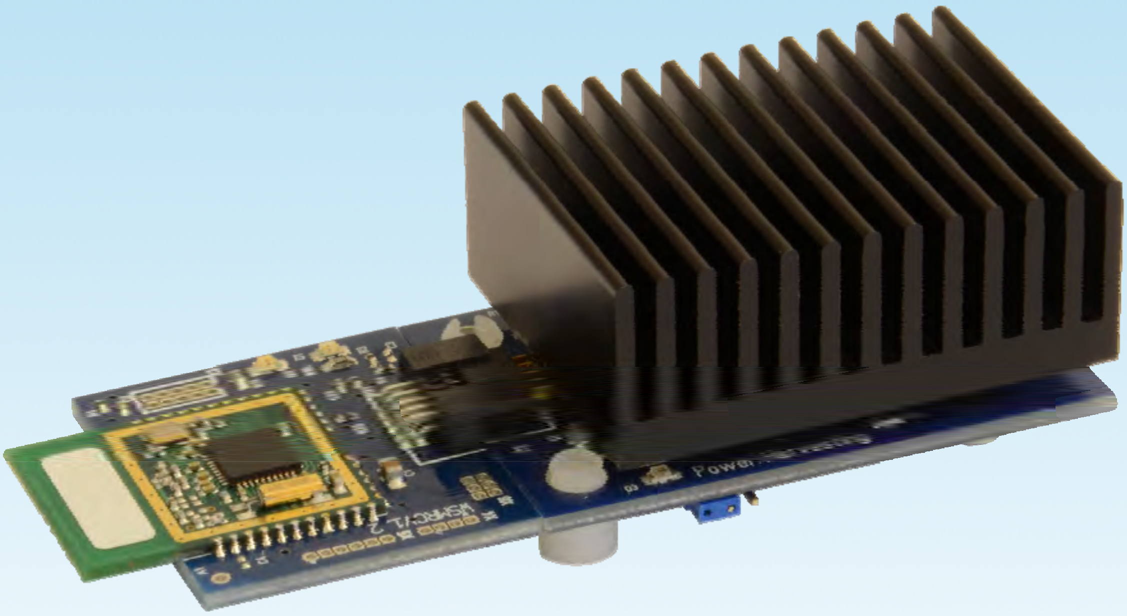
# TE-CORE /RF

## ThermoHarvesting Wireless Sensor System

## Featuring ThermoGenerator-in-Package

- TGP-651
- TGP-751

Preliminary Datasheet



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## Contents

## Contents

**Congratulations !**

You have chosen a powerful and versatile thermal energy harvesting module. The TE-CORE /RF serve you for desk and lab evaluation purposes or it may be used as an embedded green power supply for energy autonomous low-power electrical systems - typically with low duty cycles for control or maintenance.

We appreciate your choice of using Micropelt's thermoharvesting technology to explore the use of free ambient thermal power or waste heat instead of batteries. For a smooth start and sustainable success with your new device, please consider the following:

- Avoid intensive mechanical stress on the heat sink (shear or shock).
- Do not expose the TE-CORE /RF Module to temperatures exceeding 105 °C [221°F].
- Protect the device against extensive humidity and direct water exposure
- The heat sink may be removed or replaced with appropriate care.

## Important Notices – Please read carefully prior to use

### 1. Micropelt Products are prototypes

Micropelt supplies *thermoelectric* coolers and *generators,* as well as *energy harvesting modules* (hereinafter referred to as “Prototype Products”). The Prototype Products distributed by Micropelt to date are prototypes that have not yet been released to manufacturing and marketing for regular use by end-users. The Prototype Products are still being optimized and continuously tested. As such, the Prototype Products may not fully comply with design-, marketing-, and/or manufacturing-related protective considerations, including product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards.
In addition, the Products have not yet been fully tested for compliance with the limits of computing devices, neither pursuant to part 15 of FCC rules nor pursuant to any other national or international standards, which are designed to provide reasonable protection against radio frequency interference.

### 2. Use of Products restricted to demonstration, testing and evaluation

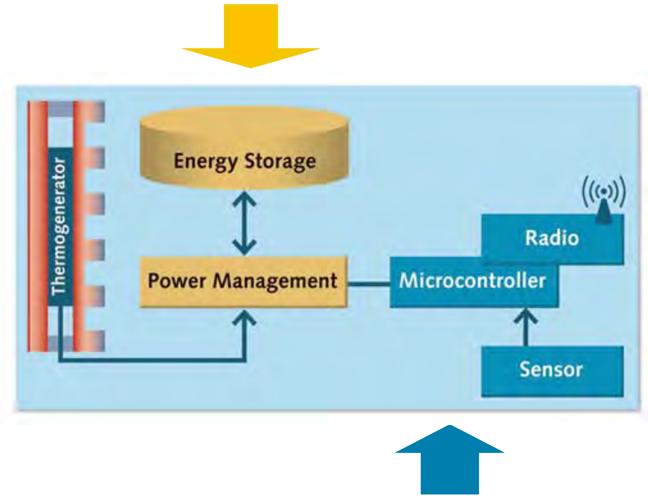
Micropelt’s Prototype Products are intended exclusively for the use for demonstration, testing and evaluation purposes.
The Prototype Products must not be used productively. In particular, the Prototype Products must not be used in any safety-critical applications, such as (but not limited to) life support systems, near explosion endangered sites, and/or any other performance critical systems.
The Prototype Products must only be handled by professionals in the field of electronics and engineering who are experienced in observing good engineering standards and practices.

# 1. Introduction

## 1.1 System Introduction

The TE-CORE /RF is a complete thermo-powered, self-sufficient wireless sensor node system (WSN).

The TE-CORE /RF is based on an **Energy Harvesting module** with power management function, which converts locally available waste heat thermoelectrically to indefinite free electric energy.



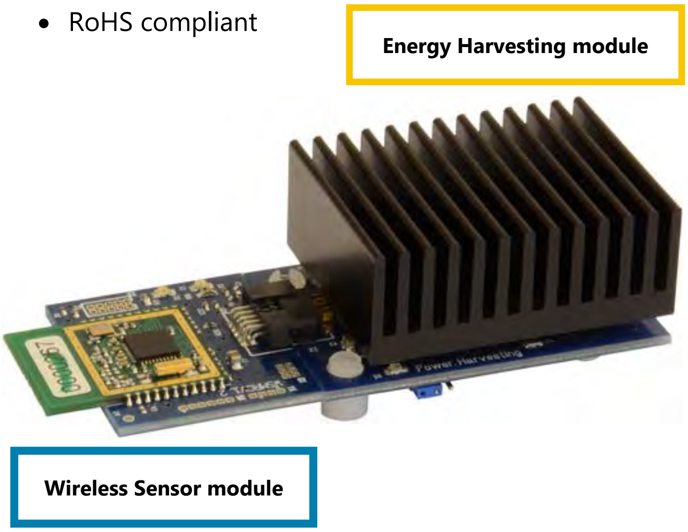

A **Wireless Sensor module** is connected to the TE-CORE /RF and is equipped with Texas Instruments (TI) ultra-low power technology (CC2530).

A temperature difference as little as 10 °C between a hot surface and ambient air is enough for the TE-CORE /RF to make a temperature measurement and a radio transmission every two seconds.
Via an USB receiver and PC application software, information about the thermal profile of the heat source, the generated output power, the thermal generator output voltage, the energy storage voltage and battery equivalent are displayed.

## 1.2 Features

- Operates from temperature differentials of < 10 °C between a surface and ambient
- Connector for (pre-certified) radio modules,
- Standard equipped with pre-qualified ETSI EN 300 440-2 V1.4.1., iM222A Zigbee Network Processor of IMST, operating in 2.4 GHz ISM band
  http://www.wireless-solutions.de/wireless-solutions/en/products/zigbee/im222aproz.php

  datasheet http://www.wireless-solutions.de/wireless-solutions/en/support/hardware-dokumente/im222aproz/iM222A-ZNP_Datasheet_V2_0.pdf
- iM222a is based on Texas Instruments (TI) CC2530 SoC, tailored for IEEE 802.15.4 and Zigbee
- Application software TE-Power SCOPE for thermal and electrical evaluation and simulation
- Duty-cycle 2 seconds
- Average energy consumption is <90 µW
- Interfaces available: I2C, SPI, GPIO's and JTAG
- High-efficiency low-cost DC-DC booster
- Supports Micropelt thermogenerator packages TGP-751 (TE-CORE7 /RF) and TGP-651 (TE-CORE6 /RF)
- RoHS compliant




## 1.3 Applications

Maintenance-free wireless sensors and actuators:

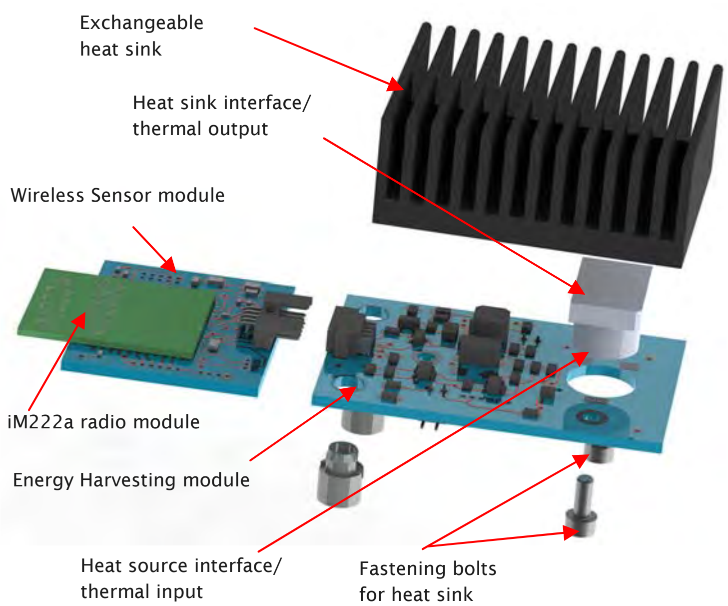
- Wireless sensors and sensor networks (WSN)
- Autonomous intelligent valves
- Industrial process control & condition monitoring
- Thermal event logging and alerting
- Smart metering
- Remote sensing & tracking

## 1.4 Modular Thermo-Mechanical Design

The **Energy Harvesting module** of the TE-CORE /RF operates from a heat (or cold) thermal energy source. The TGP's aluminum top side, its thermal input, is supposed to be attached to the heat source. The thickness of the thermal input acts as a spacer to protect the PCB and to ensure a thermal separation between the hot and cold sides; i.e. optimizing energy harvesting performance through suppression of thermal 'cross talk'.

The thickness of the TGP's thermal output was chosen to provide an initial heat spreading effect towards a heat sink and at the same time allowing for population of electronic components next to the TGP, even below the heat sink which usually extends well over the footprint of the TGP.

**TE-CORE /RF main components**




## 1.5 Absolute Maximum Ratings

Please ensure that during operation of the TE-CORE /RF system the below maximum ratings, see below, are not exceeded:

| | min | TYP | max |
|---|---|---|---|
| Hot side temperature | +10 °C | - | + 100 °C |
| Operating temp | 0 °C | | + 70 °C |
| Storage temp | +5 °C | | + 35 °C |
| ESD sensitivity | - | - | 9000 V |

## 1.6 Mechanical and Thermal Interfaces

The PCB and the heat sink are connected by two fastening screws, which fixes the TPG at the same time. Clamping force is max. 25 cNm, because of PCB. (see picture "TE-CORE /RF main components") Between TGP and the heat sink a Graphite foil ensures a good thermal path. eGraph type Hitherm 2505 with 127µm is used as thermal interface material.

## 1.7 Available Versions

The TE-CORE/RF ThermoHarvesting Wireless Sensor System is available in two variations, differentiated by two thermal generator types:

- **TE-CORE7 /RF**: TGP-751 *(thin-film TEG MPG-D751 )*
- **TE-CORE6 /RF:** TGP-651 *(thin-film TEG MPG-D651)*

**Select TE-CORE7 over TE-CORE6 for:**

- operation at lowest temperature gradients
- higher output power with better heat sink;
  —> 2x power over the TE-CORE6 is possible.

| | TE-CORE7 /RF | TE-CORE6 /RF |
|---|---|---|
| DC-DC startup at 25 °C ambient | 33.5 °C<br>92.3 °F | 35.0 °C<br>95.0 °F |

## 2 Introducing the TGP Package

Micropelt thermogenerators offer a unique power density, but mechanically they are quite sensitive. The TGP packaged generator protects the TEG chip, facilitates system integration and automated assembly. Its robustness simplifies thermal coupling and maximizes power output.

### 2.1 TGP Properties

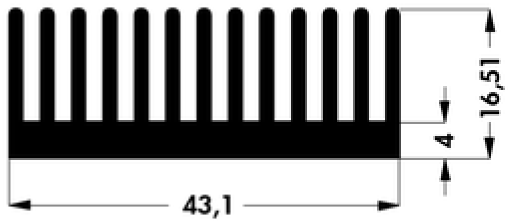
| **Properties of TGPs** | **TGP-751** | **TGP-651** |
|---|---|---|
| TEG chip inside | MPG-D751 | MPG-D651 |
| Electrical resistance $R_i$ | 200 - 350 Ω | 150 - 230 Ω |
| Thermal resistance $R_{th}$ | 18 K/W | 28 K/W |
| Thermovoltage S | 110 mV/K | 60 mV/K |
| Footprint (l x w x h) | 15 x 10 x 9.3 mm | |

### 2.2 Output Power Performance in Application

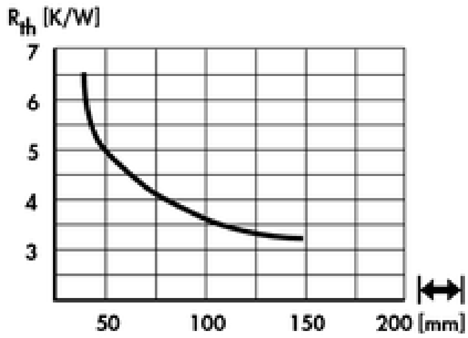
The matched output power depends on the characteristics of the thermal path from heat source to ambient (cold side). The heat sink type, dimensions and position are of influence.

