SCANIVALVE DTS3250 UNCERTAINTY ANALYSIS

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Abstract

This report provides uncertainty estimates associated with the Scanivalve model DTS3250 32 channel temperature scanner (with screw terminals). These analyses apply to the scanner itself, and do not include uncertainties of the thermocouples and/or extension wire that are part of the customer's infrastructure. Also excluded are installation uncertainty sources, such as mounting the units in a dynamic thermal environment, or subjecting the DTS to temperature gradients. The 2 SIGMA uncertainty of the DTS3250/32 channel scanner, $U_{95,}$ is 0.24°C.

Introduction

The DTS3250 is a precision thermocouple scanner available in 16, 32 and 64 channel units. It utilizes a solid aluminum Uniform Temperature Reference (UTR) block as the cold junction for 16 thermocouple inputs. The UTR consists of a thick, rectangular, aluminum plate with isolated brass slugs, serving as connection points for the thermocouples. The temperature of the UTR is measured by two 100 Ohm platinum RTD's, one screwed into each end of the UTR. The UTR temperature, combined with the voltages measured across the thermocouple leads are used to calculate the thermocouple temperature. The DTS3250 incorporates the ITS-90 (International Temperature Scale) conversion tables for data conversion to Engineering Units.

Picture below is model DTS3250/32 without the insulating cover.

Analysis Assumptions

Because there are many variables such as thermocouple type, thermocouple voltage ranges, operating environment, installation and common mode noise, we have made the following assumptions. Making these assumptions limited our study and allowed us to make a thorough investigation of the measurement uncertainties.

1. The analysis is limited to the Type K thermocouple.
2. The input signal from the Type K thermocouple is within the range of -6 to +50 mV. This corresponds to temperature measurements of -208 to 1230 C.
3. The input signal from the test article is low frequency, in the range of DC to 1 kHz.
4. Channel to channel crosstalk is negligible.
5. The ambient operating temperature range of the DTS is -5°C to 60°C.

Test Setup and Specific Environment

1. Testing was performed using 18 model DTS3250/32Tx 32 channel thermocouple scanners. This number was selected as statistically significant. Each DTS3250/32Tx has two UTR's, two individual A/D boards and four RTD's.
2. Testing was performed in Scanivalve's laboratory at a controlled temperature of 22°C, over a one week period.
3. Each DTS3250/32Tx was configured the same. Scan configurations were set as follows:

SET PERIOD 200 (µs, time between channels)
SET AVG 4 (number of averages per frame of data)
SET FPS 0 (continuous scan mode)
SET XSCANTRIG 0 (hardware trigger disabled)
SET FORMAT 0 (sets scrolling data format)
SET BIN 0 (sets ASCII data)
SET UNITS C or V (depending on the test)

UTR Temperature Uncertainties

There are two UTRs in a 32 channel DTS3250. Each UTR block has a PT-100 platinum 100 Ohm RTD embedded in each end of the UTR. The UTR uncertainty propagates directly into the thermocouple conversion calculations. The RTD uncertainties have a number of sources.

1. Voltage measurement (A/D) uncertainty.
2. Uncertainty in RTD calibration. (Callendar Van Dusen correction).
3. Excitation current uncertainty.
4. Uncertainty of converting A/D readings to temperature.
5. Non uniformity of UTR due to self heating of DTS.

We chose to evaluate the first four sources with an end-to-end measurement.

Each RTD was validated by being submerged in a Fluke 7102 calibration bath while being scanned by DTS. The bath temperature was monitored with a Fluke 1529 Precision Thermometer and a calibrated RTD.
These temperatures were -5°C, 0°C, 20°C, 40°C and 60°C, which cover the entire operating temperature range of the DTS3250. The readings were logged and are shown in Appendix C. A summary of these errors and uncertainties is shown below, all in degrees C.

