HTPA32x32dR1L5.0/0.85F7.7eHiC

Thermopile Array With Lens Optics

Rev.20: 2018.01.10 Schnorr/M. Lupp

Content

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1 Principal Schematic for HTPA32x32d:

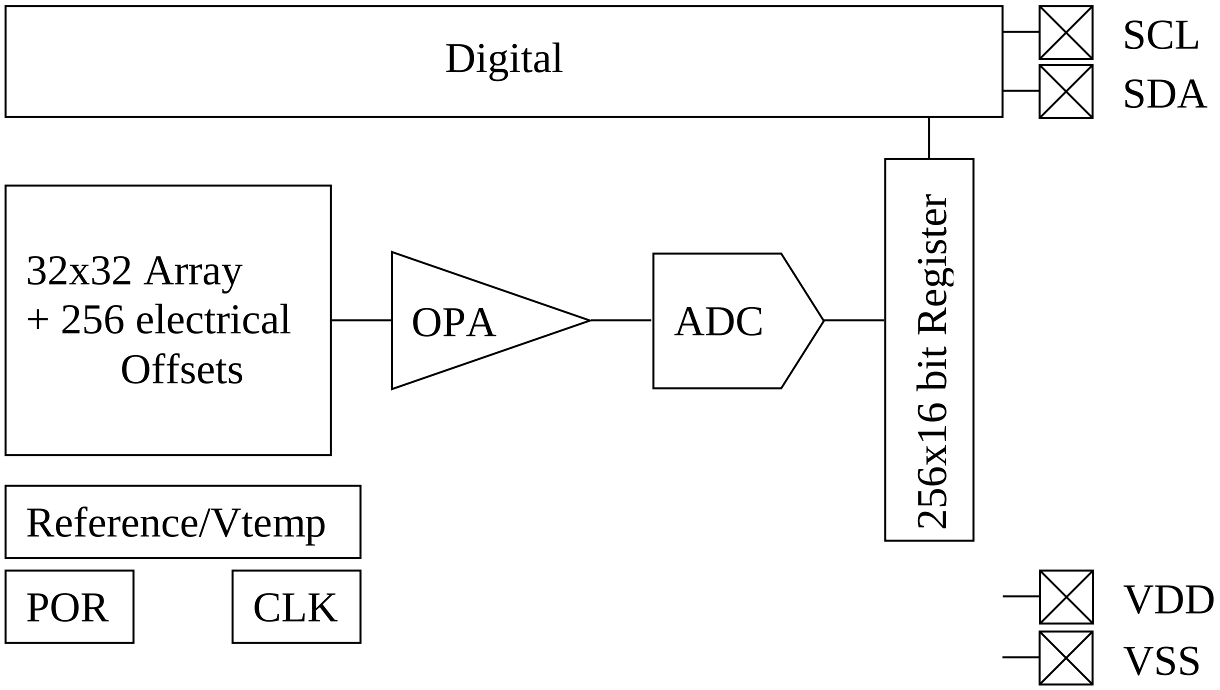

Figure 1: Schematic for HTPA32x32d

2 Pin Assignment– Bottom View:

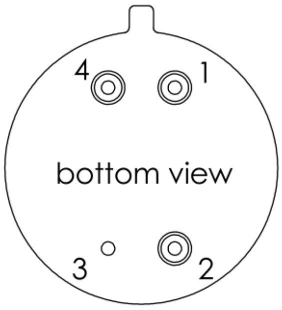

Figure 2: pin-allocation

Pin	Symbol	Description
1	SCL	Digital I/O, Open Drain, 100k PU, Serial Clock
2	VDD	Positive supply voltage
3	VSS	Negative supply voltage / Ground (0V) (connected to housing)
4	SDA	Digital I/O, Open Drain, 100k PU, Serial Data

3 Optical Orientation:

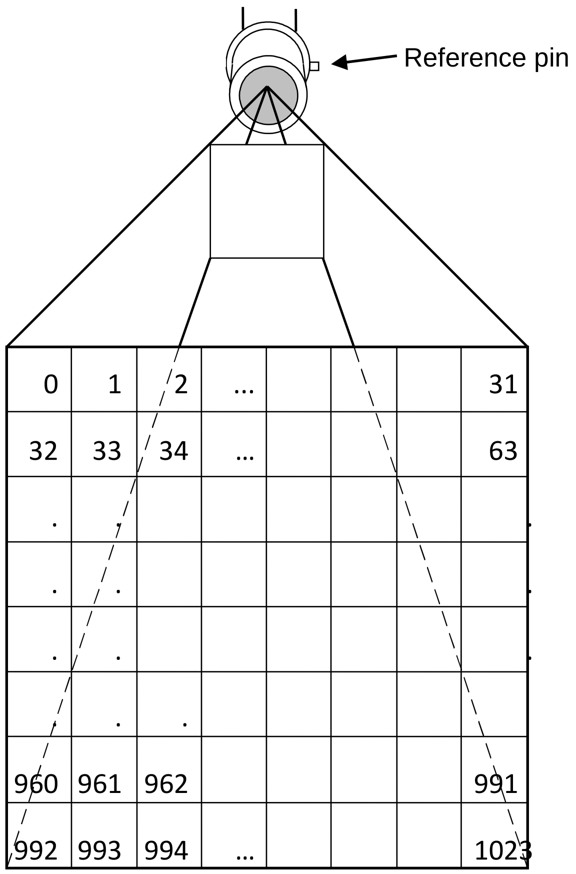

Figure 3: Optical orientation

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4 Order Code Example

HTPA32x32	S	d	R1	L10/0.95	F8-14	e	Hi	M	(SPI)	[Si]

Type:

HTPA32x32	Please contact support for all available HTPA and module combinations.

Package:

S	SMD variant
Not declared	TO can variant

Output:

d	HTPA sensor with digital output
Not declared	HTPA sensor with analogous output

Revision:

R1	Silicon revision 1

Optics:

L	Focal length: In example L10 = 10.0 mm focal length
/	F-Number: In example /0.95
	For optics see also "HTPA standard optics"

Filter:

F	Filter characteristics. In example F8-14 (µm, Bandpass)
Not declared	Broad band ARC

External aperture:

Not declared	without external aperture
e	with external aperture

Sensitivity:

UHi	Ultra high sensitivity
Hi	Increased sensitivity
Not declared	Standard sensitivity

Version:

A	Application set: comes with GUI, housing, power supply. Always UDP Interface.
C	Calibrated sensor (only digital). Carries calibration constants on internal EEPROM
M	Module: HTPA sensor soldered to PCB, calibrated stream
S	HTPA sensor only. Raw voltage output, not calibrated

Interface:

SPI	SPI device; Two variants: Analogous HTPAs: 14bit ADC Digital HTPA: 16bit ADC
UDP	Ethernet, CAT5 cable connection
PoE	Power over Ethernet, CAT5 connection, UDP protocol

Lens Material:

Si	Silicon
Not declared	Germanium

Figure 4: Exemplary order code

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5 Serial Order of Frame

The sensor is divided into two parts (top and bottom half) which are again separated into 4 blocks. The readout order is shown below for the different blocks.