The TGP measurements are done with TE-CORE7 and TE-CORE6, using different heat sinks from Fischer Elektronik, type Sk422 with a length of 33 mm, 50 mm and 90 mm, **placed in vertical position and thermal compound (paste) between the hot source and the thermal input.**

**TGP thermal generator in package**




Dimensions Sk422 heat sink

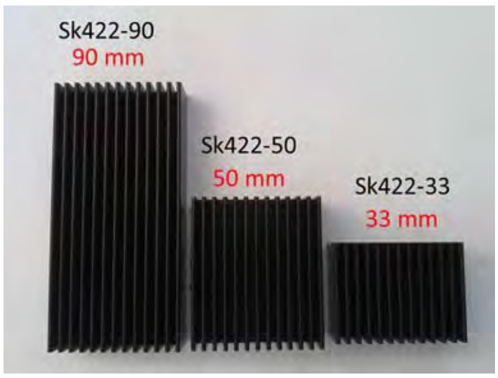



Performance diagram of Sk422 heat sink

Supplier of heat sink: www.fischerelektronik.de

For direct link to heatsink page use link below

http://tinyurl.com/cw9aun6

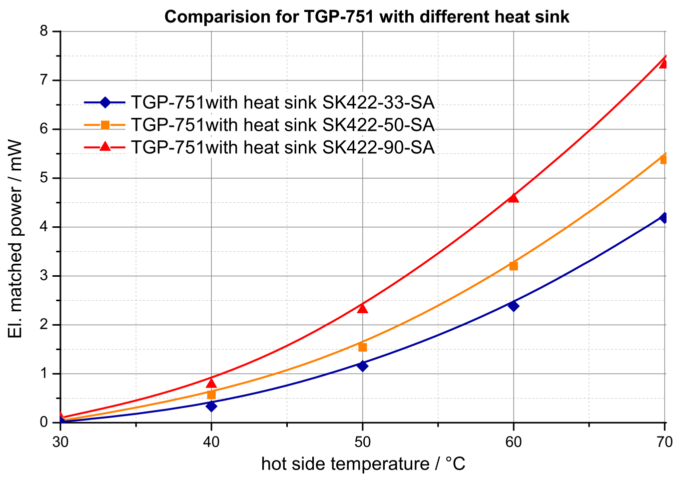


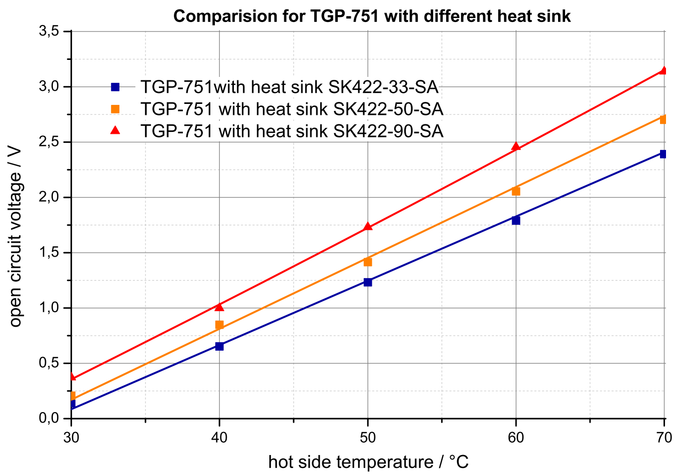

Different heat sink types of Sk422

**Vertical test position of TE-CORE /RF with heat sink Sk422-33**

## 2.3 TGP Electrical Performance without DC-DC Booster

The direct output performance of the TGP devices are measured at an ambient temperature of 25 °C with heat sink fins in vertical orientation for best natural convection (see § 4.1).

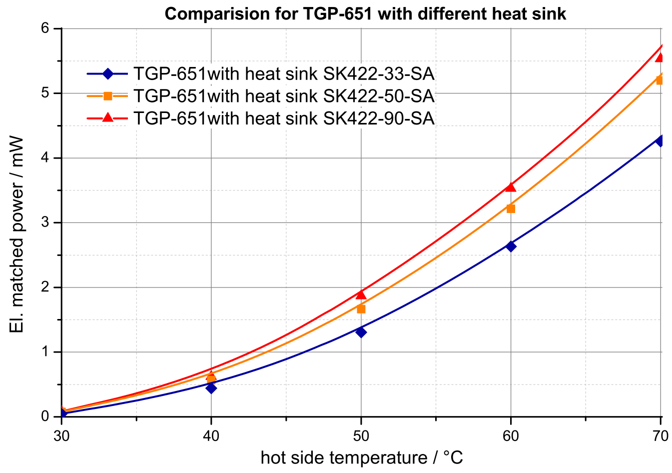


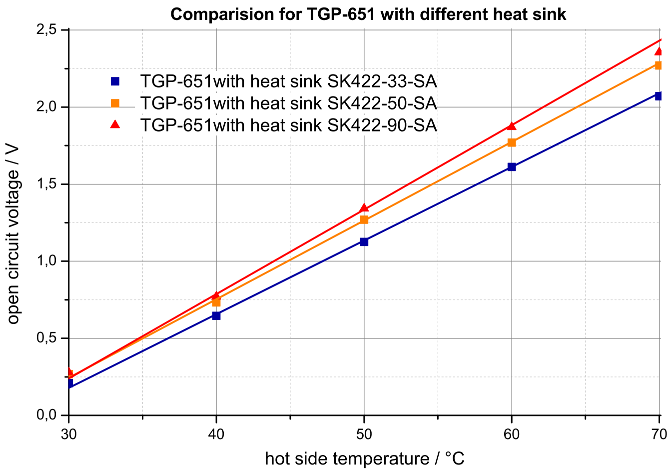



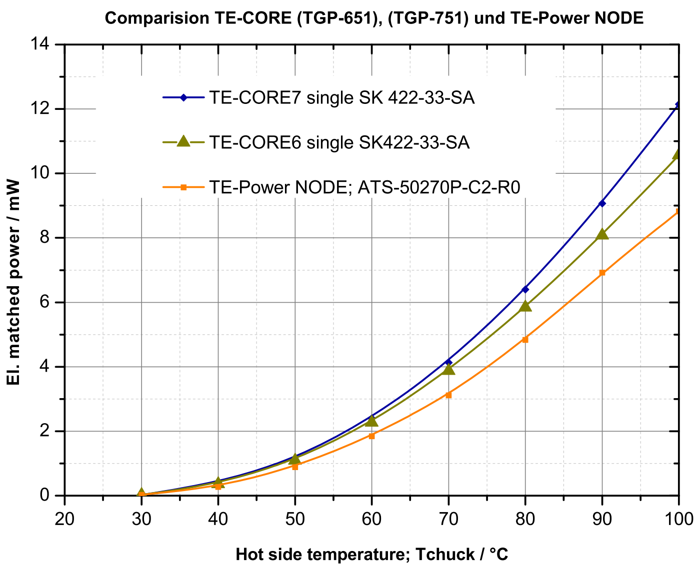

The performance of the TGP-751 exceeds that of the reference system TE-Power ONE/NODE, although both are based on the same TEG MPG-D751 chip.
A reduced parasitic heat flux by using the TGP component causes this improvement.

The difference in performance between TGP-D651 and TGP-D751 increases with heat sink performance and higher gross temperature differentials.

The diagrams provide the output- voltages and power of TGP-751 and TGP-651, each integrated in a standard TE-CORE module. DC-DC Booster is not used.
Between the heat source and thermal input of the TGP, thermal paste is used for a good thermal connection.

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## 2.4 Output Power and Battery Benchmark

The next table lists selected output characteristics of the TGP-751, integrated in a TE-CORE7 /RF **Energy Harvesting module** in standard configuration and under standard lab conditions. The DC-DC booster is not used.
For an easy matching with known battery consumption figures an annual 'gross' harvesting result is provided., assuming constant thermal conditions.

**TGP Output power and Battery-Equivalent (at 25°C ambient)**

| | $T_{hot}$ [°C] | $U_{oc}$ [Volt] | Power [mW] | Annually [mAh] | Batteries [AA] |
|---|---|---|---|---|---|
| **TE-CORE7 /RF*** | 40 | 0.56 | 0.36 | 2.102 | 1-2 |
| EH module | 50 | 0.96 | 1.1 | 6.424 | 3-4 |
| | 60 | 1.4 | 2.2 | 12.848 | > 6 |

*Heat sink: Fischer Electronic, Sk422-33-SA

The output voltage of the TGP-751 at a given external (gross) temperature differential is higher than the TGP-651 one. Hence the DC-DC booster starts at lower ΔT conditions. Better starting conditions may be achieved by using a more efficient heat sink, as mentioned in the following table (at ambient 25°C / 77°F): The TE-CORE / RF will start operation at an open circuit TGP voltage of typical 360 mV and therefore under the next temperature profile conditions:

| | Small HS *(Sk422 33)* | Midsize HS *(Sk422 50)* | Larger HS *(Sk422 90)* |
|---|---|---|---|
| **TE-CORE6 /RF** | 35.0 °C [95.0 °F] | 34.5 °C [94.1 °F] | 33.5 °C [92.3 °F] |
| **TE-CORE7 /RF** | 33.5 °C [92.3 °F] | 33.0 °C [91.4 °F] | 32.0 °C [89.6 °F] |

The next table describes the increase of output power with different heat sink sizes, which can be used in combination with the **Energy Harvesting module**:

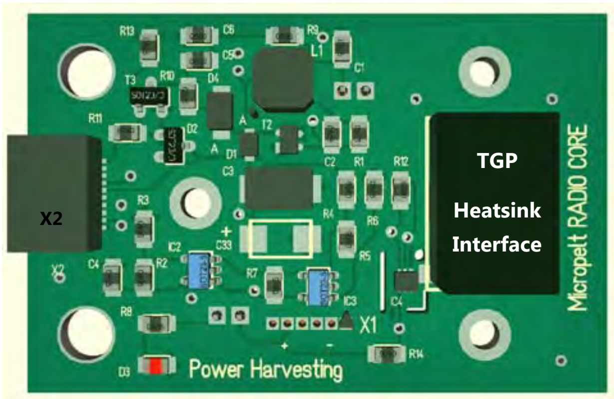
| | Small HS *(Sk422 33mm* | Midsize HS *(Sk422 50)* | Larger HS *(Sk422 90)* |
|---|---|---|---|
| **TE-CORE6 /RF** | 100% | 125% | 135% |
| **TE-CORE7 /RF** | 100% | 130% | 185% |

TE-CORE7 /RF with a bigger heat sink generates a significant increased output power, due to the lower thermal resistance of TPG-751. Whereas for TE-CORE6 /RF the advantages of large heat sinks are limited.

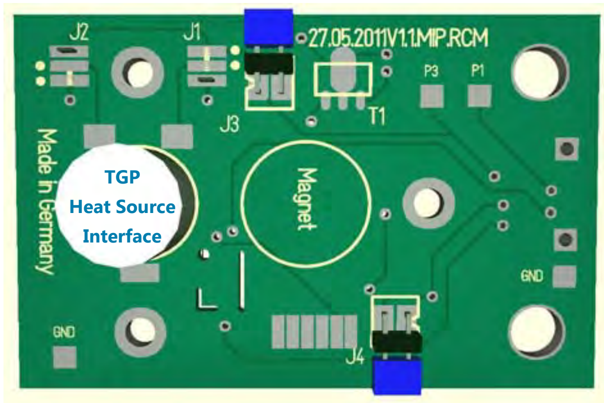
# 3. TE-CORE /RF Components and Connectors

## 3.1 Energy Harvesting board

### *3.1.1 DC-DC booster module hardware*




**PCB top view**




**PCB bottom view**

TGP: TGP-751 or TGP-651

X2: Connector for external radio board
Zigbee Network Processor module
iM222A from IMST with TI CC2530 TI SoC

$C_3$: Storage capacitor 220 µF

$C_{33}$: Capacitor extension interface

X1: Additional contacts for Vcc (2) and GND (5)

$J_1$, $J_2$: Soldering pads output polarity selection

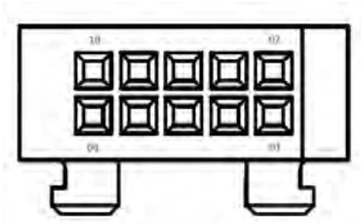
$J_3$: Jumper to disconnect TGP from
DC-DC booster / power management

$J_4$: Jumper to connect indicator LED $D_3$

$P_1$: Test pad for voltage value at storage capacitor

$P_3$: Raw TGP voltage output

Magnet - Mounting position for permanent magnet



**X2 Pin position** for SFMH connector from SAMTEC Model SFMH-105-02-L-D-LC, pitch 1.27 mm (Front view)

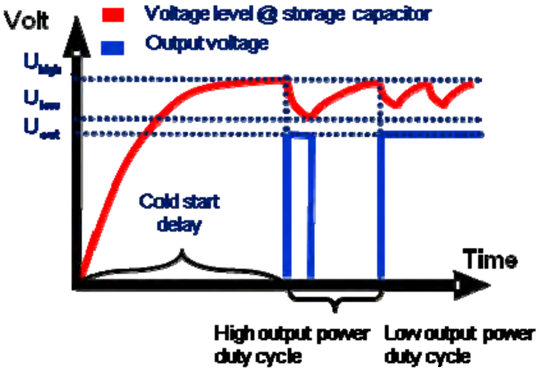
**X2 - Terminal connector to Wireless Sensor module**

| X2 PIN NO | X2 PIN NAME | IMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 01, 05, 09 | GND | GND | GND | Ground connection | Supply |
| 02 | SCL* | GPIO3 | P1_0 | $I^2C$ Clock wire | IN/OUT |
| 03 | SDA* | reserved | P1_1 | $I^2C$ Data wire | IN/OUT |
| 04 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) | Supply |
| 06 | Ucap | GPIO0/AIN0 | P0_0 | Ucap (Voltage measurement at storage capacitor) | OUT |
| 07 | Uteg | GPIO1/AIN1 | P0_1 | Measurement from TGP voltage | OUT |
| 08 | | | | not wired | |
| 10 | GPIO2 | GPIO2 | P0_6 | IO wire to T3 control (TGP open circuit voltage measurement) | IN |

** pull up 10 kOhm resistor R12 and R14 for $I^2C$ interface*

### 3.1.2 DC-DC Booster

The TGP output voltage is up-converted to a maximum voltage of 5.5 V. The harvested energy is buffered in capacitor $C_3$. A configurable hysteresis control ensures that the buffer is charged before the output voltage is activated and switches off the output voltage when the buffer has not enough energy to operate. The output voltage is controlled by a configurable comparator.