	-5°C	0°C	20°C	40°C	60°C
Mean	-0.022	-0.029	-0.041	-0.044	-0.043
Sigma σ	0.032	0.026	0.030	0.027	0.030
Uncertainty	0.039	0.039	0.051	0.051	0.052

Summary of all of the RTD errors at all 5 temperatures (°C):

Mean	-0.038
Sigma σ	0.030
Uncertainty	0.048

Thermocouple Voltage Uncertainties

We chose to evaluate the thermocouple voltage uncertainty with an end-to-end measurement. Each thermocouple channel has a separate 22 bit A/D, so they can be considered independent error sources.

Each channel was connected individually to a Fluke 5700 voltage standard. The applied voltages were -6, 0, 25, and 50mV. The voltage output of the DTS3250 was then measured and compared to the Fluke 5700 voltage standard. The error difference was documented and shown on Appendix B. A summary of all 32 channels of the errors and uncertainty for these errors is shown below.

Error= Measured Value – True Value (Applied Voltage, units of mV)

	-6 mV	0 mV	25 mV	50 mV
Mean (all channels)	-0.003	-0.003	-0.002	-0.001
Sigma σ	0.002	0.002	0.003	0.004
Uncertainty	0.004	0.004	0.003	0.004

Total Analog Uncertainty

	Mean	Sigma σ	U_{95} Uncertainty
mV	-0.002	0.003	0.004
Deg C	-.05	0.07	0.09

UTR Gradient errors

The UTR temperature is determined by averaging the two RTDs installed at each end of the UTR. This average temperature is used as the cold junction reference temperature of the UTR. Self-heating within the DTS may introduce gradients in the UTR. The error measured was the difference between the measured value at the +Terminal of each channel, and reported value (the average of the two RTDs). Appendix D has the detailed measurements. A summary of the UTR gradient errors are shown below.

Error versus T/C input position (°C)

	Tx Inputs 1-16	Tx Inputs 17-32
Mean	-0.031	-0.028
Sigma σ	0.030	0.033
Uncertainty	0.043	0.033

Conversion of A/D readings to temperature (ITS-90 conversion tables)

The DTS3250 has the ITS-90 conversion tables saved in memory for the conversion from voltage to temperature. These conversion tables were generated by a program traceable to NIST (National Institute of Standards and Technology). Because the DTS3250 does not have an actual ice point reference, the offset temperature of the UTR must be corrected for in order to generate a voltage reading applicable to the standard IST-90 conversion tables. The DTS3250 uses the tables directly for the EU conversion. At the higher temperatures, the table appears to be more accurate than utilizing a polynomial for the conversion. However, for this uncertainty analysis we looked at the worst case of using a polynomial and estimated an uncertainty of ±0.025°C. This estimated uncertainty number was derived from the book “Fundamentals of Pressure, Temperature, and Flow” by Robert Benedict.

Summary of Errors:

ERROR COMPONENT	STANDARD UNCERTAINTY, U, in °C
Analog Voltage Measurement (See Appendix B)	0.09
UTR RTD Error (See Appendix C)	0.05
UTR Gradient (See Appendix D)	0.05
Interpolation Error (Estimated)	0.025
Fluke 7102	0.012
Fluke 1529	0.003
RDF 29259	0.014
Fluke 5700A (See Appendix A)	0.013
Root Sum Square	0.119
MULTIPLIER for 95% Coverage	*k* = 2
EXPANDED UNCERTAINTY, 95%, 2 SIGMA (U_{95})	**0.24°C**

Conclusion

When all of the errors are taken into account, the 2 SIGMA measurement uncertainty of the DTS3250/32Tx is ±0.239°C. Scanivalve data sheets specifies the accuracy of the model DTS3250 as ±.25°C in a constant ambient environment and ±.5°C when ambient temperature is changing. Since the test data was obtained in a constant temperature environment, the measurement uncertainty analysis of ±0.239°C is below Scanivalve's specified ±.25°C.