Block 0 (top)
Block 1 (top)
Block 2 (top)
Block 3 (top)
Block 3 (bottom)
Block 2 (bottom)
Block 1 (bottom)
Block 0 (bottom)

Figure 5: Division of blocks

Whenever a conversion is started the Block x of the top and bottom half are measured at the same time. Each block consists of 128 Pixel that are sampled fully parallel. The readout order on the bottom half is mirrored compared to the top half so that the central lines are always read last.

32x32d active Pixel

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223
224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255
256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287
288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319
320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351
352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383
384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415
416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447
448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479
480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511
512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543
544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575
576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607
608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639
640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671
672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703
704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735
736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767
768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799
800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831
832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863
864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895
896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927
928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959
960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991
992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023

Figure 6: 32x32d readout order for active pixel

The electrical offsets are sampled in parallel for the top and bottom half. The matching rows for the corresponding electrical offsets and active Pixel are marked with the same color. The conversion of the electrical offsets is started by sending the command for the BLIND bit during the start command, see 8.3.

32x32d electrical Offset

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223
224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255

Figure 7: 32x32d readout order for electrical offsets

6 Characteristics:

6.1 Common Specifications:

Technology	n-poly/p-poly Si
Element Resistance	approx. 300 kOhms
Sensitivity	approx. 450 V/W without optics and filter
Thermal pixel time constant	<4 ms
Digital Interface	I²C
Analog Output	No
selectable Clock	1 to 13 MHz
EEPROM size	64 kBit

Pitch	90 µm
Absorber size	44 µm
Max. Framerate	60 Hz

(complete frame with maximum I²C and sensor clock speed and reduced ADC resolution)
1024 sensitive elements

6.2 Optical characteristics:

Focal length:	5.0 mm ("L" equals the focal length of the lens)
F-Number:	0.85
Field of view:	33 x 33 deg
Lens coating:	LWP-Coating 7.7
	Cut On (Tr. 5%): 7.7 µm ± 0.3 µm

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Electric Specifications:

Table 1: Absolute Maximum Ratings

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
Supply Voltage	V_{DD}		-0.3		3.6	V
Voltage at All inputs and outputs	V_{IO}		-0.3		V_{DD}+0.3	V
Storage Temperature	T_{STG}		-40		85	Deg. C

Table 2: Operating Conditions

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
Supply Voltage	V_{DD}		3.3	3.35	3.6	V
Supply Current (sensor running)	I_{DD}		5.0	5.5	6.4	mA
Supply Current (sensor in idle state)	I_{DD}		tbd	5.2	tbd	mA
Standby Current (sensor in sleep state)	I_{SBY}		2.0	2.1	2.5	µA
Operation Temperature	T_A		-20		65	Deg. C
ESD-Protection		Human body model 100pF + 1k5Ohm	2.0			kV

Table 3: Electrical Characteristics

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
Digital Input						
Internal Clock frequency	F_{CLK}		1	5	13	MHz
Internal I²C Pull up	R_{PU}		1	100	100	kOhm
Bias current	I_{BIAS}		1	3	13	µA
BPA current	I_{BPA}		0.2	1.5	4.0	µA
Input voltage high	V_{IH}		0.7xV_{DD}			V
Input voltage low	V_{IL}				0.3xV_{DD}	V
PTAT						
Temperature range			TBD		TBD	Deg. C
PTAT gradient			170	174	178	K/V

Table 4: Preamplifier / ADC

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
Chopper frequency	F_{CHP}			20		kHz
Preamplifier Noise	N_{PA}	at 20 kHz		72		$nV/HZ^{1/2}$
Frame rate (Full Array)	FR1		2	9	60	Hz
Frame rate (Quarter Array)	FR4		8	36	240	HZ
ADC pos. Reference	V_{REFP}	REF_CAL 00		1.529		V
		REF_CAL 01		1.442		
		REF_CAL 10		1.355		
		REF_CAL 11		1.268		
ADC neg. Reference	V_{REFN}	REF_CAL 00		0.850		V
		REF_CAL 01		0.901		
		REF_CAL 10		0.968		
		REF_CAL 11		1.056		
ADC resolution	ADC_{LSB}	at 16 Bit	6.5		20.7	µV

7 I²C Timings HTPA32x32d:

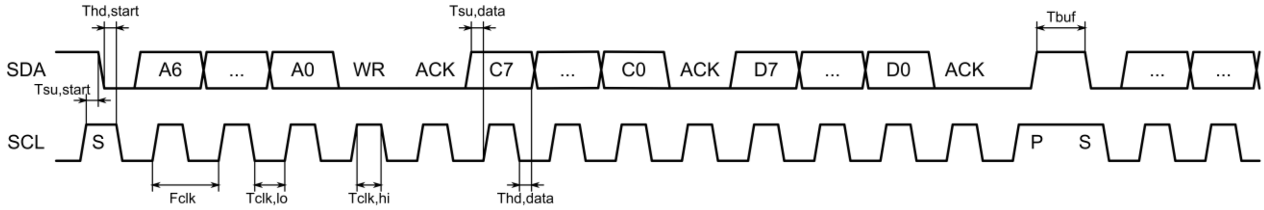

Figure 8: I²C Timings of HTPA32x32d

Table 5: I²C Timings

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
I²C clock frequency	F_{CLK}			400	1000	kHz
low pulse duration	$T_{CLK,lo}$		0.50			µs
high pulse duration	$T_{CLK,hi}$		0.26			µs
data set up time	$T_{SU,data}$		0.05			µs
data hold time	$T_{hd,data}$		0.00			µs
start setup time	$T_{SU,start}$		0.26			µs
start hold time	$T_{hd,start}$		0.26			µs
stop setup time	$T_{SU,stop}$		0.26			µs
stop hold time	$T_{hd,stop}$		0.26			µs
time between STOP / START	T_{buf}		0.50			µs

8 I²C Communication:

The chip uses the **7-bit I²C address 0x1A** for configuration and **sensor** data and the **7-bit I²C address 0x50** to access the internal **EEPROM**. The address byte is followed by a W/R bit and an 8-bit command.

8.1 Write Command

In case of a write access to an internal register the command is followed by the data byte. The chip acknowledges each byte with a low active ACK bit.

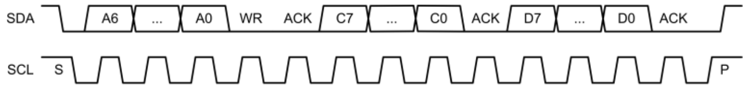

Figure 9: Write command

8.2 Read Command

To read data from the chip first the address and read command must be sent. After the last ACK a new start-bit (repeated start) and the address with a set read-flag initiates the read sequence. There can be bytes read as many as required. The last byte must be denoted by a not-acknowledge. The shown example below can be used e.g. to get the status register.

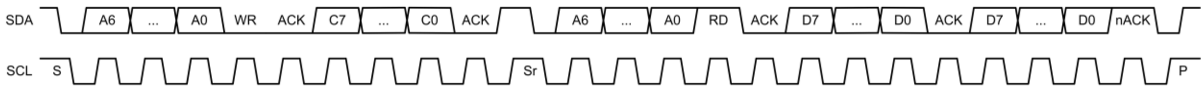

Figure 10: Read command

8.3 Sensor Commands

The sensor has several registers that can be written and read, they are listed below.

