduction

The STP01 is a sensor for very accurate measurement of temperature versus depth (also called “temperature gradient”) in the soil. A heating wire offers the possibility of self-testing, increasing the level of quality assurance. An experimental option is to determine soil thermal conductivity as a function of depth.

The measurement of soil temperature profiles has many applications, particularly in determining soil energy balance. STP01 contains 5 thermocouples, tc, (at 2, 5, 10, 20 and 50 cm depth, A to E) and one reference Pt100 temperature sensor (at 50 cm, E). The key item in the design is the central copper-nickel (CuNi) wire (5). By having the reference tc junction in the sensor and only measuring differential tc voltages (relative to the reference tc junction at 50 cm), the gradient accuracy is record breaking (down to +/- 0.02 degrees C) and cabling can be simple all copper (Cu) wire. As an extra, there is a heating wire incorporated (6) from I to II. The reaction of the tc’s to sudden heating (tc pulse response) is a test for sensor performance in the inaccessible environment.

The STP01 has several advantages over existing designs:

- high accuracy gradient measurement by accurate positioning of the tc joints (+/- 1mm), and measurement of tc voltage relative to the junction at 50 cm (+/- 0.02 K is achievable)
- high accuracy and stability of the relative distance between sensors (+/- 0.5 mm)
- thin, 0.6 mm only, (non disturbing) construction (contrary to conventional stick designs) does not disturb the thermal flow pattern
- sensor to logger cabling is all copper; easily extendable.
- easy quality assurance & servicing: self-test is possible by heating and looking at the pulse response, saving servicing time.

Wiring diagrams and programming for Campbell Scientific CR10X and CR1000 are available at Hukseflux.

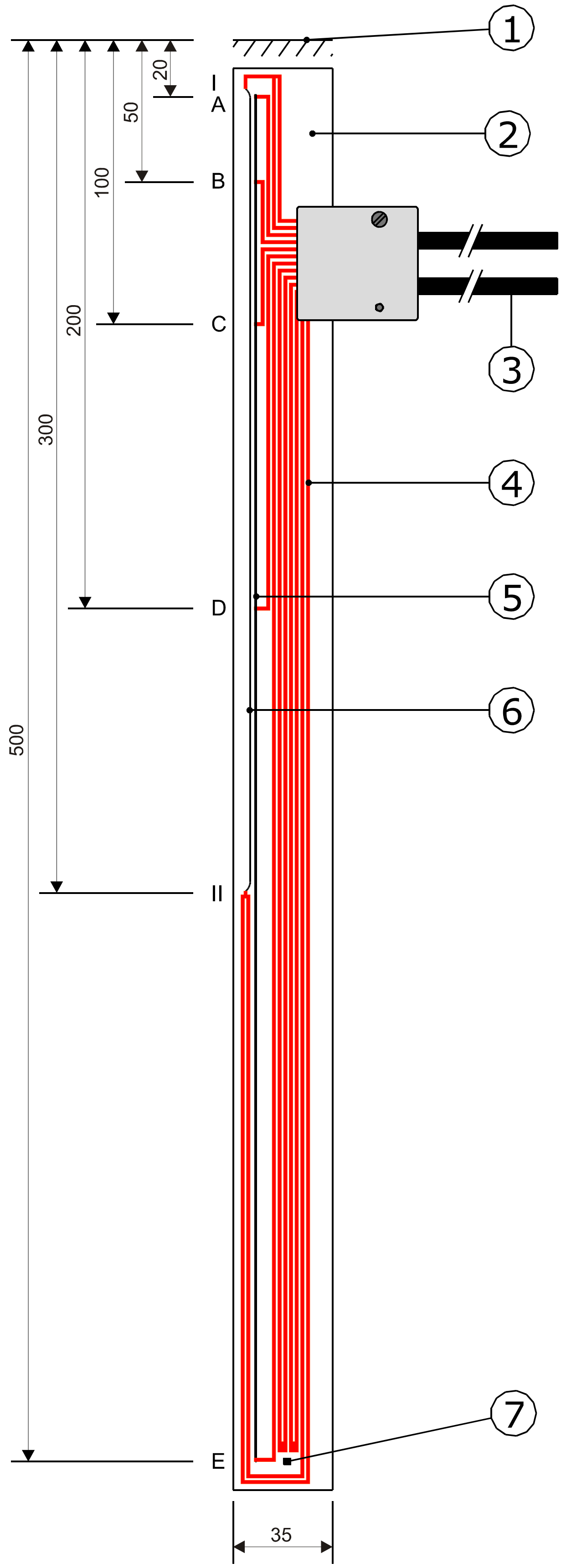

Figure 0.1 *Layout of STP01*
1 soil surface
2 sensor foil (0.6 mm thickness, 2.5 at Pt 100)
3 cables (5 m), extendable
4 copper leads
5 constantan wire for thermocouples
6 constantan wire for heater
7 Pt 100 (4 wire connection)
I and II: end of heating wire (2 times 2 wire connection) A, B, C, D and E: tc junctions