APPENDIX A – EQUIPMENT SPECIFICATIONS

Fluke 7102 Calibration Bath
- Uniformity +/- .02°C
- Rectangular Distribution
- Standard Uncertainty 0.02 / √3= 0.012°C

Fluke 1529 Precision Thermometer
- Accuracy +/- .006°C
- Rectangular Distribution
- Standard Uncertainty 0.006 / √3= 0.003°C

RDF 29259-T01-C-48 100 Ohm Platinum RTD
- Calibrated Uncertainty +/- 0.025 C
- Rectangular Distribution
- Standard Uncertainty 0.025 / √3= 0.014°C

FLUKE 5700A Voltage Reference

Fluke 5700A data sheet specifies one year 95% uncertainty of 7.0ppm of setting + 0.6uV (220 mV scale). Maximum calibration point is 70 mV.

- 70,000 * (7/1E6) + 0.6 = 1.09 uV
- Normal Distribution
- Standard Uncertainty = $U_{95}/2$ = 0.545 uV
- For Type K thermocouple, 0.545/41 = 0.013°C

APPENDIX B - ANALOG ERRORS

Chan	-6 mV	0 mV	25 mV	50 mV
1	-6.007	-0.006	24.993	49.996
2	-6.002	-0.001	24.998	49.999
3	-6.004	-0.004	24.999	50.001
4	-6.001	-0.001	25.001	50.003
5	-6.003	-0.003	24.997	49.997
6	-6.004	-0.004	24.998	50
7	-6.009	-0.009	24.992	49.992
8	-6.006	-0.007	24.994	49.994
9	-6	-0.001	25	50
10	-6.003	-0.003	25	50.004
11	-6.003	-0.004	24.999	50.001
12	-6.001	0	25.001	50.003
13	-6.004	-0.003	25.001	50.003
14	-6.003	-0.002	25	50.002
15	-6.003	-0.002	24.998	49.998
16	-6.006	-0.006	24.993	49.991
17	-6.002	-0.003	24.996	49.997
18	-6.004	-0.005	24.996	49.997
19	-6.001	-0.002	24.999	50
20	-6.001	0	25.001	50.002
21	-6.002	-0.002	25.003	50.006
22	-6.001	-0.002	24.999	50
23	-6.004	-0.004	24.995	49.994
24	-6.004	-0.005	24.996	49.998
25	-6.002	-0.002	24.998	50
26	-6.002	-0.003	24.999	50.001
27	-6.004	-0.004	24.999	50
28	-6.002	0	25.001	50.003
29	-6.005	-0.005	24.996	49.997
30	-6.005	-0.005	24.996	49.998
31	-6.001	-0.001	24.999	49.999
32	-6.002	-0.002	25.001	50.004

DEG C = mV/0.041

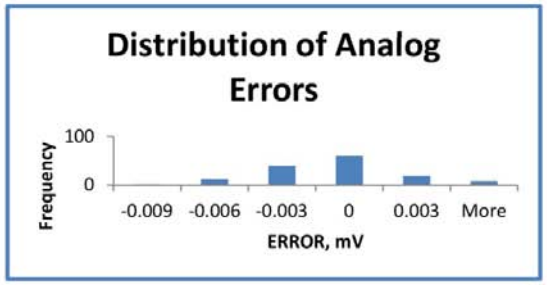
ERROR = Measured Value - True Value				
-6 mV	0 mV	25 mV	50 mV	
-0.007	-0.006	-0.007	-0.004	
-0.002	-0.001	-0.002	-0.001	
-0.004	-0.004	-0.001	0.001	
-0.001	-0.001	0.001	0.003	
-0.003	-0.003	-0.003	-0.003	
-0.004	-0.004	-0.002	0	
-0.009	-0.009	-0.008	-0.008	
-0.006	-0.007	-0.006	-0.006	
0	-0.001	0	0	
-0.003	-0.003	0	0.004	
-0.003	-0.004	-0.001	0.001	
-0.001	0	0.001	0.003	
-0.004	-0.003	0.001	0.003	
-0.003	-0.002	0	0.002	
-0.003	-0.002	-0.002	-0.002	
-0.006	-0.006	-0.007	-0.009	
-0.002	-0.003	-0.004	-0.003	
-0.004	-0.005	-0.004	-0.003	
-0.001	-0.002	-0.001	0	
-0.001	0	0.001	0.002	
-0.002	-0.002	0.003	0.006	
-0.001	-0.002	-0.001	0	
-0.004	-0.004	-0.005	-0.006	
-0.004	-0.005	-0.004	-0.002	
-0.002	-0.002	-0.002	0	
-0.002	-0.003	-0.001	0.001	
-0.004	-0.004	-0.001	0	
-0.002	0	0.001	0.003	
-0.005	-0.005	-0.004	-0.003	
-0.005	-0.005	-0.004	-0.002	
-0.001	-0.001	-0.001	-0.001	
-0.002	-0.002	0.001	0.004	
-0.003	-0.003	-0.002	-0.001	AVG
0.002	0.002	0.003	0.004	SIGMA
0.004	0.004	0.003	0.004	uc