Table 6: Configuration register (write only)

Addr / CMD	0x1A (7 Bit!) / 0x01							
Config Reg	7	6	5	4	3	2	1	0
Name	RFU		BLOCK		START	VDD_MEAS	BLIND	WAKEUP
Default	0	0	0	0	0	0	0	0

The WAKEUP bit is used to switch on / off the chip and must be set prior all other operations. After the START bit is set the chip starts a conversion of the array or blind elements and enters the idle state (not sleep!) when finished. The BLOCK selects one of the four multiplexed array blocks.
If the BLIND bit is set the electrical offsets are sampled instead of the active pixel and the setting of the BLOCK is ignored.
If VDD_MEAS bit is set the VDD voltage is measured instead of the PTAT value.
RFU means reserved for future use and can be subject to change.

Table 7: Status Register (read only)

Addr / CMD	0x1A (7 Bit!) / 0x02							
Status Reg	7	6	5	4	3	2	1	0
Name	RFU		BLOCK		RFU	VDD_MEAS	BLIND	EOC

If the EOC flag is set a previous started conversion has been finished.

Table 8: Trim Register 1 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x03							
Trim Reg 1	7	6	5	4	3	2	1	0
Name	RFU		REF_CAL		MBIT TRIM			

REF_CAL: selectable amplification, see **Fehler! Verweisquelle konnte nicht gefunden werden.** for more detail
MBIT_TRIM: m = 4 to 12 ⇒ (m+4) bit as ADC resolution

Table 9: Trim Register 2 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x04							
Trim Reg 2	7	6	5	4	3	2	1	0
Name	RFU			BIAS TRIM TOP				

BIAS_TRIM_TOP: 0 to 31 ⇒ 1µA to 13µA
This setting is used to adjust the bias current of the ADC. A faster clock frequency requires a higher bias current setting.

Table 10: Trim Register 3 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x05							
Trim Reg 3	7	6	5	4	3	2	1	0
Name	RFU			BIAS TRIM BOT				

BIAS_TRIM_BOT: 0 to 31 ⇒ 1µA to 13µA
This setting is used to adjust the bias current of the ADC. A faster clock frequency requires a higher bias current setting.

Table 11: Trim Register 4 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x06							
Trim Reg 4	7	6	5	4	3	2	1	0
Name	RFU		CLK TRIM					

CLK_TRIM: 0 to 63 ⇒ 1MHz to 13MHz
NOTE: The measure time depends on the clock frequency settings. One quarter frame takes about:

$$t_{FR4} = \frac{32 \cdot \left(2^{MBIT} + 4\right)}{F_{CLK}} \approx 27ms@5MHz$$

Table 12: Trim Register 5 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x07							
Trim Reg 5	7	6	5	4	3	2	1	0
Name	RFU			BPA TRIM TOP				

BPA_TRIM_TOP: 0 to 31 ⇒ 0.2µA to 4.0µA
This setting is used to adjust the common mode voltage of the preamplifier.

Table 13: Trim Register 6 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x08							
Trim Reg 6	7	6	5	4	3	2	1	0
Name	RFU			BPA TRIM BOT				

BPA_TRIM_BOT: 0 to 31 ⇒ 0.2µA to 4.0µA
This setting is used to adjust the common mode voltage of the preamplifier.

Table 14: Trim Register 7 (write only)

Addr / CMD	0x1A (7 Bit!) / 0x09							
Trim Reg 7	7	6	5	4	3	2	1	0
Name	PU SDA TRIM				PU SCL TRIM			

PU_SDA_TRIM: select internal pull up resistor on SDA
PU_SCL_TRIM: select internal pull up resistor on SCL
“1000” = 100 kOhm; “0100” = 50 kOhm; “0010” = 10 kOhm; “0001” = 1 kOhm

Table 15: Read Data 1 Command (Top Half of Array)

Addr / CMD	0x1A (7 Bit!) / 0x0A							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 1 MSB / LSB or Vdd 1 MSB / LSB							
3. Byte / 4. Byte	Pixel (0+BLOCK*128) MSB / LSB							
5. Byte / 6. Byte	Pixel (1+BLOCK*128) MSB / LSB							
…	…							
257. Byte / 258. Byte	Pixel (127+BLOCK*128) MSB / LSB							

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Table 16: Read Data 2 Command (Bottom Half of Array)

Addr / CMD	0x1A (7 Bit!) / 0x0B							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 2 MSB / LSB or Vdd 2 MSB / LSB							
3. Byte / 4. Byte	Pixel (992-BLOCK*128) MSB / LSB							
5. Byte / 6. Byte	Pixel (993-BLOCK*128) MSB / LSB							
…								
65. Byte / 66. Byte	Pixel (1023-BLOCK*128) MSB / LSB							
67. Byte / 68. Byte	Pixel (960-BLOCK*128) MSB / LSB							
69. Byte / 70. Byte	Pixel (961-BLOCK*128) MSB / LSB							
…								
129. Byte / 130. Byte	Pixel (991-BLOCK*128) MSB / LSB							
131. Byte / 132. Byte	Pixel (928-BLOCK*128) MSB / LSB							
…								
257. Byte / 258. Byte	Pixel (927-BLOCK*128) MSB / LSB							

The complete sensor data must be read at once. If the communication fails somewhere in between, all successive data will be corrupted. The readout can be stopped anywhere by pausing the clock. A new initialized readout proceeds at this stopped byte by continuing the clock, but the index is reset when a new conversion has been started.
If the bit for the electrical offsets (Bit 1 in Config 0x01) is set the electrical offsets are sampled and can be read similar to the active pixel:

Table 17: Read Data electrical offsets (Top Half of Array)

Addr / CMD	0x1A (7 Bit!) / 0x0A							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 1 MSB / LSB or Vdd 1 MSB / LSB							
3. Byte / 4. Byte	electrical offset (0) MSB / LSB							
5. Byte / 6. Byte	electrical offset (1) MSB / LSB							
…	…							
257. Byte / 258. Byte	electrical offset (127) MSB / LSB							

Table 18: Read Data electrical offsets (Bottom Half of Array)

Addr / CMD	0x1A (7 Bit!) / 0x0B							
Read Data	7	6	5	4	3	2	1	0
1. Byte / 2. Byte	PTAT 2 MSB / LSB or Vdd 2 MSB / LSB							
3. Byte / 4. Byte	electrical offset (224) MSB / LSB							
5. Byte / 6. Byte	electrical offset (225) MSB / LSB							
…	…							
65. Byte / 66. Byte	electrical offset (255) MSB / LSB							
67. Byte / 68. Byte	electrical offset (192) MSB / LSB							
…	…							
257. Byte / 258. Byte	electrical offset (159) MSB / LSB							

The complete sensor data must be read at once. If the communication fails somewhere in between, all successive data will be corrupted. The readout can be stopped anywhere by

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pausing the clock. A new initialized readout proceeds at this stopped byte by continuing the clock, but the index is reset when a new conversion has been started.
Depending on the setting of VDD_MEAS the PTAT or the VDD is transmitted.