Wiring schedule:
1 heater power
2 heater measure
3 thermocouple 2 cm
4 thermocouple 5 cm
5 thermocouple 10 cm
6 thermocouple 20 cm
7 thermocouple 50 cm
8 Pt100 +
9 Pt100 +
10 Pt100 –
11 Pt100 –
12 heater power
13 heater measure
All dimensions are in mm.

1 Theory

The theory governing STP01 is quite simple. It is specially designed to measure thermal gradients in the soil. Usually this is done by a series of separate sensors. This method causes large uncertainty in positioning and also the accuracy of the measurement is typically rather low, because two absolute temperatures are measured, rather than one differential temperature.
STP01 has improved this. The accuracy in positioning and the accuracy of the temperature gradient measurement are typically a factor 2 better compared to using normal sensors.

The thermocouples can be treated like normal Copper-Constantan (type T) thermocouples, only taking into account that one has to measure between the wire attached to the joint at E and the others. The temperature at E is by definition equal to the temperature that is measured by the Pt100. (platinum temperature sensor, with 100 Ohms resistance at 0 degrees C) The Pt100 can be treated like any normal Pt100.

The primary purpose of the heating wire is to serve as a check whether or not everything is in good order. When giving a heating pulse, this will serve as a diagnosis of the entire system.

It is recommended to give a heating pulse at regular intervals, for example every 3 hours.
The experimental option of utilizing the heating pulse to analyze thermal conductivity of the surrounding soil, is treated in the appendix.

2 Specifications of STP01

STP01 soil temperature profile sensor is intended to measure temperature profiles in the soil in which it is inserted.
It can only be used in combination with a suitable measurement and control system.

GENERAL	
Suitable Media	Granular materials (grain size smaller than 0.2 mm) like soils
Temperature range	-30 to +70 degrees C
CE requirements	STP01 complies with CE directives
Options	Insertion tol IT01, Extended cable
SENSOR SPECIFICATIONS	
Thermocouples, tc:	Cu-CuNi (Type T)
Depths below soil surface (mm):	20, 50, 100, 200 & 500 +/-1
Reference junction:	Pt100 DIN class B
Required readout:	4 diff volt, 1 common ground, Pt100-4 wire
Thermocouple resistance:	5 ohm (nominal)
Sensor dimensions	Foil: 500 by 35 by 1 mm
Thickness (nominal)	1 mm (2.5 mm at Pt100)
Cable length	5 meters
Weight including 5 meters cable	0.3 kg
HEATER SPECIFICATIONS	
Heating power / m (Q):	1 W/m (nominal)
Resistance / effective length (nominal):	200 Ohms / 300 mm
Voltage input	9-15 VDC
Duration of the self test:	± 10 min at 0.3 Watt, typically once every 3 hours, at least once every 24 hours
Required readout:	1 diff volt
Average power consumption	0.05 Watt
CALIBRATION	
Calibration traceability	To thermocouple type T
Recommended recalibration interval	Every 2 years

Table 2.1 *List of STP01 specifications.*

3 Short user guide

The sensor should be installed following the directions of paragraph 4. Essentially this requires a datalogger and control system capable of switching, readout of voltages, and capability to perform calculations based on the measurement.

The first step that is described in paragraph 4 is and indoor test. The purpose of this test is to see if the system works. It can be done in a very simple way, just using a water bath.

4 Putting STP01 into operation

First test the sensor functionality by checking the impedance of the sensor and heater, and by checking if the sensor works, according to the following table:

Check the 4 wire connection of the heater. Use a multimeter at the 100 ohms range. Measure between two wires that are connected at the same end of the heater. The measurement will give the value of twice the cable resistance. Repeat at the other end of the heater. Take down the measured value. This is the cable resistance.	The typical impedance of the wiring is 0.1 ohm/m. A typical impedance should be 10 ohms for the total resistance of two wires (back and forth) of each 5 meters. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the heater impedance. Use a multimeter at the 1000 ohms range. Measure between two wires that are connected at opposite ends of the heater. Subtract the resistance value that was measured during the previous measurement. What is left is the heater resistance.	This should be between about 200 ohms. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the impedance of the thermocouples. Use a multimeter at the 100 ohms range. Measure at the output. Subtract the resistance value of the wiring that was measured during the previous measurement. What is left is the thermocouple resistance. Warning: during this part of the test, please put the sensor in a thermally quiet surrounding, holding the sensor foil in still air.	A typical sensor impedance should be between 4 and 5 ohms. If a careful measurement is done, one can see differences between wire 7 and 6, 7 and 5, 7 and 4, 7 and 3. Infinite indicates a broken circuit, zero indicates a short circuit.
Check if the sensor reacts to a heating pulse. Use a multimeter at the millivolt range. Measure at the sensor output. Generate a signal by connecting a battery or power source to the heater.	The thermocouples should react by generating a millivolt output signal.

Table 4.1 *Checking the functionality of the sensor. The procedure offers a simple test to get a better feeling how STP01 works, and a check if the sensor is OK.*

The STP01 should be connected to the measurement and control system as in the chapter on the electrical connection.
The programming of dataloggers is the responsibility of the user.
Please contact the supplier to see if directions for use with your system are available.

5 Installation of STP01

STP01 is generally installed at the location where one wants to measure.

The more the foil of STP01 is in contact with the surrounding soil, the better.
Usually it is sufficient to prepare the path below the connector block simply by temporarily inserting a knife. When the knife is taken out, the path has much less resistance to insertion of the sensor than the same medium in its original state.
In meteorological applications, permanent installation is preferred. The sensor orientation should be such that the flow of water through the soil is not obstructed. It is recommended to fix the location of the sensor by attaching a metal pin to the cable. Attachment of the pin to the cable can be done using a tie-wrap.

Table 5.1 *General rules for installation of STP01.*

6 Maintenance of STP01

Once installed, STP01 is essentially maintenance free. Usually errors in functionality will appear as unreasonably large or small signals.
As a general rule, this means that a critical review of the measured data is the best form of maintenance.

At regular intervals the quality of the cables can be checked.

On a 2 yearly interval the calibration can be checked.

7 Requirements for data acquisition and control

Wiring diagrams and programming for Campbell Scientific CR10X and CR1000 are available at Hukseflux.

Capability to measure	Microvolt signals from the thermocouples and to measure the Pt100, and optionally to measure the voltage across the heater.
Capability of switching	12 volt at 0.1A
Requirements for power supply of the heater	Capability to supply 12 Volt, at 0.1 A In meteorological applications, this is typically done for 10 minutes every 3 hours. The average required power across the day in this case is 0.05 Watt
Capability for the datalogger or the software	To store data.

Table 7.1 *Requirements for data acquisition and control.*

8 Electrical connection of STP01

In order to operate, STP01 should be connected to a measurement and control system as described above. The numbering of wires is shown in figure 0.1. For the purpose of making a correct measurement of the Pt100 there is a 4 –wire connection. Two wires carry the current, the others are used for the measurement. Through these wires there is a negligible current, so that there is no voltage drop across the wires, and the true voltage across the heater wire is measured.

The measurements are done between wires 7 and 6, 7 and 5, 7 and 4 and 7 and 3.
Wire number 7 is common between all thermocouples.

Warning:
putting more than 15 volt across the heater may result in permanent damage to the sensor

Wire number	Cable	Color code
1 heater power	Lower	Grey
2 heater measure	Lower	White
3 thermocouple 2	Upper	Blue
4 thermocouple 5	Upper	White
5 thermocouple 10	Upper	Red
6 thermocouple 20	Upper	Green
7 thermocouple 50	Upper (common wire for all thermocouple measurements)	Brown
8 Pt100	Lower	Green
9 Pt100	Lower	Red
10 Pt100	Lower	Blue
11 Pt100	Lower	Brown
12 heater power	Lower	Pink
13 heater measure	Lower	Yellow

Table 8.1 *Color code of STP01 in the standard configuration.*

Wiring diagrams and programming for Campbell Scientific CR10X and CR1000 are available at Hukseflux.

9 Appendices

9.1 Calibration of STP01

Calibration of STP-01 can be done in any laboratory that has the necessary electronic equipment. The procedure for calibration is as follows:

First put the sensor completely in a temperature bath of one and the same temperature, preferably around 20 degrees. The Pt 100 should be calibrated in this condition. The thermocouple differential signals should read zero,

The second step is to put the Pt 100 and the “thermocouple 50” outside the bath. They should however be put in a stable thermal environment like a water bath that deviates from 20 degrees, for example at 10 degrees. This temperature can now be measured using the Pt 100. The accuracy of the differential temperature can now be determined. The measurements can be done as usual between 7 and 6, 7 and 5, 7 and 4 and 7 and 3.