NOTE: The uncertainty is flat across the inputs

COMPOSITE			
	AVG	SIGMA	uc
mV	-0.002	0.003	0.004
Deg C	-0.05	0.07	0.09

NOTE: This is the total analog uncertainty in degrees C

Bin	*Frequency*
-0.009	2
-0.006	12
-0.003	39
0	60
0.003	19
More	8



APPENDX C - RTD ERRORS

ERROR is defined as the difference between a measured value and the truth. For the RTD, truth is the Calibration Temperature

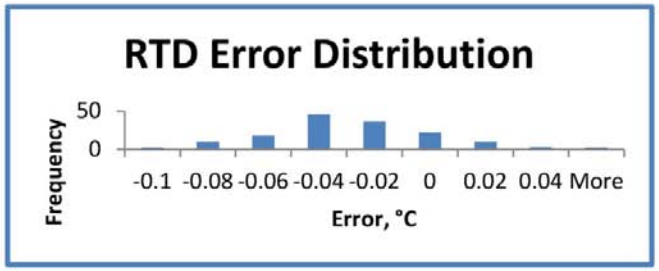
	RTD Temp	Cal Temp	ERROR	RTD Temp	Cal Temp	ERROR	RTD Temp	Cal Temp	ERROR	RTD Temp	Cal Temp	ERROR	RTD Temp	Cal Temp	ERROR
DTS SN: 1016	-5.01	-4.953	-0.057	-0.01	-0.054	0.044	19.92	20.01	-0.09	39.82	39.919	-0.099	59.71	59.794	-0.084
DTS SN: 1016	-5	-4.953	-0.047	0.01	0.054	-0.044	19.92	20.01	-0.09	39.82	39.919	-0.099	59.71	59.794	-0.084
DTS SN: 1159	-4.91	-4.874	-0.036	0.07	0.114	-0.044	19.96	20.015	-0.055	39.85	39.913	-0.063	59.72	59.786	-0.066
DTS SN: 1159	-4.89	-4.874	-0.016	0.09	0.114	-0.024	19.97	20.015	-0.045	39.85	39.913	-0.063	59.69	59.786	-0.096
DTS SN: 1160	-4.85	-4.874	0.024	0.1	0.114	-0.014	19.95	20.015	-0.065	39.87	39.913	-0.043	59.73	59.786	-0.056
DTS SN: 1160	-4.92	-4.874	-0.046	0.06	0.114	-0.054	19.96	20.015	-0.055	39.86	39.913	-0.053	59.72	59.786	-0.066
DTS SN: 1161	-4.88	-4.892	0.012	0.1	0.101	-0.001	19.99	20.12	-0.13	39.88	39.907	-0.027	59.72	59.784	-0.064
DTS SN: 1161	-4.89	-4.892	0.002	0.09	0.101	-0.011	19.99	20.012	-0.022	39.86	39.907	-0.047	59.71	59.784	-0.074
DTS SN: 1162	-4.95	-4.892	-0.058	0.07	0.101	-0.031	20.04	20.012	0.028	39.88	39.907	-0.027	59.74	59.784	-0.044
DTS SN: 1162	-4.94	-4.892	-0.048	0.05	0.101	-0.051	19.96	20.012	-0.052	39.84	39.907	-0.067	59.69	59.784	-0.094
DTS SN: 1168	-4.93	-4.904	-0.026	0.06	0.097	-0.037	19.95	20.016	-0.066	39.83	39.906	-0.076	59.72	59.777	-0.057
DTS SN: 1168	-4.93	-4.904	-0.026	0.07	0.097	-0.027	19.99	20.016	-0.026	39.87	39.906	-0.036	59.74	59.722	0.018
DTS SN: 1170	-4.93	-4.904	-0.026	0.05	0.097	-0.047	19.96	20.016	-0.056	39.84	39.906	-0.066	59.73	59.777	-0.047
DTS SN: 1170	-4.9	-4.904	0.004	0.09	0.097	-0.007	20	20.016	-0.016	39.89	39.906	-0.016	59.78	59.777	0.003