8.4 EEPROM communication

The built-in EEPROM (24AA64 from Microchip) consists of 8 blocks of 1K x 8-bit. The chip select of the EEPROM is set to 000 (A2 to A0). For further information please see the corresponding datasheet:
http://ww1.microchip.com/downloads/en/DeviceDoc/21189f.pdf

8.5 I²C Example Sequences – Init and Read Thermopile Array

(There should be a delay of at least 5 ms between the write of each Configuration Register)
Please be reminded, that you readout the calibration settings for MBIT, BIAS, CLK, BPA and PU and use them for a correct temperature calculation.

	ADDR	W/R	CONFIG_REG	WAKEUP	
S	0x1A	0	0x01	0x01	P

	ADDR	W/R	TRIM_REG1	MBIT_TRIM	
S	0x1A	0	0x03	0x0C	P

	ADDR	W/R	TRIM_REG2	BIAS_TRIML	
S	0x1A	0	0x04	0x0C	P

	ADDR	W/R	TRIM_REG3	BIAS_TRIMR	
S	0x1A	0	0x05	0x0C	P

	ADDR	W/R	TRIM_REG4	CLK_TRIM	
S	0x1A	0	0x06	0x14	P

	ADDR	W/R	TRIM_REG5	BPA_TRIML	
S	0x1A	0	0x07	0x0C	P

	ADDR	W/R	TRIM_REG6	BPA_TRIMR	
S	0x1A	0	0x08	0x0C	P

	ADDR	W/R	TRIM_REG7	PU_TRIM	
S	0x1A	0	0x09	0x88	P

	ADDR	W/R	CONFIG_REG	START|WAKEUP	
S	0x1A	0	0x01	0x09	P

	ADDR	W/R	STATUS_REG		ADDR	W/R	STATUS	
S	0x1A	0	0x02	Sr	0x1A	1	??	P

Wait 30 ms

	ADDR	W/R	STATUS_REG		ADDR	W/R	STATUS	
S	0x1A	0	0x02	Sr	0x1A	1	??	P

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	ADDR	W/R	READ_DATA 1		ADDR	W/R	PTAT1 MSB	PTAT1 LSB	P0,0 MSB	P0,0 LSB	…	Px,y MSB	Px,y LSB	
S	0x1A	0	0x0A	Sr	0x1A	1	??	??	??	??	…	??	??	P

	ADDR	W/R	READ_DATA 2		ADDR	W/R	PTAT2 MSB	PTAT2 LSB	P0,0 MSB	P0,0 LSB	…	Px,y MSB	Px,y LSB	
S	0x1A	0	0x0B	Sr	0x1A	1	??	??	??	??	…	??	??	P

	ADDR	W/R	CONFIG_REG	SLEEP	
S	0x1A	0	0x01	0x00	P

Figure 11: Init and Read Thermopile Array

9 Temperature calculation

The object and ambient temperature can be calculated from the sensor output and the stored calibration data. The table below is showing an overview of the EEPROM.

32x32d	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07	0x08	0x09	0x0A	0x0B	0x0C	0x0D	0x0E	0x0F
0x0000	PixCmin [float]				PixCmax [float]				gradScale			TN as 16 bit unsigned		epsilon		
0x0010											MBIT(calib)	BIAS(calib)	CLK(calib)	BPA(calib)	PU(calib)	
0x0020			Arraytype				VDDTH1		VDDTH2							
0x0030					PTAT-gradient (float)				PTAT-offset (float)				PTAT (Th1)		PTAT (Th2)	
0x0040															VddScGrad	VddScOff
0x0050					GlobalOff	GlobalGain										
0x0060	MBIT(user)	BIAS(user)	CLK(user)	BPA(user)	PU(user)											
0x0070					DeviceID											NrOfDefPix
0x0080	DeadPixAdr as 16 bit unsigned values															
0x0090																
0x00A0																
0x00B0	DeadPixMask															
0x00C0	DeadPixMask								free to use							
0x00D0 … 0x0330	free to use															
0x0340 … 0x0530	VddCompGrad$_{ij}$ stored as 16 bit signed values															
0x0540 … 0x0730	VddCompOff$_{ij}$ stored as 16 bit signed values															
0x0740 … 0x0F30	ThGrad$_{ij}$ stored as 16 bit signed values															
0x0F40 … 0x1730	ThOffset$_{ij}$ stored as 16 bit signed values															
0x1740 … 0x1F30	P$_{ij}$ stored as 16 bit unsigned values															

Figure 12: EEPROM overview 32x32d

All values are stored as unsigned 8 bit values unless they are specified otherwise. The little endian format is used for larger values. Grey marked areas are used during calibration or for future use and are Heimann Sensor reserved.
MBIT(calib), BIAS(calib), CLK(calib), BPA(calib) and PU(calib) are the settings for the registers that have been used during calibration (see chapter 8.3 on how to set them).
We recommend the usage of calibration settings of MBIT (stored in 0x1A), BIAS (0x1B), CLK (0x1c), BPA (0x1D) and PU (0x1E).
MBIT(user), BIAS(user), CLK(user), BPA(user) and PU(user) are free to be set by the user.
The temperature calculation is only valid if the same settings are used that have been set during calibration!
TN is the tablenumber and has to match the given tablenumber in the sample code.
GlobalOff is stored as an 8 bit signed value, GlobalGain and VddCalib are both stored as 16 bit unsigned.
VDDTH1 and VDDTH2 is the used supply voltage during calibration measured by the sensor itself and stored in Digits.

The corresponding order of $ThGrad_{ij}$, $ThOffset_{ij}$ and P_{ij} to the Pixelnumber is given by the following overview:

$ThGrad_{0,0}$ → Pixel 0	$ThGrad_{0,1}$ → Pixel 1	…	$ThGrad_{0,31}$ → Pixel 31
$ThGrad_{1,0}$ → Pixel 32	$ThGrad_{1,1}$ → Pixel 33	…	$ThGrad_{1,31}$ → Pixel 63
.			
.			
.			
$ThGrad_{15,0}$ → Pixel 480	$ThGrad_{15,1}$ → Pixel 481	…	$ThGrad_{15,31}$ → Pixel 511
$ThGrad_{16,0}$ → Pixel 992	$ThGrad_{16,1}$ → Pixel 993	…	$ThGrad_{16,31}$ → Pixel 1023
$ThGrad_{17,0}$ → Pixel 960	$ThGrad_{17,1}$ → Pixel 961	…	$ThGrad_{17,31}$ → Pixel 991
.			
.			
.			
$ThGrad_{31,0}$ → Pixel 512	$ThGrad_{31,1}$ → Pixel 513	…	$ThGrad_{31,31}$ → Pixel 543

Figure 13: Readout order 32x32d

The order of $VddCompGrad_{ij}$ and $VddCompOff_{ij}$ is similar to the electrical Offsets and have to be used block by block.