### 3.1.3 Storage Charge Hysteresis Configuration

The comparator (IC2, MICREL *MIC833*) turns the output ON, once the voltage of capacitor $C_3$ reaches $U_{high}$ ; set by the resistors $R_4$, $R_5$ and $R_6$ according the equations below. The output is turned OFF when the voltage of $C_3$ is below $U_{low}$ ; so the entire harvested energy is used to recharge the storage capacitor $C_3$.

$$U_{low} = U_{ref} \cdot \left(\frac{R4 + R5 + R6}{R5 + R6}\right) \quad \textbf{(Eq. 1)}$$

$$U_{high} = U_{ref} \cdot \left(\frac{R4 + R5 + R6}{R6}\right) \quad \textbf{(Eq. 2)}$$

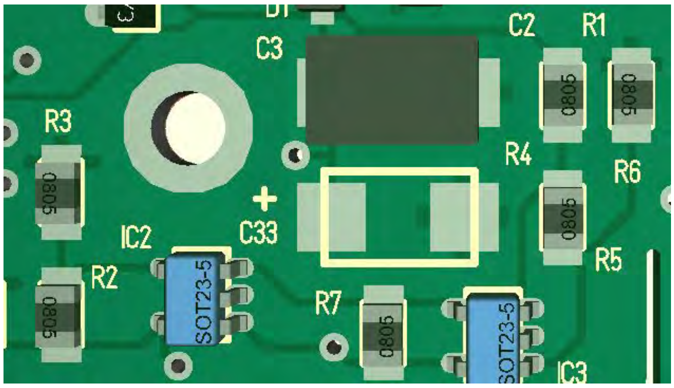
$$U_{ref} = 1.24 \; Volt$$

### 3.1.4 Output Voltage Configuration

The comparator ($IC_3$, TI *TPS780 Series*) controls the configurable constant output voltage of the Energy Harvesting module (2.4 V by default) as long as the voltage from $IC_2$ is ON. The voltage level is set by the resistors $R_2$ and $R_3$ according Equation 3.

$$U_{out} = U_{FB} \cdot \left(1 + \frac{R2}{R3}\right) \quad \textbf{(Eq. 3)}$$

$$U_{FB} = 1.216 \; Volt$$




**Power Management Circuitry**

Above screenshot shows the voltage regulator $IC_2$ TPS78001, the hysteresis comparator MIC833 and the related resistors $R_2$ - $R_6$.
To change the TE-CORE output voltage and/or hysteresis, please refer the table below. Use equations 1, 2 and 3 to calculate different settings.

| Voltage regulator | | | Comparator hysteresis | | | | |
|---|---|---|---|---|---|---|---|
| Uout [V] | $R_3$ [MΩ] | $R_2$ [MΩ] | $R_4$ [kΩ] | $R_5$ [kΩ] | $R_6$ [kΩ] | $U_{low}$ [V] | $U_{high}$ [V] |
| 1.8 | 2 | 0.953 | 470 | 200 | 680 | 1.9 | 2.46 |
| 2.0 | 2 | 1.3 | 550 | 150 | 680 | 2.1 | 2.5 |
| 2.4 | 2 | 2 | 1100 | 200 | 860 | 2.5 | 3.1 |
| 2.7 | 1.5 | 1.8 | 1000 | 150 | 680 | 2.73 | 3.3 |
| 3.0 | 1 | 1.5 | 1500 | 150 | 845 | 3.1 | 3.66 |
| 3.3 | 1 | 1.8 | 2500 | 249 | 1200 | 3.37 | 4.1 |
| 4.5 | 1 | 2.7 | 2000 | 75 | 680 | 4.52 | 5 |

### 3.1.5 Thermogenerator Direct Access

De-solder contacts of $J_3$ to disconnect thermogenerator and power management. With open $J_3$, both open circuit voltage ($U_{oc}$) and short circuit current ($I_{sc}$) of the TEG can be measured at the circuit control points $P_3$ and $P_2$. The measured values at any specific operating point allow for calculation of the maximum available output power $P_{max}$ according Equation 4.

$$P_{max} = Uoc \cdot \frac{Isc}{4} \quad \textbf{(Eq. 4)}$$

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### *3.1.6 Energy storage*

Energy harvesting power supply implies a duty cycling application. The harvester usually does not provide enough power to run the application during its active mode. An energy storage device (buffer) is required. Capacitance and maximum current characteristics of the storage capacitor in concert with the hysteresis settings must comply with both surge current and pulse duration of the application's active cycle.

Important parameters of energy storage devices:

- Low leakage
- Low equivalent serial resistance (ESR) << 1 Ohm

**Note:** In case thin film batteries (TFB) are considered instead of capacitors, e.g. for their extremely low leakage, additional care must be taken to avoid damage of the TFB through overcharge or deep discharge.

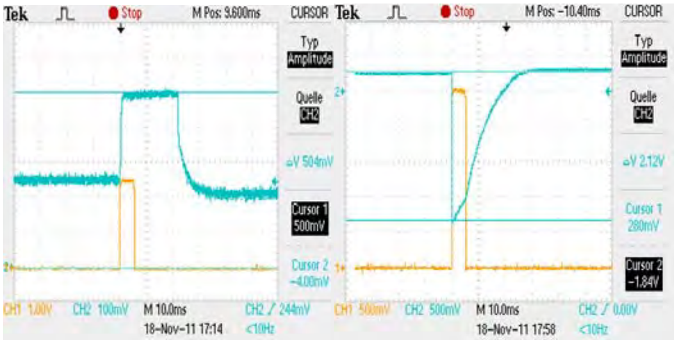
### *3.1.7 Energy Efficiency of DC-DC Booster*

Additional information about more options of the DC-DC Booster and the power efficiency can be found in the datasheet of the TE-CORE Thermoharvesting module: http://www.micropelt.com/down/datasheet_te_core.pdf

- *Characteristics*
- *Options*
- *Efficiency*
- *Calculation example storage capacitor*

### 3.1.8 *TGP output voltage measurement*

The direct output voltage of TGP will be read at port P0_1 of the CC2530 CPU (voltage divider of 1:1).




Yellow - IO Voltage (GPIO2)
Cyan - Booster Input voltage

Yellow - IO Voltage
Cyan - Voltage Pin 2 at capacitor C5

**Direct output voltage measurement at TGP**

A special circuitry is used to monitor the open circuit output voltage of the TGP and to analyze thereby the harvested output power. The oscillation circuit of the DC-DC Booster is shortly interrupted by transistor $T_2$ and the TGP output voltage is being connected to the ADC of the CPU. This interruption is being realized by pulling a 30 kOhm resistor $R_{10}$ to ground via control transistor $T_3$. The time constant for this function $t_{off}$ can be set by an RC combination ($C_5$, $R_{10}$) and should be kept longer as the required measurement time of the ADC.

**(Eq. 5)**

$$t_{off} = R_{10} \cdot C_5 = 30\,kOhm \cdot 0.22\,\mu F = 6.6\,ms$$

### 3.1.9 *Temperature sensor*

Absolute temperature of the TGP generator is measured by a digital temperature sensor from Texas Instrument TMP102.


**Temperature sensor TMP102**

The temperature sensor is located next to the "cold side" of the TGP and connected via a cupper sheet. Since the temperature gradient is directly proportional to the open circuit voltage of the TGP, the hot side temperature can be calculated and thereby the temperature gradient over the TGP generator, according equitation 6.

**(Eq. 6)**

$$Thot\ [^\circ C] = Tcold\ [^\circ C] + Uocv\ [V] \cdot 110\,[\frac{mV}{K}]$$

## 3.2 Wireless Sensor module

The TE-Power CORE /RF **Wireless Sensor module** runs exclusively on the power supplied by the TGP thermo-generator. It's purpose is to collect data from the temperature sensor, TGP output voltage and storage capacitor voltage and transmit those in an energy efficient manner wireless to the associated RF USB receiver.

A pre-qualified ETSI EN 300 440-2 V1.4.1. ,iM222A Zigbee Network Processor of IMST, operating in 2.4 GHz ISM band is used, based on TI's CC2530 SoC.

### *3.2.1 Radio Transceiver & Protocol*

The RF transceiver operates in ISM channel 11 = 2.462 GHz, RF power: +4.5dBm, data rate: 250 kBaud. The total active cycle includes one temperature and two voltage measurements, protocol preparation (14 bytes) and uni-directional point-to-point RF transmission; all done within 3.6 msec. The net "on-air" time is less than 1 msec and the duty cycle is 2 seconds.

**The Byte assignment (value) is:**

**<u>CORE Adress</u>**:

Byte 1 and 2=Transmitter address (1... 65636);

**<u>TGP cold side temperature:</u>**

Byte 3 =$T_{cold}$ low byte; Byte 4 =$T_{cold}$ high byte;

**<u>Voltage at storage capacitor:</u>**

Byte 5 =$U_{cap}$ low byte; Byte 6 =$U_{cap}$ high byte;

**<u>TGP open circuit voltage:</u>**

Byte 7 =$U_{TGP\_OCV}$ low byte; Byte 8=$U_{TGP\_OCV}$ high byte;

**<u>DC-DC Booster input voltage:</u>**

Byte 9 =$U_{TGP}$ low byte; Byte 10=$U_{TGP}$ high byte;

**<u>Sum Byte 1 + Byte 2 + ... + Byte 10:</u>**

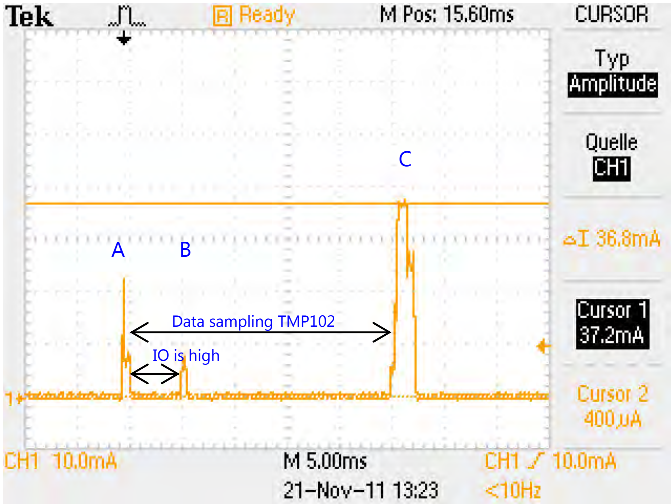
Byte 11 Checksum low byte; Byte 12 Checksum high byte;

**<u>Data terminator / end character:</u>**

Byte 13 -CR; Byte 14 - LF;

### *3.2.2 Signal processing & Radio*

The following figure presents the signal processing and measurement time and energy consumption for one operation cycle.




**Timing and Current consumption for one operation cycle**

The operation cycle contains three actions:

**<u>Point A:</u>**

Microcontroller wakes-up, from sleep mode, after which the measurement of the temperature sensor TMP102 is started and the storage capacitor voltage is being measured. Also the TGP OCV (open circuit voltage) measurement circuit is activated.

**<u>Point B:</u>**

Open circuit voltage of the TGP is being measured and the related measurement circuit deactivated.

**<u>Point C:</u>**

The temperature is being measured by TMP102. Radio is activated and data is broadcasted.