9.2 Cable extension for STP01

It is a general recommendation to keep the distance between datalogger and sensor as short as possible. Cables generally act as a source of distortion, by picking up capacitive noise. STP01 cable can however be extended without any problem to 100 meters. If done properly, the sensor signal, although small, will not degrade, because the sensor impedance is very low. Also the 4 wire connection of the heater is immune to cable extension.
Cable and connection specifications are summarized below.

Cable:	Two 8-wire shielded, copper core
Core resistance	0.1 Ω/m or lower
Outer diameter	(preferred) 5 mm
Outer sheet	(preferred) polyurethane (for good stability in outdoor applications).
Connection:	solder the new cable core and shield to the original sensor cable, and make a waterproof connection, or use gold plated waterproof connectors.

Table 9.2.1 *Specifications for cable extension of STP01*

9.3 Trouble shooting

This paragraph contains information that can be used to make a diagnosis whenever the sensor does not function.

It is recommended to start any kind of trouble shooting with a simple check of the sensor and heater impedance, and a check to see if the thermopile gives a signal.

Check the 4 wire connection of the heater. Use a multimeter at the 100 ohms range. Measure between two wires that are connected at the same end of the heater. The measurement will give the value of twice the cable resistance. Repeat at the other end of the heater. Take down the measured value. This is the cable resistance.	The typical impedance of the wiring is 0.1 ohm/m. A typical impedance should be 10 ohms for the total resistance of two wires (back and forth) of each 5 meters. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the heater impedance. Use a multimeter at the 1000 ohms range. Measure between two wires that are connected at opposite ends of the heater. Subtract the resistance value that was measured during the previous measurement. What is left is the heater resistance.	This should be between about 200 ohms. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the impedance of the thermocouples. Use a multimeter at the 100 ohms range. Measure at the output. Subtract the resistance value of the wiring that was measured during the previous measurement. What is left is the thermocouple resistance. Warning: during this part of the test, please put the sensor in a thermally quiet surrounding, holding the sensor foil in still air.	A typical sensor impedance should be between 4 and 5 ohms. If a careful measurement is done, one can see differences between wire 7 and 6, 7 and 5, 7 and 4, 7 and 3. Infinite indicates a broken circuit, zero indicates a short circuit.
Check if the sensor reacts to a heating pulse. Use a multimeter at the millivolt range. Measure at the sensor output. Generate a signal by connecting a battery or power source to the heater.	The thermocouples should react by generating a millivolt output signal.

Table 9.3.1 *A copy of the table 4.1. Checking the functionality of the sensor. The procedure offers a simple test to get a better feeling how STP01 works, and a check if the sensor is OK.*

No signal from the sensor	Check the sensor impedance as in table 9.3.1. This can also be done while the sensor is still in place
	Check the data acquisition system by applying an artificially generated voltage to the input. Preferably a millivolt generator s used for this purpose.
	Check the heater connection and impedance
	Check the functionality of the heater by putting it on. When it is on, check the voltage across the heater.
	Check the sensor connection
Signal too high or too low	Check the data acquisition system by applying an artificially generated voltage to the input. Preferably a millivolt generator s used for this purpose.
	Put on the heater. Measure the voltage across the heater. This should be between around 12 Volts. Check the sensor output in air with the heater on for example between wires 7 and 3. This should be in the order of magnitude of several microvolts. One can also put the thermocouple at E in cold water and another in a warm environment, and measure the output.
	Check the zero level of the data acquisition system by putting a 50 ohm resistor in place of the thermocouples. The data acquisition system should read less than 5 microvolts. Now put the heater on. The signal should not react to this by more than 5 microvolts. If there is a larger reaction, there is a ground loop from the heater to the sensor. Check the electrical connection.
Signal shows unexpected variations	Check is there are no large currents in your system which can cause a ground loop. If these are there, switch them off, and see if any of these is causing the disturbance.
	Check the surroundings for large sources of electromagnetic radiation. Radar installations, microwave emitters, etc.
	Inspect the sensor itself. The surface should be smooth and have no scratches.

Table 9.3.2 *Extensive checklist for trouble shooting.*

9.4 Estimating thermal conductivity of the soil

When using the heater, the tc pulse response can be used to calculate soil thermal conductivity at 3 depths; 5, 10 and 20 cm. The well established thermal needle or non-steady-state probe technique is applicable.

The possibility to perform this measurement is an experimental option and the measurement accuracy is not specified by Hukseflux.