$VddCompGrad_{0,0}$ → Pixel 0	$VddCompGrad_{0,1}$ → Pixel 1	…	$VddCompGrad_{0,31}$ → Pixel 31	top half
$VddCompGrad_{1,0}$ → Pixel 32	$VddCompGrad_{1,1}$ → Pixel 33	…	$VddCompGrad_{1,31}$ → Pixel 63	
$VddCompGrad_{2,0}$ → Pixel 64	$VddCompGrad_{2,1}$ → Pixel 65	…	$VddCompGrad_{2,31}$ → Pixel 95	
$VddCompGrad_{3,0}$ → Pixel 96	$VddCompGrad_{3,1}$ → Pixel 97	…	$VddCompGrad_{3,31}$ → Pixel 127	
$VddCompGrad_{0,0}$ → Pixel 128	$VddCompGrad_{0,1}$ → Pixel 129	…	$VddCompGrad_{0,31}$ → Pixel 159	
.				
.				
.				
$VddCompGrad_{3,0}$ → Pixel 480	$VddCompGrad_{3,1}$ → Pixel 481	…	$VddCompGrad_{3,31}$ → Pixel 511	
$VddCompGrad_{4,0}$ → Pixel 992	$VddCompGrad_{4,1}$ → Pixel 993	…	$VddCompGrad_{4,31}$ → Pixel 1023	bottom half
$VddCompGrad_{5,0}$ → Pixel 960	$VddCompGrad_{5,1}$ → Pixel 961	…	$VddCompGrad_{5,31}$ → Pixel 991	
$VddCompGrad_{6,0}$ → Pixel 928	$VddCompGrad_{6,1}$ → Pixel 929	…	$VddCompGrad_{6,31}$ → Pixel 959	
$VddCompGrad_{7,0}$ → Pixel 896	$VddCompGrad_{7,1}$ → Pixel 897	…	$VddCompGrad_{7,31}$ → Pixel 927	
$VddCompGrad_{4,0}$ → Pixel 864	$VddCompGrad_{4,1}$ → Pixel 865	…	$VddCompGrad_{4,31}$ → Pixel 895	
.				
.				
.				
$VddCompGrad_{7,0}$ → Pixel 512	$VddCompGrad_{7,1}$ → Pixel 513	…	$VddCompGrad_{7,31}$ → Pixel 543	

Figure 14: Readout of VDDCompGrad 32x32d

The order for *DeadPixAdr_Pij* isdescribed more detailed in 9.7.

9.1 Ambient Temperature

The ambient temperature (Ta) is calculated from the average measured PTAT value, the $PTAT_{gradient}$ and the $PTAT_{offset}$.

$$Ta = PTAT_{av} \cdot PTAT_{gradient} + PTAT_{offset}$$ (Value is given back in dK)

where:

$PTAT_{gradient}$	is the gradient of the PTAT stored in the EEPROM as a float value
$PTAT_{offset}$	is the offset of the PTAT stored in the EEPROM as a float value

$PTAT_{av} = \frac{\sum_{i=0}^{7} PTAT_i}{8}$ is the average measured PTAT value

9.2 Thermal Offset

The thermal offset of the sensor needs to be subtracted for each pixel to compensate for any thermal drifts.

$$V_{ij\_Comp} = V_{ij} - \frac{ThGrad_{ij} \cdot PTAT_{av}}{2^{gradScale}} - ThOffset_{ij}$$

where:

ij	represents the row (i) and column (j) of the pixel
V_{ij_Comp}	is the thermal offset compensated voltage
V_{ij}	is the raw pixel data (digital), readout from the RAM
$ThGrad_{ij}$	is the thermal gradient, stored in the EEPROM from 0x740 to 0xF3F
$ThOffset_{ij}$	is the thermal offset, stored in the EEPROM from 0xF40 to 0x173F
$gradScale$	is the scaling coefficient for the thermal gradient stored in the EEPROM

9.3 Electrical Offset

The electrical offset is used to compensate changes in the supply voltage. This compensation is only a substraction so it can be done before or after the thermal offset compensation (here done afterwards).

The compensation for the top half is done by using the following formula:

$$V_{ij\_Comp}* = V_{ij\_Comp} - elOffset[(j + i \cdot 32)\%128]$$

and the bottom half analogue with this formula:

$$V_{ij\_Comp}* = V_{ij\_Comp} - elOffset[(j + i \cdot 32)\%128 + 128]$$

where:

ij	represents the row (i) and column (j) of the pixel and electrical offset
$V_{ij\_Comp}*$	is the thermal and electrical offset compensated voltage
V_{ij_Comp}	is the thermal offset compensated voltage
$elOffset[ij]$	is the electrical offset belonging to Pixel ij
$i\%128$	is the rest of the integer division of i by 128 (e.g. 130%128=2)

Please see chapter 5 for the serial order.

9.4 Vdd Compensation

A supply voltage compensation called VddComp is used to take care of supply voltage changes. In order to use this compensation the supply voltage of the sensor (Vdd) has to be measured by the sensor from time to time by setting the configuration register and the average of Vdd 1 and Vdd 2 is resulting in Vdd (similar like $PTAT_{av}$).

The compensation for the top half is done by using the following formula:

$$VDD_{av}=\frac{\sum_{i=0}^{3}VDD_i}{8}$$

$$V_{ij\_VDDComp}=V_{ij\_Comp}{}^{*}-\frac{\left(\frac{VddCompGrad[(j+i\cdot32)\%128]\cdot PTAT_{av}}{2^{VddScGrad}}+VddCompOff[(j+i\cdot32)\%128]\right)}{2^{VddScOff}}\cdot\left(VDD_{av}-VDD_{TH1}-\left(\frac{VDD_{TH2}-VDD_{TH1}}{PTAT_{TH2}-PTAT_{TH1}}\right)\cdot(PTAT_{av}-PTAT_{TH1})\right)$$

and the bottom half analogue with this formula:

$$V_{ij\_VDDComp}=V_{ij\_Comp}{}^{*}-\frac{\left(\frac{VddCompGrad[(j+i\cdot32)\%128+128]\cdot PTAT_{av}}{2^{VddScGrad}}+VddCompOff[(j+i\cdot32)\%128+128]\right)}{2^{VddScOff}}\cdot\left(VDD_{av}-VDD_{TH1}-\left(\frac{VDD_{TH2}-VDD_{TH1}}{PTAT_{TH2}-PTAT_{TH1}}\right)\cdot(PTAT_{av}-PTAT_{TH1})\right)$$

where:

ij	represents the row (i) and column (j) of the pixel
$V_{ij\_VDDComp}$	is the Vdd compensated voltage
$V_{ij\_Comp}{}^{*}$	is the thermal and electrical offset compensated voltage
$VddCompGrad[ij]$	is the VddComp gradient belonging to Pixel ij
$VddCompOff[ij]$	is the VddComp offset belonging to Pixel ij
$i\%128$	is the rest of the integer division of i by 128 (e.g. 130%128=2)
VDD_{av}	is the average measured supply voltage of the sensor in Digits
$VddScGrad$	is a scaling coefficient and stored in the EEPROM 0x4E
$VddScOff$	is a scaling coefficient and stored in the EEPROM 0x4F
VDD_{TH1}	is the supply voltage during calibration 1 stored in the EEPROM 0x26, 0x27
VDD_{TH2}	is the supply voltage during calibration 2 stored in the EEPROM 0x28, 0x29
$PTAT_{TH1}$	is the PTAT value of calibration 1 stored in the EEPROM 0x3C, 0x3D
$PTAT_{TH2}$	is the PTAT value of calibration 2 stored in the EEPROM 0x3E, 0x3F