The total operating time of the system is 3.6 msec. With a duty cycle of 2 seconds, the energy consumption is:

$I_{average} = I_A \times t_A + I_B \times t_B + I_C \times t_C =$

$= (10mA \times 1ms + 6mA \times 0.85ms + (36.8mA \times 1ms +$

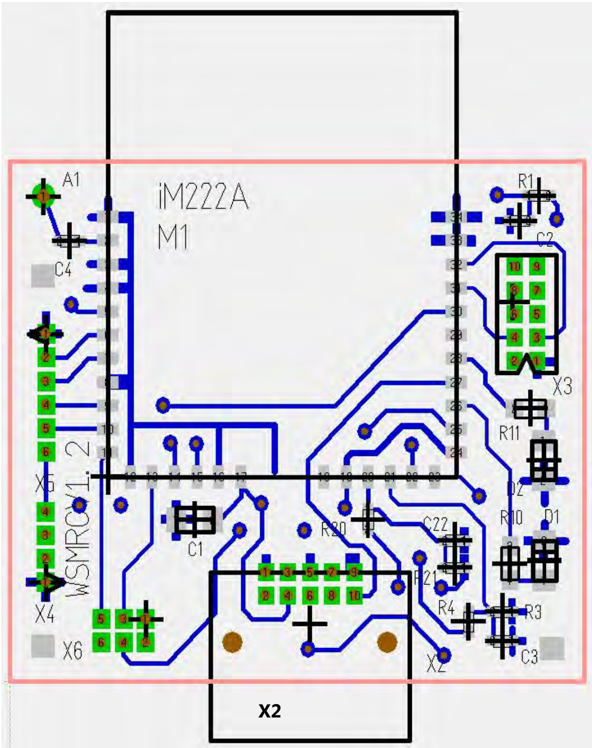
$+ 25mA \times 0.75ms)) / 2sec$

$\boldsymbol{I_{average} = 35.3\ \mu A \cdot sec}$

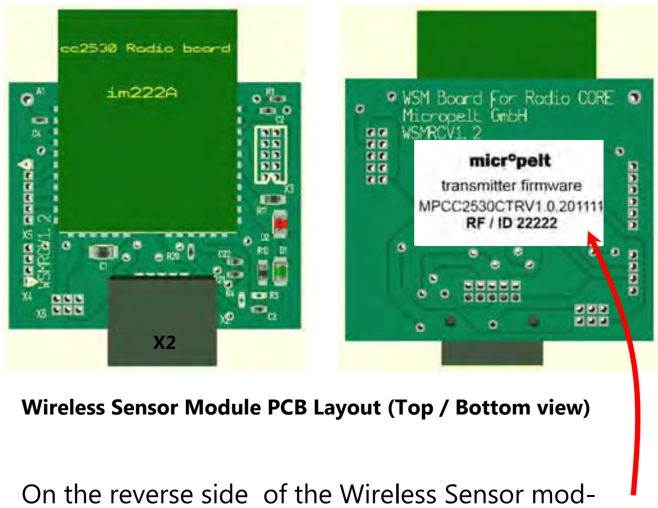
$\boldsymbol{P_{average} = I_{average} \cdot U_{supply}}$

$\boldsymbol{P_{average} = 35.3\ \mu A \cdot sec \cdot 2.45\ V = 86.5\ \mu W \cdot sec}$

### *3.2.3 Wireless Sensor module hardware*

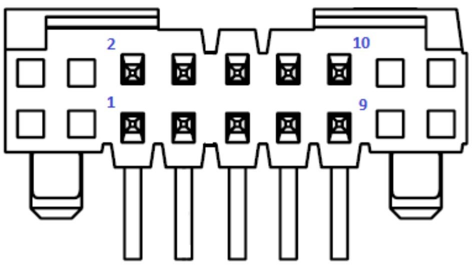



**Wireless Sensor Module, Component Placement (Top view)**




**Wireless Sensor Module PCB Layout (Top / Bottom view)**

On the reverse side of the Wireless Sensor module a label gives the Firmware ID and a unique TE-CORE /RF module ID Number. The module ID is sent to the PC receiver, refer §5 TE-Power SCOPE Software.




**X2 - Pin position** for FSH connector from SAMTEC Model FSH-105-04-L-RA-SL, pitch 1.27 mm (Front view)

## X2 - Terminal connector to Energy Harvesting module

| X2 PIN NO | X2 PIN NAME | IMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 01, 05, 09 | GND | GND | GND | Ground connection | Supply |
| 02 | SCL* | GPIO3 | P1_0 | $I^2C$ Clock wire | IN/OUT |
| 03 | SDA* | reserved | P1_1 | $I^2C$ Data wire | IN/OUT |
| 04 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) | Supply |
| 06 | Ucap | GPIO0/AIN0 | P0_0 | Ucap (Voltage measurement at storage capacitor) | OUT |
| 07 | Uteg | GPIO1/AIN1 | P0_1 | Measurement from TGP voltage | OUT |
| 08 | | | | not wired | |
| 10 | GPIO2 | GPIO2 | P0_6 | IO wire to T3 control (TGP open circuit voltage measurement) | IN |

** pull up 10 kOhm resistor for $I^2C$ interface , refer §3.1*

## X3 - µC programming JTAG connector

| X3PIN NO | X3 PIN NAME | IMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 1 | GND | GND | GND | Ground connection | Supply |
| 2 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) Target | Supply |
| 3 | DC | DC | P2_2 | Clock line for debugging and programming | IN |
| 4 | DD | DD | P2_1 | Data line for debugging and programming | IN/OUT |
| 7 | RESET | /RESET | /RESET | Low active RESET input pin | |
| 9 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) Debugger | Supply |
| 5, 6, 8, 9, 10 | | | | not wired | |

## X4 - I²C digital interface

| X4 PIN NO | X4 PIN NAME | IMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 1 | GND | GND | GND | Ground connection | Supply |
| 2 | SCL | GPIO3 | P1_0 | GPIO3 - configurable by software | IN / OUT |
| 3 | SDA | RESERVED | P1_1 | Configurable by software | IN / OUT |
| 4 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) | Supply |

## X5 - SPI digital interface

| X5 PIN NO | X5 PIN NAME | iIMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 1 | GND | GND | GND | Ground connection | Supply |
| 2 | MISO | MISO | P1_7 | SPI MISO - Master Input Save Output | OUT |
| 3 | MOSI | MOSI | P1_6 | SPI MOSI - Master Output Slave Input | IN |
| 4 | CLK | CLK | P1_5 | SPI CLK - Serial Clock | IN |
| 5 | /SS | /SS | P1_4 | SPI SS - Slave Select (low activ) | IN |
| 6 | Vcc | Vcc | Vcc | Supply voltage (typical 2.4 Volt) | Supply |

## X6 - Free IO Ports

| X6 PIN NO | X6 PIN NAME | iIMST iM222A NAME | TI CC2530 NAME | Description | PIN TYPE |
|---|---|---|---|---|---|
| 1 | P0_2 | RXD | P0_2 | RXD (UART receive pin) | IN |
| 2 | P0_3 | TXD/MRDY | P0_3 | TXD (UART transmit pin) / SPI MRDY | OUT/IN |
| 3 | P1_2 | CFGO | P1_2 | CFGO0 | IN |
| 4 | P0_4 | CTS/SRDY | P0_4 | CTS (UART CTS pin) / SPI SRDY | IN/OUT |
| 5 | P1_3 | BTL | P1_3 | Low active bootloader | IN |
| 6 | P2_0 | CFG1 | P2_0 | CFG1, GND for UART, VDD for SPI | IN |

### *3.2.4 Firmware programming*

The Wireless Sensor module can be programmed via JTAG by the CC debugger from Texas Instruments.


**CC Debugger from TI**

Connector X3 is available to contact the CC debugger via a 10-pin flat cable (2x5 1.27 mm).
More information about CC debugger can be found at:
[http://www.ti.com/lit/ug/swru197c/swru197c.pdf](http://www.ti.com/lit/ug/swru197c/swru197c.pdf)

Already compiled firmware, as HEX file, can be programmed using "SmartRF Studio" software from Texas Instruments. Description via the link (to CC debugger) above.

The Flash Software can be downloaded at:
[www.ti.com/smartrfstudio](www.ti.com/smartrfstudio)

### *3.2.5 USB RF receiver dongle*

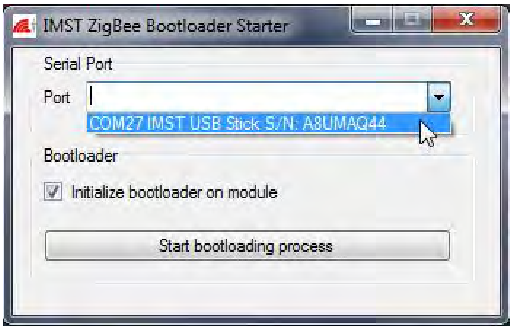
Incoming data from the TE-CORE /RF is received via the USB receiver dongle of the company IMST, (supplied with the TE-CORE /RF system) including the same iM222A radio module.

USB driver can be downloaded from the manufacturers homepage: [http://www.ftdichip.com/Drivers/VCP.htm](http://www.ftdichip.com/Drivers/VCP.htm)
For Windows PC please install only USB driver version 2.08.14.

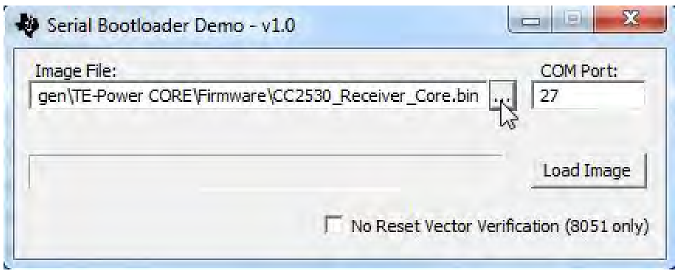
**USB receiver with and without plastic cover**

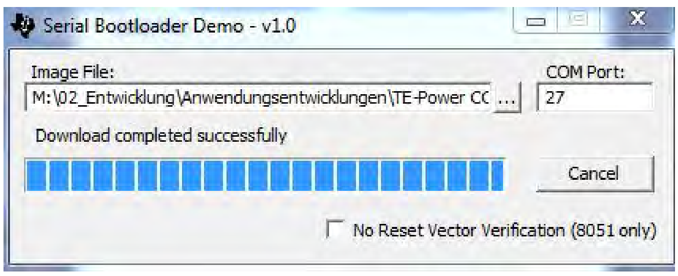

### *3.2.6 USB RF receiver firmware programming*

The USB Receiver can be programmed directly from a PC without the CC Debugger. In this case the firmware from USB receiver should be compiled to a BIN file. Put the USB Receiver to free USB Port and wait for the automatic driver installation or install the driver manually. The bootloader program "ImstZigbeeBootloderStarter.exe" must be started.

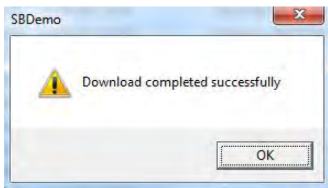



Set under "COM Port" the already installed COM port value (for example COM27) and press button "Start bootloading process". After several seconds the new program "Serial Bootloader Demo –v1.0" will automatically open.




Select the "CC2530_Receiver_Core.bin" from the file directory and select the correct COM Port name.
Finally press the button "Load Image" and wait for the program message "Download completed successfully".



# 4 Thermal and Mechanical information

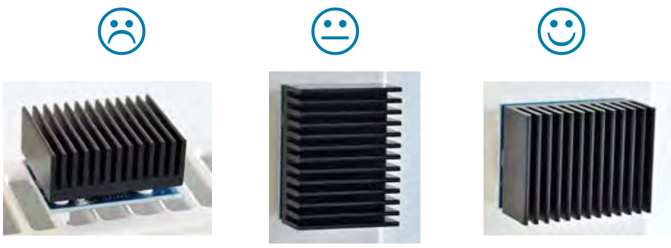
**Use thermal compound (paste) between the hot source and thermal input of the TGP, in order to achieve a good thermal performance !**

## 4.1 Heat sink and Convection

Both positioning and orientation of the TE-CORE /RF are of major importance for the harvesting yield. The orientation of the heatsink and its fins relative to the heat source and the direction of natural or forced convection deserve special attention.

Please avoid placing the TE-CORE /RF in horizontal orientation on top of a heat source. This will minimize the effective temperature differential. Prefer a mounting position on the side or underside of a heat source.

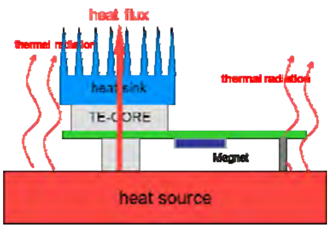
A forced air flow along the heat sink fins, e.g. from a motor fan or ventilator, usually maximizes power re-



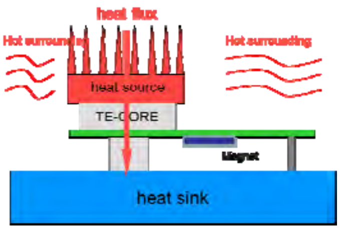
**Heat sink orientation matters!**

## 4.2 Polarity and heat flux direction

Along with a change of the heat flux direction, the polarity of the TGP's output voltage inverts.



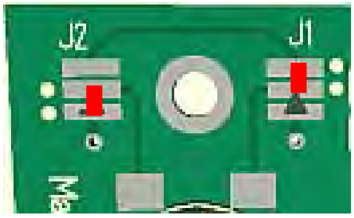

**Standard heat flux**



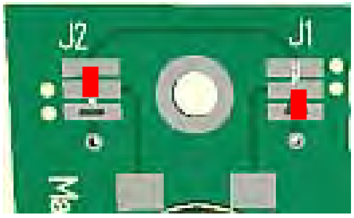

**Reverse heat flux**

Standard setting of TE-CORE /RF : the thermal input is the hot side and the heat sink is the cold side or room temperature.

Due to the uni-polar design of the TE-CORE /RF, a manual polarity option is provided. Solder pads are available on the bottom side of the PCB ($J_1$ and $J_2$), by which the polarity can be determined.