DTS SN: 1166	-4.94	-4.896	-0.044	0.04	0.083	-0.043	20	20.017	-0.017	39.9	39.908	-0.008	59.77	59.774	-0.004
DTS SN: 1166	-4.93	-4.896	-0.034	0.04	0.083	-0.043	19.97	20.017	-0.047	39.86	39.908	-0.048	59.76	59.774	-0.014
DTS SN: 1165	-4.96	-4.896	-0.064	0.02	0.083	-0.063	19.98	20.017	-0.037	39.89	39.908	-0.018	59.75	59.774	-0.024
DTS SN: 1171	-4.83	-4.901	0.071				20.2	20.187	0.013	39.2	39.188	0.012	58.28	58.277	0.003
DTS SN: 1171	-4.9	-4.901	0.001				20.17	20.187	-0.017	39.16	39.188	-0.028	58.25	58.277	-0.027
DTS SN: 1172	-4.93	-4.901	-0.029				20.15	20.187	-0.037	39.14	39.188	-0.048	58.23	58.277	-0.047
DTS SN: 1172	-4.92	-4.901	-0.019				20.14	20.187	-0.047	39.14	39.188	-0.048	58.22	58.277	-0.057
DTS SN: 1167							20.15	20.182	-0.032	39.14	39.178	-0.038	58.24	58.273	-0.033
DTS SN: 1167							20.14	20.182	-0.042	39.14	39.178	-0.038	58.24	58.273	-0.033
DTS SN: 1169							20.15	20.182	-0.032	39.14	39.178	-0.038	58.23	58.273	-0.043
DTS SN: 1169							20.14	20.182	-0.042	39.13	39.178	-0.048	58.23	58.273	-0.043
DTS SN: 1164							20.09	20.18	-0.09	39.11	39.212	-0.102	58.24	58.324	-0.084
DTS SN: 1164							20.16	20.18	-0.02	39.17	39.212	-0.042	58.28	58.324	-0.044
DTS SN: 1163							20.12	20.18	-0.06	39.15	39.212	-0.062	58.28	58.324	-0.044
DTS SN: 1163							20.14	20.18	-0.04	39.16	39.212	-0.052	58.26	58.324	-0.064
DTS SN: 1173							20.16	20.177	-0.017	39.19	39.203	-0.013	58.3	58.312	-0.012
DTS SN: 1173							20.15	20.177	-0.027	39.18	39.203	-0.023	58.29	58.312	-0.022
DTS SN: 1174							20.1	20.177	-0.077	39.14	39.203	-0.063	58.25	58.312	-0.062
DTS SN: 1174							20.15	20.177	-0.027	39.15	39.203	-0.053	58.26	58.312	-0.052
DTS SN: 1175							20.16	20.167	-0.007	39.23	39.217	0.013	58.35	58.323	0.027
DTS SN: 1175							20.15	20.167	-0.017	39.2	39.217	-0.017	58.29	58.323	-0.033
DTS SN: 1176							20.13	20.167	-0.037	39.17	39.217	-0.047	58.28	58.323	-0.043
DTS SN: 1176							20.14	20.167	-0.027	39.19	39.217	-0.027	58.31	58.323	-0.013
AVERAGE			-0.022			-0.029			-0.041			-0.044			-0.043
SIGMA			0.032			0.026			0.030			0.027			0.030
uc			0.039			0.039			0.051			0.051			0.052