9.5 Object Temperature

The calculation of the object temperature is done by using a look-up table and doing a bi-linear interpolation, the matching table is given by the tablenumber (TN). The table is supplied in a separate file named “Table.c”. If you do not have the file, please ask Heimann Sensor for support.
The sensitivity coefficients ($PixC_{ij}$) are calculated in the following way:

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$$PixC_{ij} = \left(\frac{P_{ij} \cdot (PixC_{\max} - PixC_{\min})}{65535} + PixC_{\min} \right) \cdot \frac{epsilon}{100} \cdot \frac{GlobalGain}{10000}$$

where:

$PixC_{ij}$	is the sensitivity coefficient for each pixel
P_{ij}	is the stored sensitivity coefficient scaled to 16 bit
$PixC_{\min}$	is the minimum sensitivity coefficient, used for scaling
$PixC_{\max}$	is the maximum sensitivity coefficient, used for scaling
$epsilon$	is the emissivity factor
$GlobalGain$	is a factor for fine tuning of the sensitivity for all Pixel

Leading to a compensation of the pixel voltage

$$V_{ij\_PixC} = \frac{V_{ij\_VDDComp} \cdot \mathrm{PCSCALEVAL}}{PixC_{ij}}$$

where:

V_{ij_PixC}	is the sensitivity compensated IR voltage
PCSCALEVAL	is a defined scaling coefficient, typically set to $1 \cdot 10^8$

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9.6 Example calculation

Example values:

$$PTAT_{av} = \frac{\sum_{i=0}^{7} PTAT_i}{8} = 38152\ Digits$$

$$PTAT_{gradient} = 0.0211\ dK / Digit$$

$$PTAT_{offset} = 2195.0\ dK$$

$$V_{00} = 34435\ Digits$$

$$elOffset[0] = 34240$$

$$gradScale = 24$$

$$ThGrad_{00} = 11137 \xrightarrow[sign\,check]{} 11137$$

$$ThOffset_{00} = 65506 \xrightarrow[sign\,check]{} -30$$

$$VDD_{av} = 35000$$

$$VDD_{TH1} = 33942$$

$$VDD_{TH2} = 36942$$

$$PTAT_{TH1} = 30000$$

$$PTAT_{TH2} = 42000$$

$$VddCompGrad[0] = 10356 \xrightarrow[sign\,check]{} 10356$$

$$VddCompOff[0] = 51390 \xrightarrow[sign\,check]{} -14146$$

$$VddScGrad = 16$$

$$VddScOff = 23$$

$$PixC_{00} = 1.087 \cdot 10^8$$

$$\mathrm{PCSCALEVAL} = 1 \cdot 10^8$$

Calculation of ambient temperature:

$$Ta = PTAT_{av} \cdot PTAT_{gradient} + PTAT_{offset} = 38152 \cdot 0.0211 + 2195.0\ dK = 3000\ dK$$

Compensation of thermal offset:

$$V_{00\_Comp} = V_{00} - \frac{ThGrad_{00} \cdot PTAT_{av}}{2^{gradScale}} - ThOffset_{00} = 34435 - \frac{11137 \cdot 38152}{2^{24}} - (-30) = 34439$$

Compensation of electrical offset:

$$V_{00\_Comp}{}^{*} = V_{00\_Comp} - elOffset[0] = 34439 - 34240 = 199$$

Compensation of supply voltage:

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$$V_{ij\_VDDComp} = V_{ij\_Comp} * -\frac{\left(\frac{VddCompGrad[0] \cdot PTAT_{av}}{2^{VddScGrad}} + VddCompOff[0]\right)}{2^{VddScOff}}$$

$$\cdot\left(VDD_{av} - VDD_{TH1} - \left(\frac{VDD_{TH2} - VDD_{TH1}}{PTAT_{TH2} - PTAT_{TH1}}\right) \cdot (PTAT_{av} - PTAT_{TH1})\right)$$

$$= 199 - \frac{\left(\frac{10356 \cdot 38152}{2^{16}} - 14146\right) \cdot (35000 - 33942 - 2038)}{2^{23}} = 199 - (1) = 198$$

Table 19: Example look-up table

TA[dK]/dig	2882	3032	3182	3332
-64	1494	2128	2491	2775
-32	2466	2692	2898	3091
0	2882	3032	3182	3332
32	3170	3285	3406	3530
64	3396	3491	3592	3699
96	3584	3665	3754	3848
128	3746	3818	3897	3981
160	3890	3954	4025	4102
192	4019	4078	4143	4214
224	4137	4191	4251	4317
256	4246	4296	4351	4413
288	4347	4393	4445	4503
320	4441	4485	4534	4588

$$V_{00\_PixC} = \frac{198 \cdot 1 \cdot 10^8}{1.087 \cdot 10^8} = 182$$

Ta was calculated before to 3000 dK.
The matching region in the look-up table is already marked yellow, the bi-linear interpolation is leading to an object temperature of 3941 dK = 120.9 °C.
A global Offset (GlobalOff) is used for fine tuning of the measured object temperature and has to be added to the object temperature. This value is stored in the EEPROM.

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9.7 Pixel Masking

A maximum of 5 defect Pixels are allowed on the complete array, this means that at least 99.5 % of the Pixels are working correctly. The amount of defect Pixels is given in the EEPROM at address 0x007F and is named $NrOfDefPix$. $DeadPixAdr$ is the address of the defect Pixels and $DeadPixMask$ determines the neighbours that should be used for masking the pixel. A simple averaging of all selected nearest neighbours is done to overwrite the temperature value of these Pixel. Only the amount of pixels "$NrOfDefPix$" is stored in $DeadPixAdr$. These values are stored as 16 bit unsigned values. For example: If only one pixel has to be masked, then the other values of $DeadPixAdr$ are set to 0.
The order of the top and bottom half is the same as the readout order that is stated in 5.
The value stored in $DeadPixAdr$ is equal to the pixel number if $DeadPixAdr$ is <0x0200. If the value is greater, that means between 0d512 and 0d1024, the actual read-out pixel has to be calculated first. For example: If you have a pixel number of 997 stored to the EEPROM, this is actually 517 (please refer to 5). The pixel number, that is stored in the EEPROM corresponds to the number of the read-out pixel. So the bottom half is mirrored.
Example calculation:

$$adaptedAdr[i] = 1024 + 512 - DeadPixAdr[i] + k[i] \cdot 2 - 32$$

$where:$

$adaptedAdr[i]$ is the adapted dead pixel address

$k[i]$ is the column of the corresponsive pixel (for pixel number 997 this would be 5)

$$adaptedAdr[i] = 1024 + 512 - 997 + 10 - 32 = 517$$

The neighbours to use is given in a binary format and the order is shown in the overview below in decimal and binary values for the top and bottom half.