The temperature field around a heating wire that is switched on at t = 0 remaining constant power from that moment on, is a function of sensor geometry as well as soil properties.

For large t, the temperature T signal slope becomes independent from the thermal diffusivity, so that

$$T = (Q / 4 \cdot \pi \cdot \lambda) \cdot (-0.577 + \ln (4 \cdot a \cdot t / r^2))$$
$$\text{for } (4 \cdot a \cdot t) / r^2 >> 1 \qquad 9.4.1$$

This property is often used to detect changes in the thermal conductivity.

By curve fitting one can find the thermal conductivity λ.

$$Q = (U_{heat})^2 / R_{em\ heat} \qquad 9.4.2$$

Please ask for more information at Hukseflux.

9.5 Thermocouple reference table Type T.

International thermocouple reference table for copper / copper-nickel.
To IEC 584.1 : 1995 / BS EN 60584.1 Part 5 : 1996
This standard is based upon the International Temperature Scale of 1990 (ITS-90). Temperatures are expressed in degrees Celsius (t_{90}) and the emf outputs in microvolts (µV).
Note: °C(t_{90}) denotes a temperature value expressed in degrees Celsius based upon the International Temperature Scale of 1990 (Acronym ITS-90)

°C(t_{90})	0	1	2	3	4	5	6	7	8	9
-40	-1475	-1510	-1545	-1579	-1614	-1648	-1683	-1717	-1751	-1785
-30	-1121	-1157	-1192	-1228	-1264	-1299	-1335	-1370	-1405	-1440
-20	-757	-794	-830	-867	-904	-940	-976	-1013	-1049	-1085
-10	-383	-421	-459	-496	-534	-571	-608	-646	-683	-720
-0	0	-39	-77	-116	-154	-193	-231	-269	-307	-345
0	0	39	78	117	156	195	234	273	312	352
10	391	431	470	510	549	589	629	669	709	749
20	790	830	870	911	951	992	1033	1074	1114	1155
30	1196	1238	1279	1320	1362	1403	1445	1486	1528	1570
40	1612	1654	1696	1738	1780	1823	1865	1908	1950	1993
50	2036	2079	2122	2165	2208	2251	2294	2338	2381	2425
60	2468	2512	2556	2600	2643	2687	2732	2776	2820	2864
70	2909	2953	2998	3043	3087	3132	3177	3222	3267	3312
80	3358	3403	3448	3494	3539	3585	3631	3677	3722	3768
90	3814	3860	3907	3953	3999	4046	4092	4138	4185	4232

Table 9.5.1 *Absolute thermocouple e.m.f. in microvolts with the reference junction at 0℃.*

9.6 Platinum resistance thermometry.

Resistance vs temperature relationship over the range -50°C to +140°C for platinum resistance thermometer detector elements.

°C(t_{90})	0	1	2	3	4	5	6	7	8	9
-40	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70
-30	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67
-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55
-0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15
40	115.54	115.93	116.31	116.70	117.08	117.47	177.86	118.24	118.63	119.01
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86
60	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69
70	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52
80	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33
90	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13

Table 9.6.1 *resistance values of Pt100*

9.7 Temperature/resistance of prt's /Pt100

The temperature/resistance relationships that should be used are as follows:
for the range -200°C to 0°C: $R_t = R_0[1+At+Bt^2+C(t-100°C)t^3]$
for the range °C to 850°C: $R_t = R_0[1+At+Bt^2]$
For resistance thermometers satisfying the above relationships, the temperature coefficient a, defined as: $\alpha = (R_{100} - R)/(100 x R_0)$ has the value 0.00385 °C^{-1} where R_{100} is the resistance at 100°C; R_0 is the resistance at 0°C. (For calculation purposes it is useful to use the exact value of 0.00385055°C^{-1}.)

9.8 Tolerance values for 100 ohm elements.

Tolerance IEC 751:1983 (BS EN 60751:1996)
Class B

± 0.3 °C at 0 °C
± 0.8 °C at 100 °C

9.9 CE declaration of conformity

According to EC guidelines 89/336/EEC, 73/23/EEC and 93/68/EEC

We:	Hukseflux Thermal Sensors
Declare that the product:	STP01

Is in conformity with the following standards:

Emissions:	Radiated:		EN 55022: 1987	Class A
	Conducted:		EN 55022: 1987	Class B
Immunity:	ESD	IEC 801-2;	1984	8kV air discharge
	RF	IEC 808-3;	1984	3 V/m, 27-500 MHz
	EFT	IEC 801-4;	1988	1 kV mains, 500V other

Delft,
January 2006