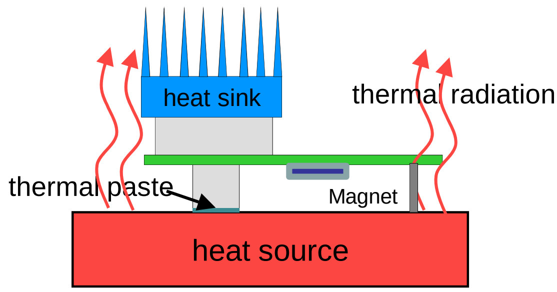

**Solder pads $J_1$ and $J_2$** connection for heat flux direction (standard delivered)




**Solder pads $J_1$ and $J_2$** connection for reversed heat flux direction

## 4.3 Connection to hot source

The best method to connect the TE-CORE /RF to a hot source is:

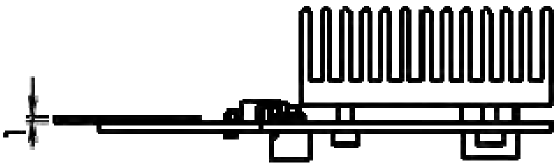


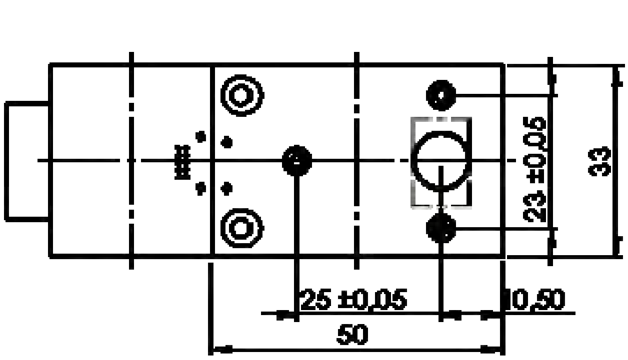

- **Magnetic surface** - in this case simply use the magnet on the reverse side from TE-CORE /RF
- **None magnetic surface** - use the enclosed self-adhesive magnetic disks to connect to the hot surface. Just remove the protector foil from the self-adhesive magnetic disks and connect to the warm surface.
- With bolts a firm connection is achieved between the thermal input and the hot source. Attach bolts though the isolated rings of the Energy Harvesting module.

**Thermal compound (paste) must be used between the hot source and thermal input of the TGP**

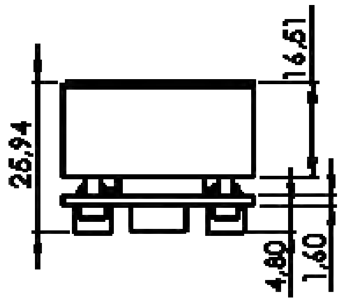
### 4.3 Mechanical Dimensions (mm)

Tolerances according ISO 2768-mK (medium), see table next page.
Except tolerances ± are given in the drawing.

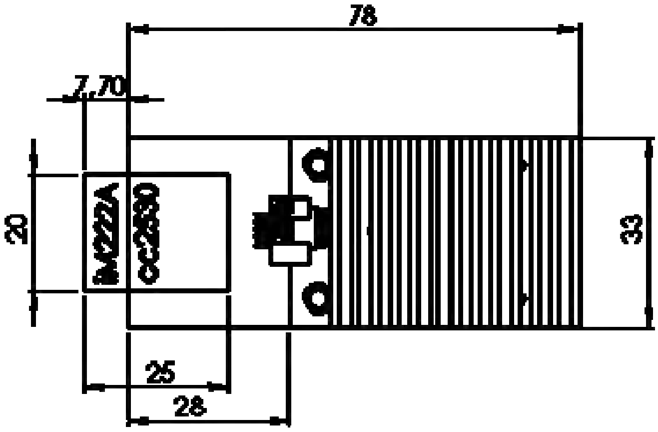





**TE-CORE /RF (bottom view) position for drillings**




**TE-CORE /RF (side view)**




**TE-CORE /RF (top view)**

### 4.4 General tolerances for linear and angular dimensions according DIN ISO 2768-mk

For TE-CORE /RF tolerance class „medium“ is applicable.

| Permissible deviations in mm for ranges in nominal lengths | Tolerance class designation (description) | | | |
|---|---|---|---|---|
| | f (fine) | m (medium) | c (coarse) | v (very coarse) |
| 0.5 up to 3 | ±0.05 | ±0.1 | ±0.2 | - |
| over 3 up to 6 | ±0.05 | ±0.1 | ±0.3 | ±0.5 |
| over 6 up to 30 | ±0.1 | ±0.2 | ±0.5 | ±1.0 |
| over 30 up to 120 | ±0.15 | ±0.3 | ±0.8 | ±1.5 |
| over 120 up to 400 | ±0.2 | ±0.5 | ±1.2 | ±2.5 |
| over 400 up to 1000 | ±0.3 | ±0.8 | ±2.0 | ±4.0 |
| over 1000 up to 2000 | ±0.5 | ±1.2 | ±3.0 | ±6.0 |
| over 2000 up to 4000 | - | ±2.0 | ±4.0 | ±8.0 |

## 5. TE-Power SCOPE 3.0 for Windows PC

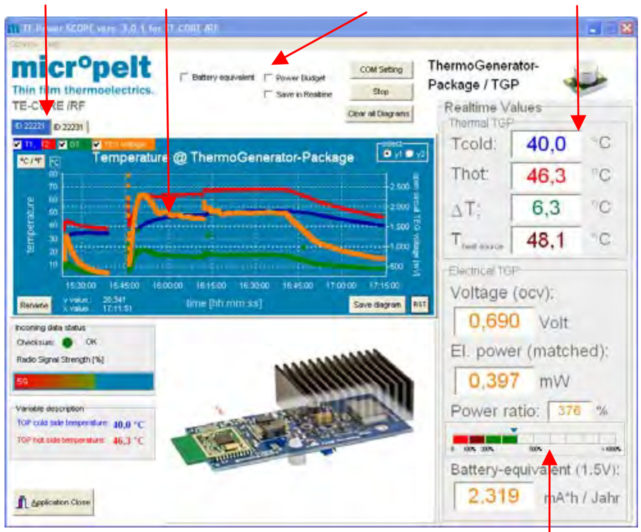
### 5.1 PC software application

The TE-Power CORE /RF system was designed to facilitate a comprehensive understanding of thermoharvesting as a technology; eventually a thermogenerator will power your application. The TE-Power SCOPE uses the signals received from the associated TE-Power CORE / RF system to indicate and visualize all relevant evaluation aspects on a convenient graphical interface.

You can easily determine in real-time:

- Temperatures and TGP voltage in a histogram with zoom capabilities
- Momentary thermal and electrical status values, including TGP open circuit voltage, thermoelectrical power
- Simulated charge progress of a configurable battery (or capacitor)
- Simulated power budget of a duty-cycle-configurable attached system, which can be hooked up to the simulated storage unit.
- Data-logger function; data stored in file.

TE-Power SCOPE 3.xx accepts and visualizes the data received from up to 5 TE- CORE /RF units.




### 5.2 Installation

1. Download the TE-Power SCOPE software from the Micropelt website (zip file 1.1 MB):
[http://www.micropelt.com/software/te_power_scope_core.zip](http://www.micropelt.com/software/te_power_scope_core.zip)

   Unzip the TE_Power_SCOPE.EXE file to you PC and execute.

2. Connect the USB receiver to a free USB port. Windows automatically installs the USB-driver (if the driver does not install automatically please read page 17). You will need administrator access to your computer to successful driver installation.

3. Select the COM-port in the “COM Settings” of the TE-Power SCOPE. For details, refer to page 22 .

4. Place the TE-CORE /RF on a target surface of at least 40 °C [104 °F].
   We recommend a vertical alignment (refer to page 18).

5. Press button “Run” on the TE-Power SCOPE

**IMPORTANT !!!**

**TO AVOID SOFTWARE MALFUNCTION, IT IS STRONGLY RECOMMENDED TO FOLLOW THE SEQUENCE DESCRIBED BELOW!**

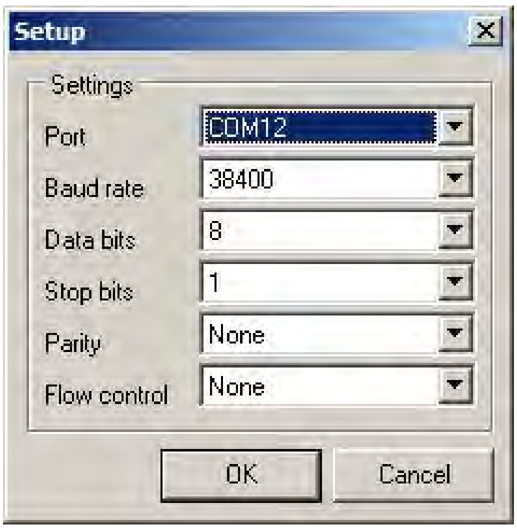
While the TE-Power SCOPE is running, removal of the USB-receiver should be avoided. If this happens, follow this instructions :
Click the “Stop” button, re-insert the USB receiver and wait 5 seconds until the COM-port is allocated. Then, verify the “Settings” to make sure that the initially selected COM-port is chosen again. Close the settings window and click “Run”.

### 5.3 Communication Settings

A couple of seconds after attaching the TE-CORE /RF to a heat source, it starts transmitting data, indicated by a flashing red LED on the Wireless Sensor module. The USB receiver indicates received signal with a blinking red LED. Only visible if the white plastic cover is removed.

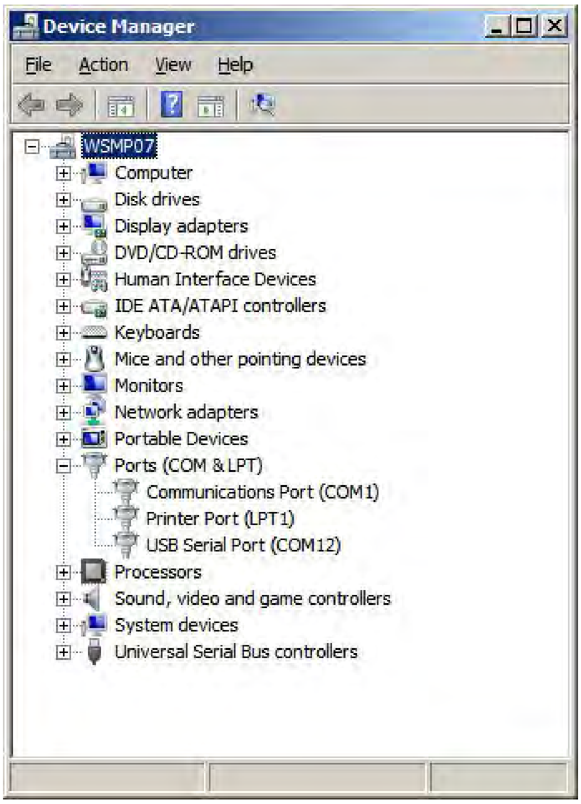
The TE-Power SCOPE V3.0 application software receives the data via a virtual COM port. This port must be correctly configured to enable the wireless data transfer.

1. Click on “COM Settings” to open the “Setup” window.
2. Click “Port” pull-down button to open the list of available ports.
3. Click on the highest value (at the bottom), then click OK.
4. Click “Run” in the main window and see if the histogram displays values and the image of the TE-CORE /RF appears below the histogram.
5. If nothing happens go back to step 1 and select the next Port value, etc.




**Screenshot Setup**

Experienced users may just look up the Windows Device Manager to find the port associated with the ‘USB Serial Port’. The port number is displayed after the device name, set in brackets, e.g. (COM12).




**Screenshot Device Manager**

COM port assignment is required for the first start only. For all other parameters in the “Settings” window, defaults remain unchanged:

Baud rate = 38400
Data bits = 8
Stop bits = 1
Parity = None
Flow Control = None

Setup values get saved to default upon clicking “OK”.

**In case you already used the Micropelt TE-Power NODE system in the past, please note that you might have to actively change the baud rate to the correct value !**

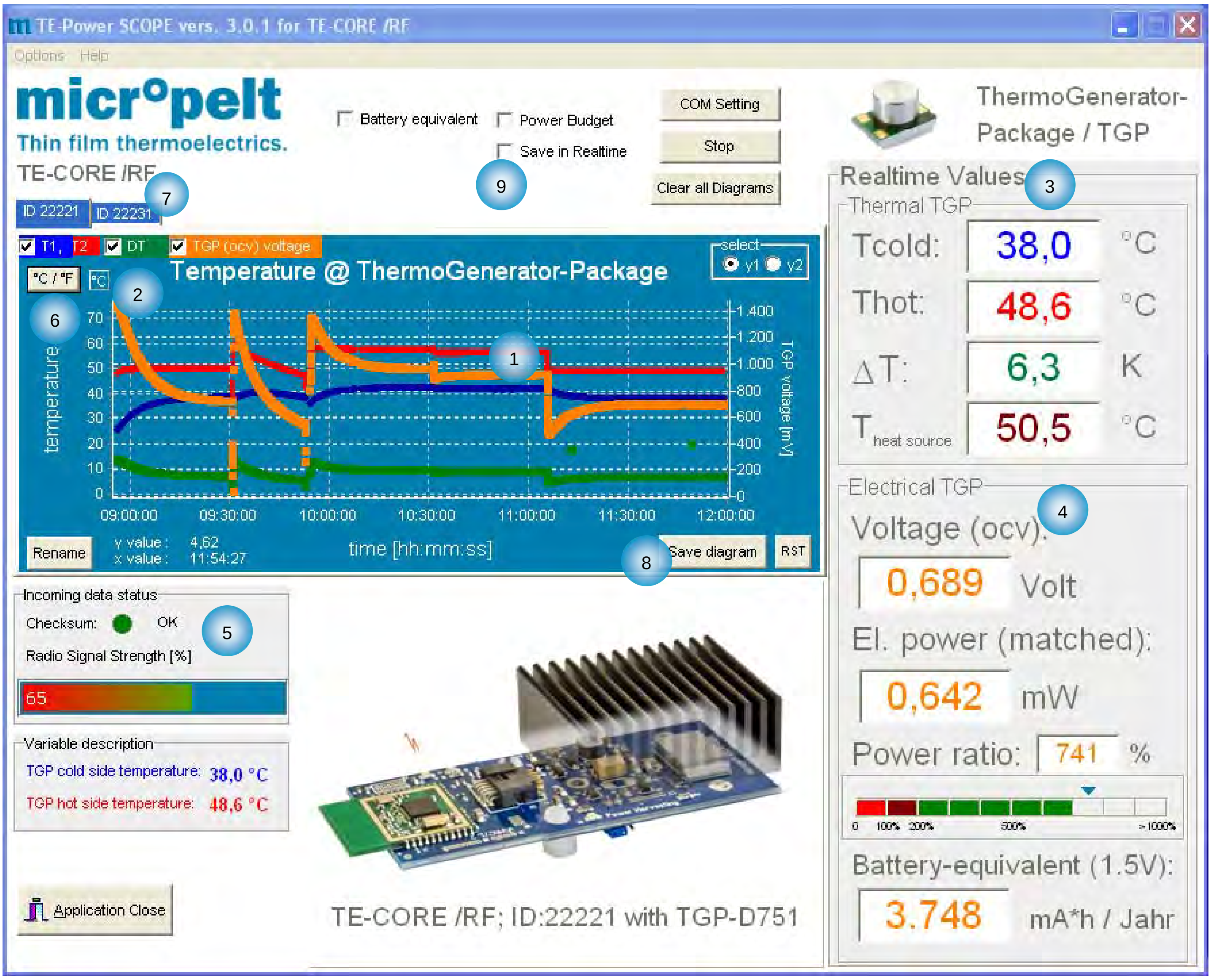
## 5.4 Thermoharvesting Monitor - Main Window Operation

Click "Run" to start receiving and displaying the data transmitted by the TE-Power CORE /RF. Next figure shows the user interface in active mode.