top half

128	1	2
64	DeadPix	4
32	16	8

0b1000 0000	0b0000 0001	0b0000 0010
0b0100 0000	DeadPix	0b0000 0100
0b0010 0000	0b0001 0000	0b0000 1000

bottom half

32	16	8
64	DeadPix	4
128	1	2

0b0010 0000	0b0001 0000	0b0000 1000
0b0100 0000	DeadPix	0b0000 0100
0b1000 0000	0b0000 0001	0b0000 0010

Example values for the masking:

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$$NrOfDefPix = 0x03$$
$$DeadPixAdr[0] = 0x000F \rightarrow \text{Pixel 15}$$
$$DeadPixAdr[1] = 0x012C \rightarrow \text{Pixel 300}$$
$$DeadPixAdr[2] = 0x0295 \rightarrow \text{Pixel 661 (read - out pixel) actual pixel number is 977}$$
$$DeadPixMask[0] = 0x7C \rightarrow 0b01111100\ (\text{top})$$
$$DeadPixMask[1] = 0x8F \rightarrow 0b10001111\ (\text{top})$$
$$DeadPixMask[2] = 0xFE \rightarrow 0b11111110\ (\text{bot})$$

The readout order is the same as shown in 5.
According to the sample values 3 Pixels are defect and need to be interpolated. 2 Pixels are on the top and 1 Pixel on the bottom half. Assuming that the neighbouring Pixels are having the temperature data stated below and the green marked cells are used for averaging (according to DeadPixMask) then the interpolated temperature will be the following:

$$\text{Pixel } 15 = \frac{3007 + 3008 + 3008 + 3011 + 3009}{5} dK = \frac{15043}{5} dK \approx 3009 dK$$
$$\text{Pixel } 300 = \frac{3010 + 3012 + 3005 + 3008 + 3009}{5} dK = \frac{15044}{5} dK \approx 3009 dK$$
$$\text{Pixel } 977 = \frac{3010 + 3012 + 3005 + 3007 + 3008 + 3008 + 3009}{7} dK = \frac{21059}{7} dK \approx 3008 dK$$

All values are given in dK

3007	Pixel 15	3008
3008	3011	3009

Pixel 14	Pixel 15	Pixel 16
Pixel 46	Pixel 47	Pixel 48

3010	3012	3005
3007	Pixel 300	3008
3008	3011	3009

Pixel 267	Pixel 268	Pixel 269
Pixel 299	Pixel 300	Pixel 301
Pixel 331	Pixel 332	Pixel 333

3010	3012	3005
3007	Pixel 977	3008
3008	3011	3009

Pixel 944	Pixel 945	Pixel 946
Pixel 976	Pixel 977	Pixel 978
Pixel 1008	Pixel 1009	Pixel 1010

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9.8 Look-up Table

The matching look-up table has to be taken from the Table.c file. Here is just shown an exemplary data for one optics.

To in dK

dig \ Ta[dK]	2782	2882	2982	3082	3182	3282	3382
-512				1295	1742	2005	2202
-448				1848	2094	2284	2442
-384				2156	2340	2496	2634
-320				2381	2534	2671	2797
-256	2042	2244	2414	2562	2697	2822	2938
-192	2287	2445	2587	2717	2839	2954	3065
-128	2481	2612	2735	2852	2964	3073	3180
-64	2642	2755	2865	2972	3078	3182	3285
0	2782	2882	2982	3082	3182	3282	3382
64	2906	2996	3089	3183	3278	3375	3473
128	3019	3101	3187	3276	3368	3462	3558
192	3121	3197	3278	3363	3452	3544	3638
256	3216	3286	3363	3445	3531	3621	3715
320	3305	3370	3443	3522	3606	3695	3787
384	3387	3449	3519	3595	3677	3764	3856
448	3465	3524	3590	3664	3745	3831	3922
512	3539	3595	3659	3731	3810	3895	3986
576	3609	3662	3724	3794	3872	3957	4047
640	3676	3727	3787	3855	3932	4016	4106
704	3740	3788	3847	3914	3990	4073	4163
768	3802	3848	3904	3971	4046	4128	4218
832	3861	3905	3960	4025	4100	4182	4271
896	3918	3960	4014	4078	4152	4233	4322
960	3973	4014	4066	4129	4202	4284	4372
1024	4026	4065	4117	4179	4251	4332	4421
1088	4077	4115	4166	4227	4299	4380	4469
1152	4127	4164	4213	4274	4345	4426	4515
1216	4175	4211	4260	4320	4391	4471	4560
1280	4222	4257	4305	4364	4435	4515	4604
1344	4268	4302	4349	4408	4478	4558	4647
1408	4312	4345	4391	4450	4520	4600	4689
1472	4355	4388	4433	4491	4561	4641	4730
1536	4398	4429	4474	4532	4601	4681	4770
1600	4439	4470	4514	4571	4640	4720	4809
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1728	4519	4548	4591	4648	4716	4796	4885
1792	4558	4586	4629	4685	4753	4833	4922
1856	4595	4623	4666	4721	4790	4869	4959
1920	4633	4660	4702	4757	4825	4905	4995
1984	4669	4696	4737	4792	4860	4940	5030
2048	4705	4731	4772	4826	4894	4974	5064
2112	4740	4765	4806	4860	4928	5008	5098
2176	4774	4799	4839	4894	4961	5041	5131
2240	4808	4832	4872	4926	4994	5074	5164
2304	4841	4865	4904	4958	5026	5106	5197
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2496	4937	4960	4998	5052	5119	5199	5291
2560	4968	4991	5029	5082	5149	5230	5321
2624	4999	5021	5059	5112	5179	5259	5351
2688	5029	5050	5088	5141	5208	5289	5381
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3200	5255	5274	5310	5362	5429	5510	5604
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3328	5308	5326	5362	5414	5481	5563	5656
3392	5334	5352	5388	5439	5507	5588	5682
3456	5360	5377	5413	5465	5532	5613	5708
3520	5385	5403	5438	5489	5557	5638	5733
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13568	7746	7751	7781	7836	7914	8015	8135
13632	7757	7761	7791	7846	7925	8025	8145
13696	7767	7771	7801	7856	7935	8035	8156
13760	7777	7781	7811	7866	7945	8046	8166
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13888	7797	7801	7831	7886	7965	8066	8187
13952	7807	7811	7841	7896	7975	8076	8197
14016	7817	7821	7851	7906	7985	8086	8207
14080	7827	7831	7861	7916	7995	8096	8218
14144	7836	7841	7871	7926	8005	8106	8228
14208	7846	7851	7881	7936	8015	8116	8238