APPENDIX C - RTD ERRORS (CONTINUED)

-0.057	0.044	-0.09	-0.099	-0.084
-0.047	-0.044	-0.09	-0.099	-0.084
-0.036	-0.044	-0.055	-0.063	-0.066
-0.016	-0.024	-0.045	-0.063	-0.096
0.024	-0.014	-0.065	-0.043	-0.056
-0.046	-0.054	-0.055	-0.053	-0.066
0.012	-0.001	-0.13	-0.027	-0.064
0.002	-0.011	-0.022	-0.047	-0.074
-0.058	-0.031	0.028	-0.027	-0.044
-0.048	-0.051	-0.052	-0.067	-0.094
-0.026	-0.037	-0.066	-0.076	-0.057
-0.026	-0.027	-0.026	-0.036	0.018
-0.026	-0.047	-0.056	-0.066	-0.047
0.004	-0.007	-0.016	-0.016	0.003
-0.044	-0.043	-0.017	-0.008	-0.004
-0.034	-0.043	-0.047	-0.048	-0.014
-0.064	-0.063	-0.037	-0.018	-0.024
0.071		0.013	0.012	0.003
0.001		-0.017	-0.028	-0.027
-0.029		-0.037	-0.048	-0.047
-0.019		-0.047	-0.048	-0.057
		-0.032	-0.038	-0.033
		-0.042	-0.038	-0.033
		-0.032	-0.038	-0.043
		-0.042	-0.048	-0.043
		-0.09	-0.102	-0.084
		-0.02	-0.042	-0.044
		-0.06	-0.062	-0.044
		-0.04	-0.052	-0.064
		-0.017	-0.013	-0.012
		-0.027	-0.023	-0.022
		-0.077	-0.063	-0.062
		-0.027	-0.053	-0.052
		-0.007	0.013	0.027
		-0.017	-0.017	-0.033
		-0.037	-0.047	-0.043
		-0.027	-0.027	-0.013

BINS
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04

Bin	*Frequency*
-0.1	2
-0.08	10
-0.06	18
-0.04	46
-0.02	36
0	22
0.02	10
0.04	3
More	2
	149