### *5.4.1 Histogram Interface Functionality*

1 The histogram displays the monitoring period in an accumulated format. All values are visible, unless the zoom function used. To zoom, click the top left corner of the region of interest and then draw a box to the bottom right of that region. The zoomed view will not be updated. Go to the original view by click on "RST" or draw a frame from bottom right to top left anywhere on the histogram area.

2 The data displayed in the diagram are selected by the user via check boxes on the top left of the histogram frame. "T1, T2" is the default setting. TGP open circuit voltage can be selected manually via the check box. The value can be read on the right-hand side of the histogram. Underlying colors correspond with the respective histogram lines. The selection may be changed at any time during the recording period as they remain stored in the histogram database. A click on "Save diagram" lets you name and save the current database to your selected location.




TE-Power SCOPE - Main window in operation

### *5.4.2 Realtime Thermal Data*

3 Momentary values from each transmission cycle (1 update per two second) are displayed numerically in the "Realtime Values" section. The numbers include TGP cold side temperature "Tcold"; TGP hot side temperature "Thot", temperature difference at TGP "ΔT" and the heat source temperature "$T_{heat\ source}$".

TGP hot side is calculated from the known average Seebeck voltage of the TGP and the measured OCV voltage.

$$Thot = Tcold + \frac{Uocv}{110\ mV\ /\ K}$$

Uocv - measured TGP open circuit voltage, and 110 mV/K - Seebeck Voltage at TGP-751 for 1 K temperature difference.

The heat source temperature is calculated by adding a correction factor to Thot and results in an accuracy of +/- 2 °C.

### *5.4.3 Realtime Electrical Performance Data*

4 Electrical performance values are displayed at the right corner at "**Electrical TGP**". Voltage (OCV) [Volt] represents the open circuit voltage from the TGP at actual thermal conditions.

The values of the electrical matched power [mW] is a calculated based on a matched load, i.e. it is assumed, that the TGP is connected to a load resistance of a magnitude similar to its internal resistance.

Power Ratio [%] is the relation between the actual measured matched output power of the TGP and the average power consumption of the TE-CORE /RF system and is calculated as following:

Battery AA cell with 1.5 Volt operating voltage. This value can be calculated by following equations:

$$Ratio = \frac{Pmatched \cdot DCbooster\_eff \cdot}{Paverage} \cdot 100\ \%$$

The default DC booster efficiency is set to 100 % and can be change, according the instruction in §5.5.

Battery-equivalent represents the calculated amount of 1.5 Volt AA batteries .

This value can be calculated by following equations:

$$C_{(1.5V)} = \frac{Pmatched \cdot DCbooster\_eff \cdot}{1.5Volt} \cdot 24h \cdot 365day$$

### *5.4.4 Incoming Data status*

5 The Radio Signal Strength RSS in [%] presents the quality of the receiving radio signal. Within the radio protocol two bytes are allocated for a check sum correction. At successful radio reception, the check sum indicator will turn green with the status information "OK".
If the transmitting data is corrupt or not complete, the indicator will turn red with the message "data error". Under the condition that no radio signal is detected, there is no checksum indicator and the message field mentions "no data".

### *5.4.5 Change the temperature unit*


6 The temperature unit is configured by default in Celsius degree [°C] and can be changed to Fahrenheit degree by using the to button "°C /°F".

### *5.4.6 Use of multiple TE-CORE /RF systems*

7 More complex monitoring of a thermal profile will likely yield faster when multiple sensors are in just one setup. To support such scenario the TE-Power SCOPE offers the MULTI-CORE functionality.

Individual device addresses for each TE-Power CORE / RF allow to connect and identify up to five units to one TE-Power SCOPE application. Once an additional TE-CORE /RF signal is being received, a new tab with the corresponding address ("CORE nnn") appears at the top of the histogram. To select a specific TE-CORE /RF, just click its tab. Click the "Rename" button to assign an individual and more informative name to the current TE-CORE /RF sensor.

If no data is received for more than 10 seconds, the corresponding tab turns grey and the image of the TE-CORE /RF below the diagram disappears. This allows fast identification of active TE-CORE /RF's.

### *5.4.7 Recording and Saving Data*

8 Histogram data may be saved for later analysis by either checking the „Save in Realtime" option or by clicking „Save diagram". Selecting either option will bring up the "Save As" dialog box, asking for name and target location of the file. Files are saved in the CSV data format, compatible with any text editor or spreadsheet software such as MS Excel. As indicated by the button's position inside the blue diagram area "Save diagram" saves just the data of the selected TE-CORE / RF. If recording is to be continued, it is necessary to save again in order to keep the new data .

### *5.4.8 Save in Realtime*

9 "Save in real-time" establishes long term recording. The function continuously logs the data of ALL active TE-CORE /RF's to a specified file - eventually, if not stopped, until the target storage medium runs out of space.

The check mark remains visible to indicate that real time saving is in progress. The horizontal time axis of the histogram will always indicate the duration of the recording.

<u>When to use "Save in realtime":</u>

To ensure all data of ALL active TE-COREs are kept safe and in one single file. It will be easy to separate them in any spreadsheet program. Any long term harvesting study or observation of random events, e.g. changing environmental conditions, calls for long term recording. Prevent data loss from unexpected system shutdown, e.g. power-loss of the PC. Recorded data is safe in such an event.

Perform data recording that continues past midnight, i.e. 00:00 system time: At 00:00 system time, all system memory (RAM) data is deleted and the diagram is cleared.

This does not apply to "Save in realtime" hard disk recordings. Data is safely kept in a log file and logging continues past midnight without interruption.

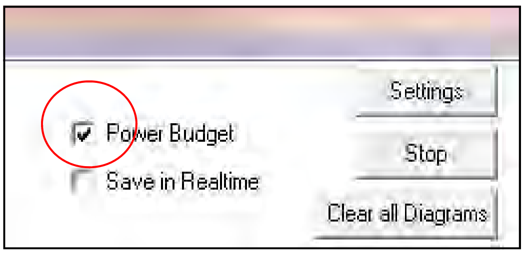
## 5.5 Power Budget Simulation

After having evaluated the power produced by the TE-CORE /RF and the behavior of the heat source over time, the next step of evaluation is due. Since all harvester driven wireless systems require some energy storage to supply the current burst for the active part of the duty cycle, it is helpful to visualize how long it will take to (re-)charge a capacitor or a battery under the prevailing harvesting conditions of each TE-CORE / RF that is actively linked with your TE-Power SCOPE.

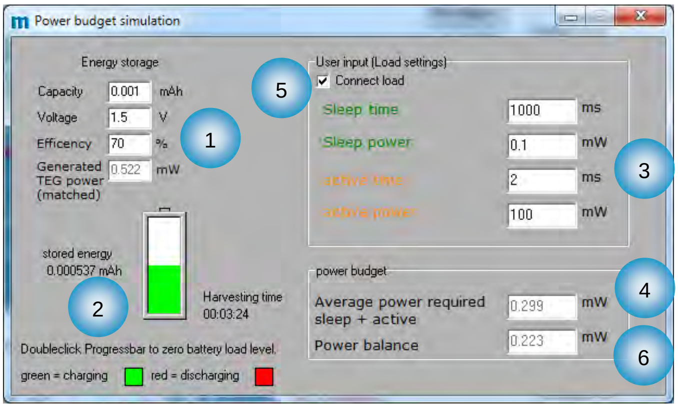
Checking the “Power Budget” checkbox opens the “Power budget simulation” window

The Power Budget Simulation lets you:

1. Parameterize a virtual energy storage device
2. Simulate and visualize charging or discharging of this energy storage in both status and progress, based on the thermoharvester’s net energy output,
3. Parameterize your ‘virtual’ target wireless system in terms of it’s basic duty cycle characteristics, which determine its average power consumption,
4. View the virtual wireless system’s resulting average power consumption,
5. Connect this virtual load to the virtual energy storage
6. to determine the resulting “Power balance”. This will prove whether or not the intended target application will run sustainably in the environment where you placed the respective TE-CORE /RF.




**Launch the “Power Budget Simulation”**




**Active “Power Budget Simulation” window**

**NOTE:**

**For optimum energy yield, both proper heat source attachment and effective heat sinking are essential. If the system yields less power than expected, a careful check of the thermal path usually solves the issue; refer §4, Thermal and Mechanical Information.**

**Due to slow propagation of heat, it’s normal for the TE-CORE /RF to start broadcasting of data only several seconds after it has been attached to the heat source.**

## 5.6 Energy Storage Simulation

The "**Capacity**" of the rechargeable (battery or capacitor) must be entered in mAh as indicated by the respective field caption. A capacitor's energy content needs to be converted using the formula:

$$[C] = \frac{[Q]}{[U]} = \frac{1\,\mathrm{As}}{1\,\mathrm{V}} = 1\,\mathrm{F}$$

Some useful unit conversions:

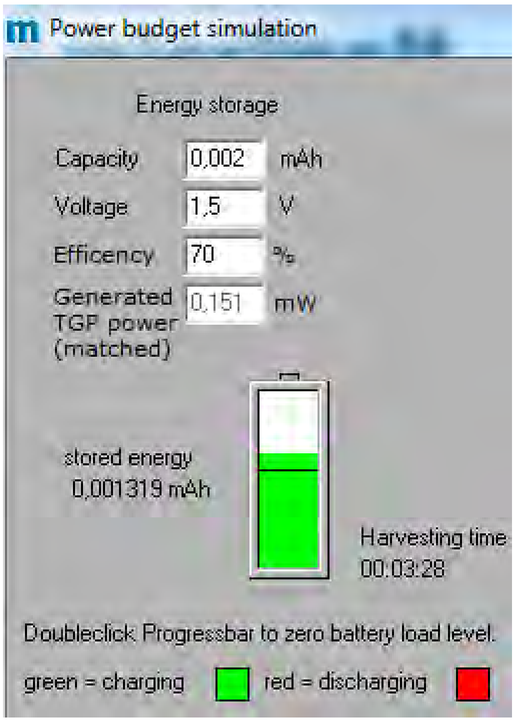
**$C_B$[mAh] = (U[V] * $C_C$[F]) / 3.6** with

U: Voltage of the considered storage unit at full charge,

$C_C$ : Capacity of a capacitor in Farad

$C_B$: Capacity of the same capacitor in mAh

*Note: This formula does not reflect that a capacitor's energy can be used only between its maximum charge level and the minimum operating voltage of the powered system. The mAh capacity given on rechargeables usually include this restriction.*

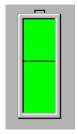



**"Energy Storage" Simulation**

Ensure the "**Voltage**" field is set to the voltage of the considered storage unit at full charge.

The "**Efficiency**" field indicates the remaining percentage of energy from the TGP after subtracting all assumed or known losses of the Energy Harvesting module or other used power conditioning The default value of 70% is at the lower end of the performance. If the attached energy storage features significant charging losses it is recommendable to include these losses by reducing the "Efficiency" value accordingly.

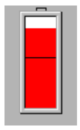
Whatever "Efficiency" has been set by the user, it will be multiplied with the gross harvesting power shown in the TE-Power SCOPE main window. The result is shown as "**Generated TGP Power"**, again assuming that the attached load resistance is matched to that of the power conditioning circuit. For the Energy Harvesting module, load matching occurs between 7 and 10 kOhms.



The charge level of the energy storage is visualized dynamically by the "**Stored Energy**" battery symbol. The smaller the "Capacity" the faster the indicated charge progress at any given harvesting input.

The length of the colored bar indicates the percentage of charge based on the set capacity. The absolute value of energy stored is displayed to the left of the battery symbol. Once the stored energy reaches the value set under


"Capacity", e.g. 0.001 mAh, the indicator bar will hit the top end of the scale. Doubling the "Capacity" value will bring it back to 50% in the middle.