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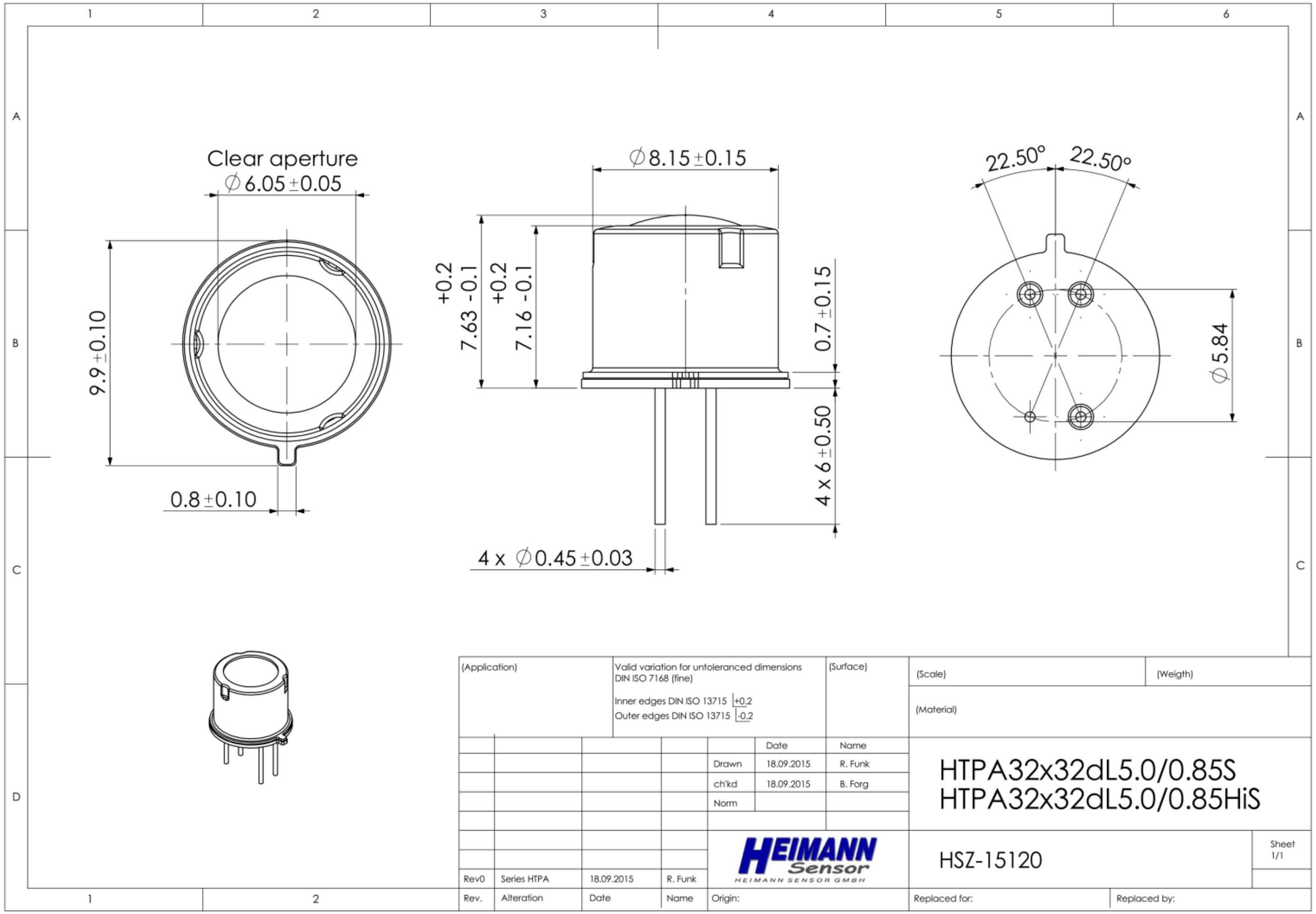
10 Outer Dimensions (without external aperture):



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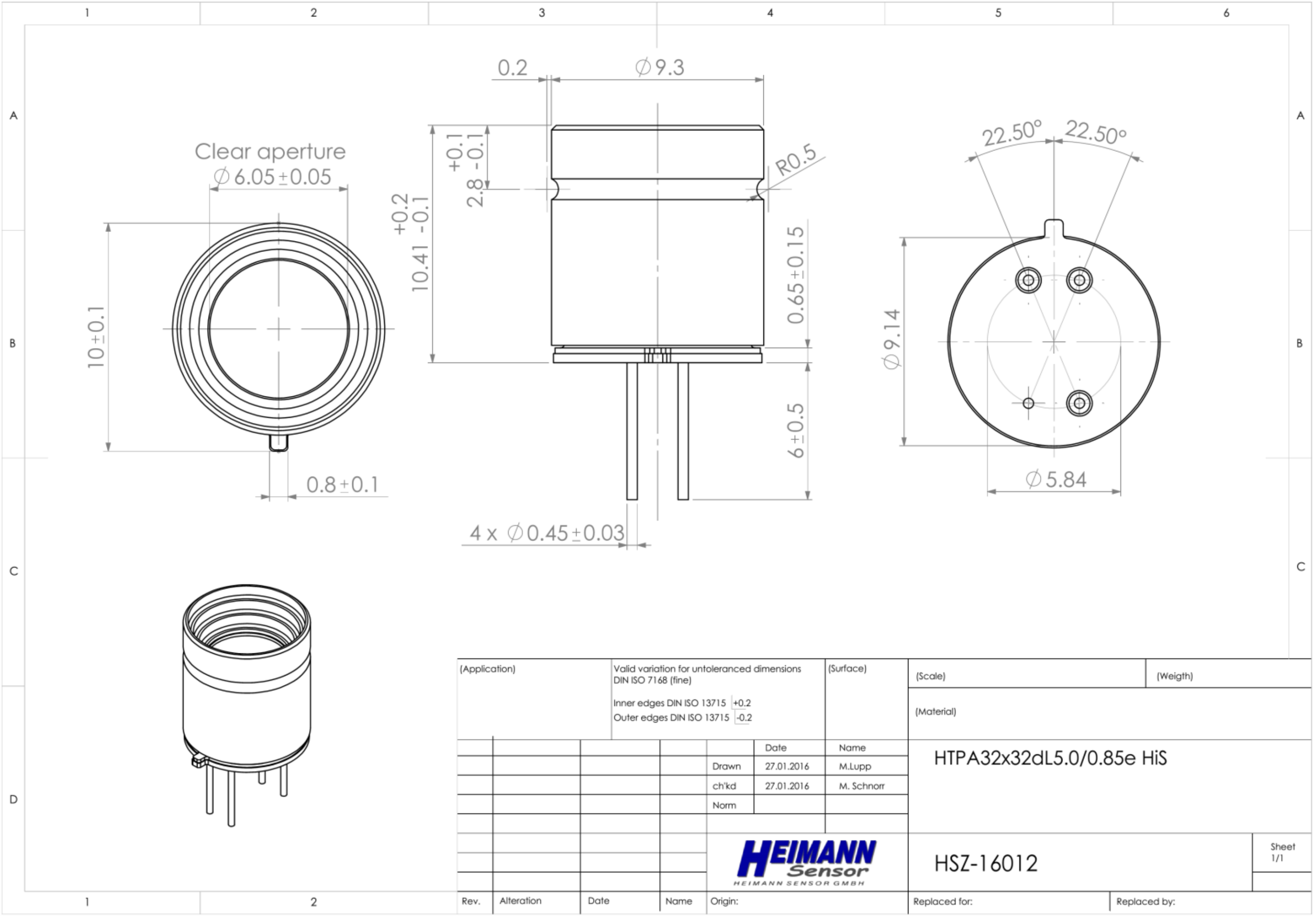
Outer Dimensions (with external aperture, standard):



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