-0.038	AVERAGE
0.030	SIGMA
0.048	uc
149	Count

NOTE: Negative bias with data

APPENDX D - UTR GRADIENTS

UTR/Screw Terminal Deltas--32

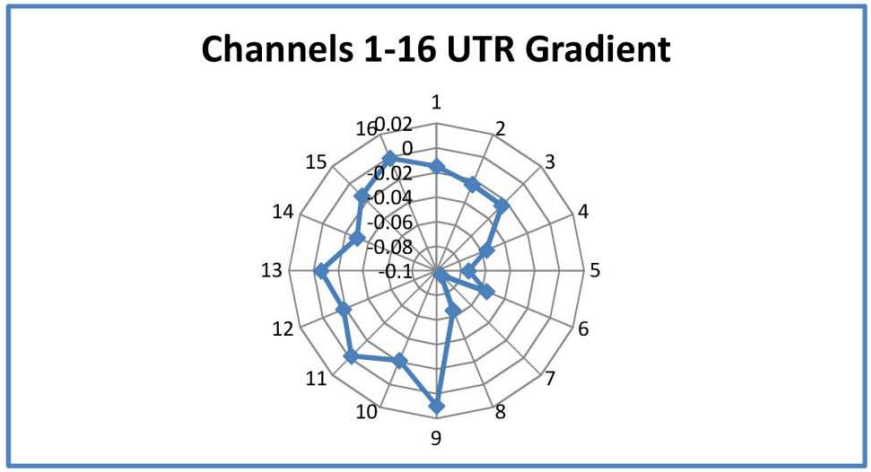
Channel DTS SN: 1016

Chan	+Terminal	-Terminal	RTD1	RTD2
1	28.56	--	28.59	28.56
2	29.296	--	29.34	29.3
3	29.48	--	29.53	29.48
4	29.659	--	29.74	29.69
5	30.981	--	31.06	31.05
6	31.549	--	31.61	31.6
7	32.185	--	32.29	32.27
8	32.1	--	32.17	32.16
9	31.965	--	31.97	31.94
10	31.904	--	31.94	31.91
11	32.053	--	32.07	32.04
12	32.092	--	32.12	32.1
13	32.279	--	32.3	32.27
14	32.295	--	32.34	32.31
15	30.576	--	30.59	30.59
16	31.059	--	31.07	31.05
Chan	**+Terminal**	**-Terminal**	**RTD3**	**RTD4**
17	31.462	--	31.51	31.48
18	31.563	--	31.61	31.58
19	31.701	--	31.73	31.7
20	31.745	--	31.78	31.74
21	31.859	--	31.89	31.85
22	32.026	--	32.05	32.01
23	31.237	--	31.29	31.26
24	31.61	--	31.63	31.61
25	31.763	--	31.77	31.74
26	31.895	--	31.94	31.91
27	31.87	--	31.93	31.89
28	31.621	--	31.69	31.65
29	31.333	--	31.4	31.35
30	31.135	--	31.21	31.17
31	31.09	--	31.15	31.12
32	31.12	--	31.18	31.13

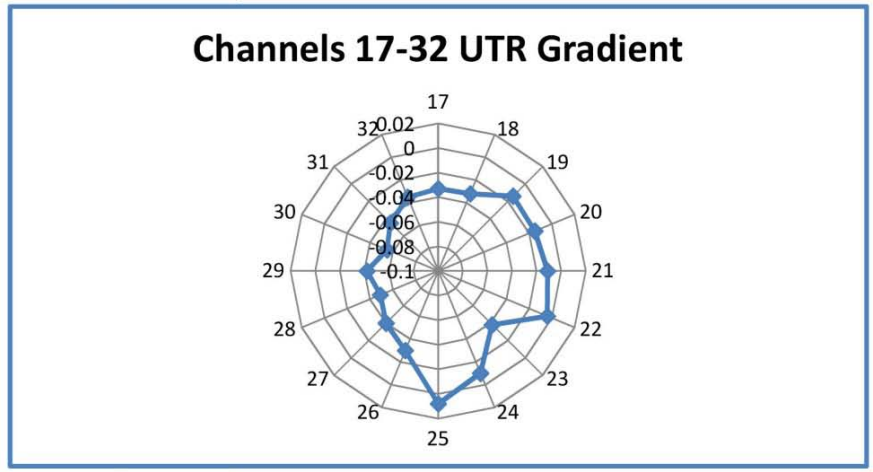
Error is the difference between the measured value (+Terminal) and truth (here the average of the two RTDs)

DELTA ERROR
-0.015
-0.024
-0.025
-0.056
-0.074
-0.056
-0.095
-0.065
0.01
-0.021
-0.002
-0.018
-0.006
-0.03
-0.014
-0.001
-0.033
-0.032
-0.014
-0.015
-0.011
-0.004
-0.038
-0.01
0.008
-0.03
-0.04
-0.049
-0.042
-0.055
-0.045
-0.035

AVG	SIGMA	uc
-0.031	0.030	0.043



AVG	SIGMA	uc
-0.028	0.018	0.033



Combined Uncertainty 0.05