A green bar indicates charging in progress, red means discharging - due to a negative "Power balance" which occurs whenever the virtuall attached load draws more energy than is currently upplied by the generator.


*Note: Entering realistic "Capacity" values, e.g. for a thin film battery, will cause the battery charge indication to slow or virtually stop as it always scales to the set "Capacity".*

"**Harvesting Time**" indicates the accumulated active time of the TE-CORE /RF. If it does not transmit it does not charge either.

## 5.7 Power Budget Simulation

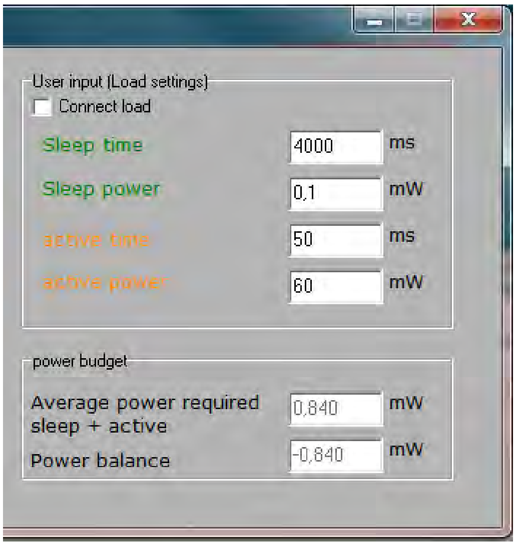
The right part of the “Power Budget Simulation” window is dedicated to configure and simulate a virtual load, which should be powered by the thermogenerator. This can be a real or just a conceived wireless application with specific power consumption and duty cycle parameters. These parameters are entered into the respective fields under “Load Settings”. The calculation concept of this function assumes that

**Duty Cycle = Sleep Time + Active Time**.

Based on the known duty cycle specifications the first part of the “Power Budget” is displayed as “Average Power Demand”. This answers the first of two essential questions:

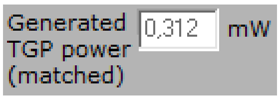
*How much power does my system consume on average?*

The final question is: *Does the thermogenerator supply enough power to run my system sustainable ?*




**“Power Balance” Simulation**

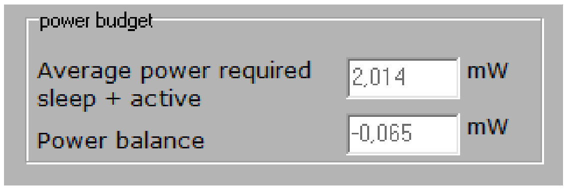
The “**Power Balance**” answers this question by subtracting from the “**Generated TGP Power**” the



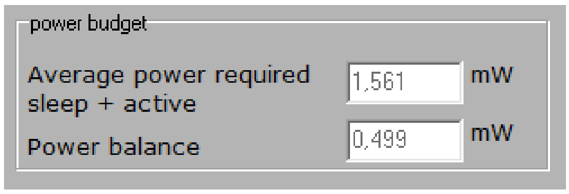

“**Average power required**“ by the virtual wireless system. Any positive value means there is more power generator than is required by the application. Hence, continuous operation is possible.

If the “Power Balance” is negative, the attached system will draw the difference from the energy storage. The charge level indicator bar will turn red as soon as the load is connected to the “Energy Storage”.

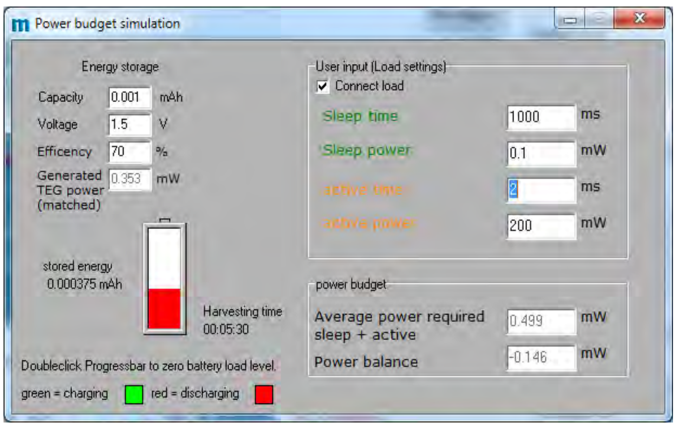
The thermal situation of the thermogenerator must be considered carefully, e.g. by checking the histogram: The Power Budget should be positive under all operating conditions and use-cases. With a sizeable energy storage, though, it is possible to bridge supply gaps.




**“Power Balance” near zero margin**




**“Power Balance” with good margin**




**Negative “Power Balance”: Charge indicator turns red when load is connected**

## 5.8 Duty Cycle Parameter Specifications

"**Sleep Time**": How long is the average or fixed period the attached system is in sleep mode with much reduced power consumption? Any period length must be entered in milliseconds.
*Note: This must not include the active period's duration.*

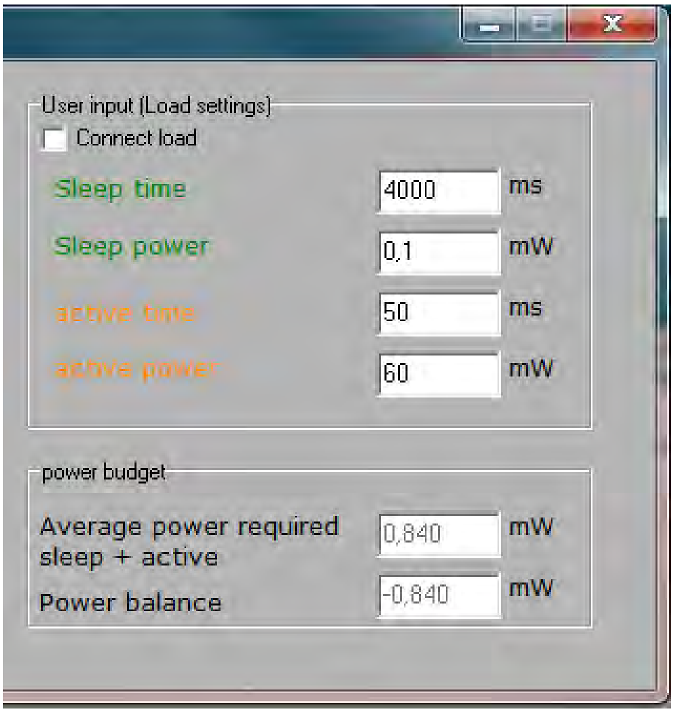
"**Sleep Power**": What is the power consumption during the sleep period? Refer to the field caption for required units.

"**Active Time**": How long is the average or fixed active period the attached system is active, doing sensing computing or radio transmission? Any period length must be entered in milliseconds.
*Note: This value must not include the sleep period.*

"**Active Power**": What is the power consumption during the active period? Since power consumption varies with the tasks carried out during the active period, each specific portion should be accumulated and averaged over the entire active period. The resulting value is entered into this field. Refer to the field caption for required units.

Checking "**Connect load**" virtually connects the load to the thermogenerator. With a positive energy balance, the battery continues to be charged (green level indicator) while a negative energy balance discharges the battery (red level indicator).

"**Power balance**" is always calculated and updated during active connection to an attached TE-CORE /RF. However, the charge level color indication only works with "Connect load" being checked




**"Power Balance" Simulation**

## 6. Glossary

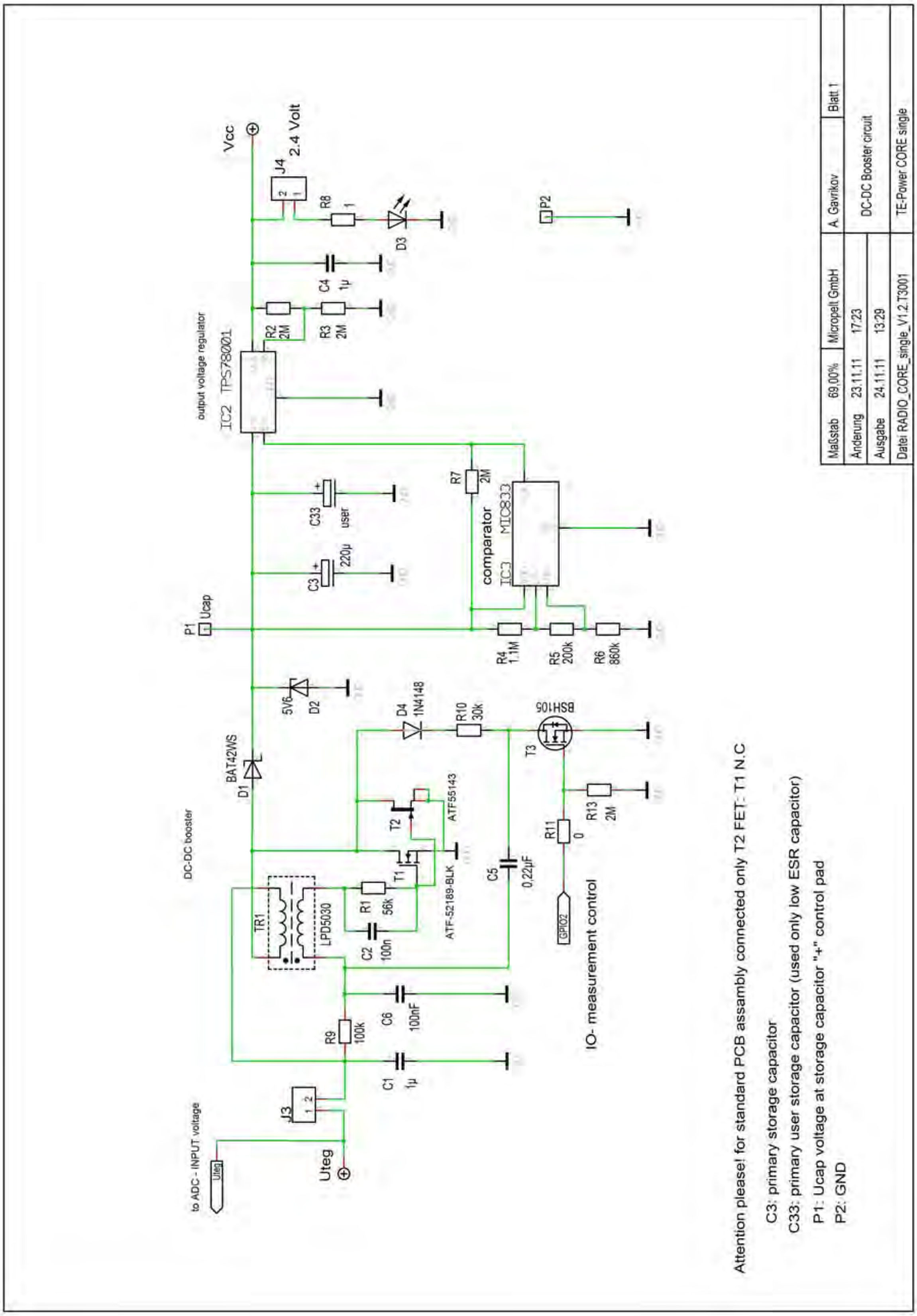
| | |
|---|---|
| TGP | Thermal Generator in Package |
| MPG-D751/D651 | Micropelt thin-film thermoelectric generator chips type |
| PCB | Printed Circuit Board |
| TEG | ThermoElectric Generator, Thermogenerator |
| OCV | Open Circuit Voltage |
| SoC | System-on-Chip or System on a Chip |

## 7. List of Document Changes

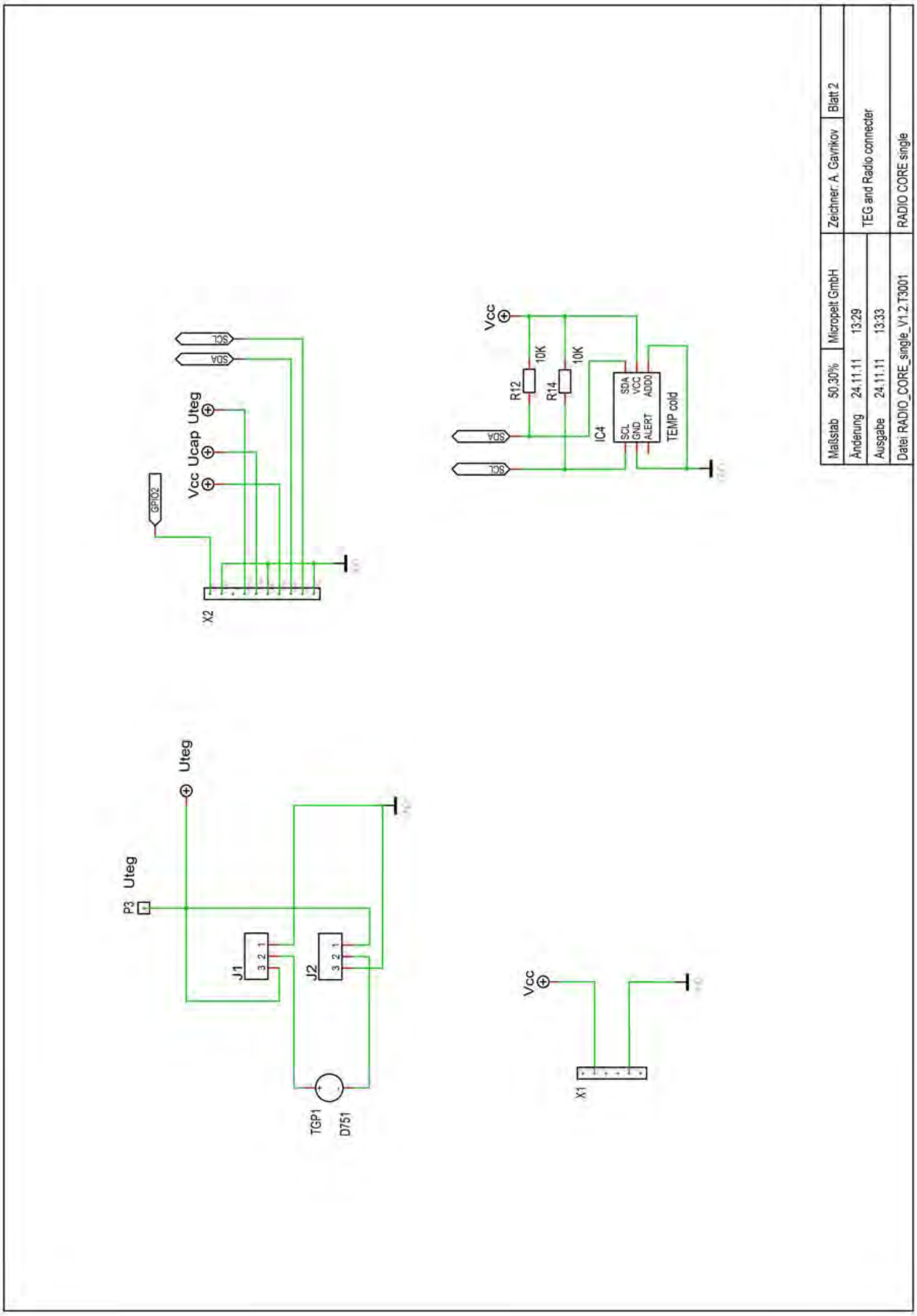
| | |
|---|---|
| **Ver. 1.0 (2011-12.13)** | First version of TE-CORE /RF datasheet |
| **Ver. 1.2 (2012-02.01)** | Links to wireless module of IMST exchanged |
| **Ver. 1.3 (2012-04.04)** | optical improvements, images; page 6, absolute max. ratings; page 7, link to supplier of heat sink Fischer Elektronik exchanged |
| **Ver. 1.4 (2012-10.17)** | page 11, 3.1.5 Thermogenerator direct access optical, corrected naming of circuit control points |

## 8. Circuit diagrams

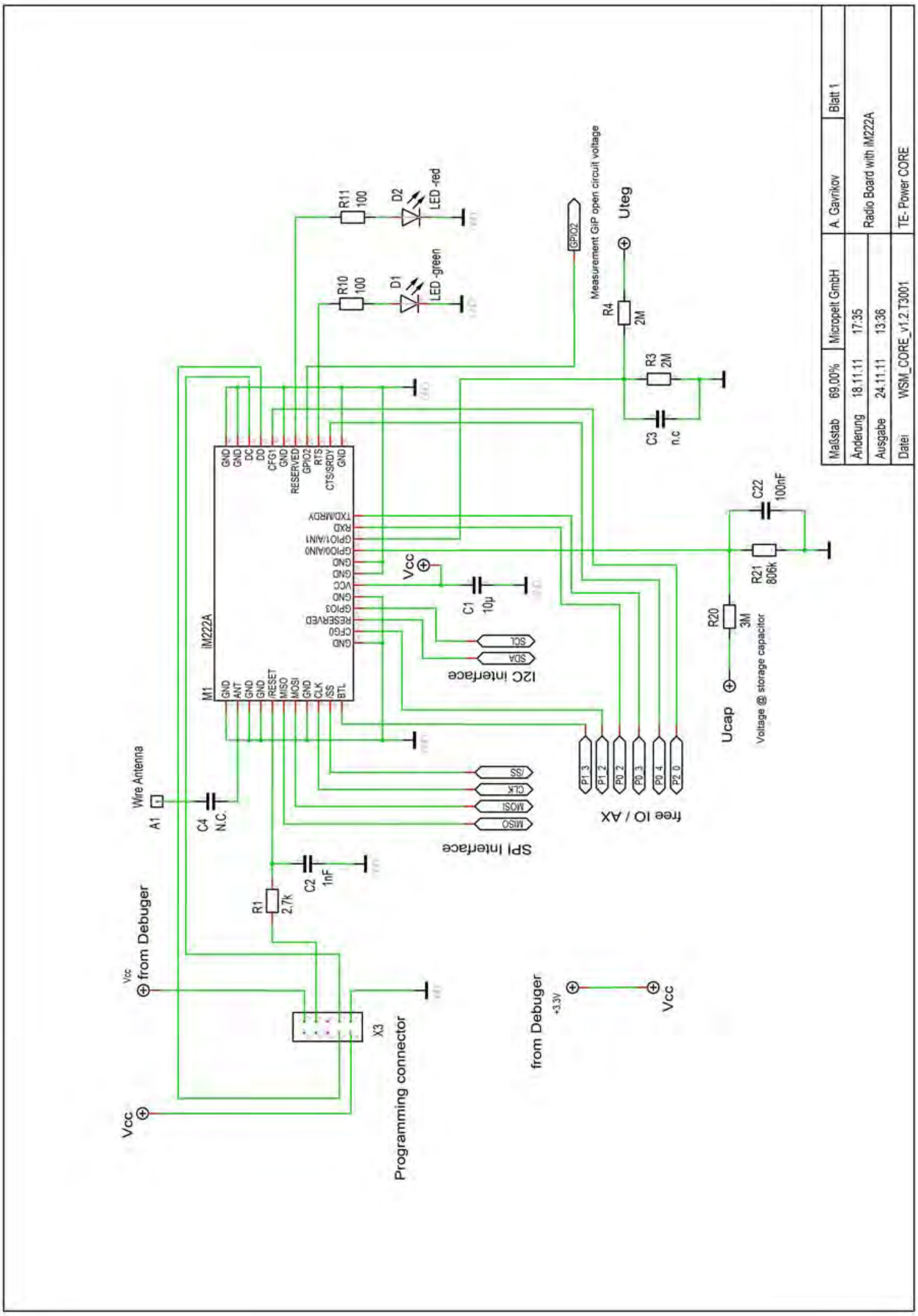
### 8.1 Energy Harvesting module: DC-Booster



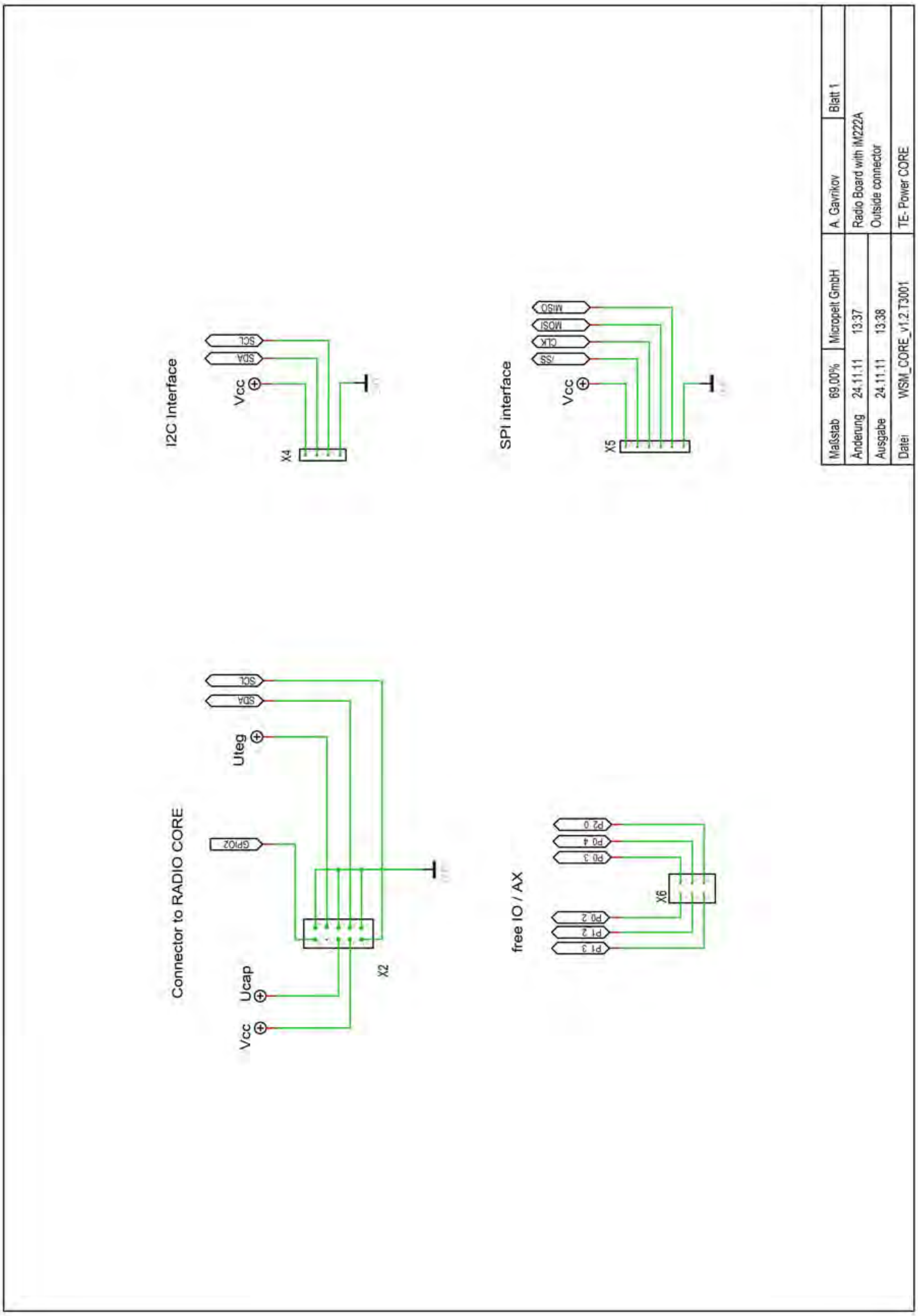
## 8.2 Energy Harvesting module: Connectivity



## 8.3 Wireless Sensor module: CPU and Radio



## 8.4 Wireless Sensor module: connectivity



## 9. Important Notices – Please read carefully prior to use

**1. Micropelt Products are prototypes**

Micropelt supplies *thermoelectric* coolers and *generators,* as well as *energy harvesting modules* (hereinafter referred to as "Prototype Products"). The Prototype Products distributed by Micropelt to date are prototypes that have not yet been released to manufacturing and marketing for regular use by end-users. The Prototype Products are still being optimized and continuously tested. As such, the Prototype Products may not fully comply with design-, marketing-, and/or manufacturing-related protective considerations, including product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards.
In addition, the Products have not yet been fully tested for compliance with the limits of computing devices, neither pursuant to part 15 of FCC rules nor pursuant to any other national or international standards, which are designed to provide reasonable protection against radio frequency interference.

**2. Use of Products restricted to demonstration, testing and evaluation**

Micropelt's Prototype Products are intended exclusively for the use for demonstration, testing and evaluation purposes.
The Prototype Products must not be used productively. In particular, the Prototype Products must not be used in any safety-critical applications, such as (but not limited to) life support systems, near explosion endangered sites, and/or any other performance critical systems.
The Prototype Products must only be handled by professionals in the field of electronics and engineering who are experienced in observing good engineering standards and practices.

**3. Warnings and use instructions**

- Using Micropelt's Prototype Products without care and in the wrong context is potentially dangerous and could result in injury or damage. The Prototype Products are designed for use within closed rooms in conditions as apply for electronics such as computers; except when indicated expressively. Keep the Prototype Products away from open fire, water, chemicals, gases, explosives as well as from temperature conditions above 100 degrees centigrade, or as indicated in the datasheet of the product. When testing temperature settings at the limits given in the datasheet for longer term, do not leave the Prototype Products alone but monitor their performance. Take special care to monitor closely whenever the Prototype Products are connected to other electrical items and/or electronics.
- If Prototype Products use wireless data transmission technology, therefore they receive and radiate radio frequency energy. They have not yet been fully tested for compliance with the limits of computing devices, neither pursuant to part 15 of FCC rules nor pursuant to any other national or international standards, which are designed to provide reasonable protection against radio frequency interference. Operation of the Prototype Products may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be necessary to correct this interference and prevent potential damage. Do take special care not to operate the Prototype Products near safety-critical applications or any other applications known to be affected by radio frequencies.
- If any of the Prototype Products elements are separated from the complete module and used independently, it is important to control each individual system's power supply to be within their acceptable voltage and/or amperage range. Exceeding the specified supply voltage and/or amperage range may cause unintended behavior and/or irreversible damage to the Prototype Products and/or connected applications. Please consult the Prototype Products' datasheet prior to connecting any load to the Prototype Products' output. Applying loads outside of the specified output range may result in unintended behavior and/or permanent damage to the Prototype Products. If there is uncertainty as to the supply or load specification, please contact a Micropelt engineer.
- During normal operation, some circuit components may have case temperatures greater than 70°C. The Prototype Products are designed to operate properly with certain components above 70°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the evaluation unit schematic located in the evaluation unit User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be as hot as to inflict the risk of burning skin when touched.
- Due to the open construction of the Prototype Products, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge and any other prevention measures for safety.

**4. User's Feedback**

Micropelt welcomes the user's feedback on the results of any tests and evaluations of the Prototype Products. In particular, we appreciate experience information on use cases with indications of strengths and weaknesses of the Prototype Products, its robustness in operation and its long-term durability. Please, contact our Micropelt Application Engineering colleagues by email at engineering@micropelt.com.

Prototype Products, its robustness in operation and its long-term durability. Please, contact our Micropelt Application Engineering colleagues by email at engineering@micropelt.com.

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