Manual

Temperature Compensating Unit

T6TCU02

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Table of Contents

1. Scope of Supply

Standard Items:

Item P/N	Name	Qty.
T6TCU02	**TCU6 Temperature Compensating Unit 2.0**	1
	including:	
	■ Mains cable with CEE 7/7 plug, length 2m	1
	■ Owner's manual	1

Optional Items

Item P/N	Name	Qty.
T6RFSC01	**TCU6 RF Sensor Card**	1
T6CRF0xy	**TCU6 RF Cable to Sensor Card**	1
	xy: length in meter	
T6CCS0xy	**TCU6 Coil Cable shielded**	1
	xy: length in meter	
T6CSS0xy	**TCU6 Sensor Cable shielded**	1
	xy: length in meter	

2. Preamble

Glossary of Terms

Customer

The customer is the organization, or entity that is using the product for its intended purpose and operation by its personnel.

User personnel

User personnel are those assigned by the customer for duties such as equipment, installation, operation, setting- up and maintenance including cleaning, troubleshooting and transportation.

Operational staff

Operational staff are personnel assigned by the customer for the operation of the system in which the product is installed.

Intended users of the manual

This manual addresses user personnel, who is in charge of the duties for installation, operation, maintenance and operational staff, which is responsible for the system operation.

The operating company has the obligation to:

- Supply and give access to this manual to user personnel and operational staff at any time.
- Train personnel concerning the use of AFT-products including safety notes.

This manual contains important information for customer about:

- Unpacking
- Installation
- Operation
- Maintenance

Intended operation

A precondition for the intended operation is the understanding of the manual. Non-compliance can cause damages to the product as well as danger to personnel and equipment. Safety items must not be disabled, or modified, or used contrary to their intended operation.

The customer is responsible for operating the product in its intended manner!

The product is intended to be operated in an industrial, scientific research laboratory or production company and should not be used in a way which can cause damage to personnel or installations.
The customer assumes responsibility for use of the product outside its intended operation or in disregarding the instructions of the manufacturer. The manufacturer will assume no responsibility for misuse of the product.
The intended operation is obtained when the product is operated according to this manual, the technical specification and any additional supplied document. The use of the product requires special knowledge. The customer is responsible to ensure that only operational staff and well trained personnel with appropriate capabilities are using this product.

Warranty and liability disclaimer

The contractually agreed warranty expires immediately if the product is changed, operated incorrectly not according to the intended operation or intentionally or negligently damaged. The warranty does not apply to natural wear and tear.

Warranty or liability claims concerning personal injuries or installation damages are forfeit if one or more of the following causes are involved:

- Improper mounting, setting up, use or maintenance of the product.
- Use of the product with non-operational, improper or defective protection and safety equipment.
- Disregard of the notes in this manual concerning transportation, mounting, setting up, use and maintenance of the product.
- Non-approved modifications of the intended installation of the product.
- Mechanical damage from foreign objects or force majeure.
- Non-intended operation of the product.

3. Safety Notes

General introduction

AFT is continuously improving the products to provide the highest safety standards and technical up to date state. To maintain this condition and to ensure safe operation, the user should read and comply with all notes and warnings.

Symbols and safety labels

Observation of the Safety Notes is necessary to avoid injuries to personnel and damage to equipment. Therefore, it is necessary to carefully read and observe all following safety notes, before setting up the product. The described symbols and labels are generally used by AFT but do not all necessarily apply to this specific product.

				
Observe important notes & instructions (a)	**Danger of electric shock (b)**	**Danger of RF radiation (c)**	**Danger of heat (d)**	**Danger of magnetic field (e)**

Fig. 3.1: Safety symbols

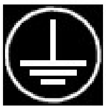
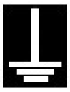
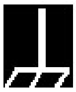
			
Equipment ground conductor	**Grounding conductor**	**Ground**	**Components sensitive to electrostatic discharge**
(a)	(b)	(c)	(d)

Fig. 3.2: Electrical symbols

Table 3.1: Signal words

Signal Words	Meaning
Danger	Indicates a dangerous area with high-risk potential. Dangerous area can lead to death or serious injuries and severe damage to the product.
Warning	Indicates a dangerous area with medium risk potential. Dangerous area can lead to death or serious injuries and severe damage to the product.
Attention	Indicates a dangerous area with low risk potential. Dangerous area can lead to minor or to no injuries and damage to the product
Regard	Indicates a possibility for a misuse, which can cause damages to the product.
Note	Indicates circumstances, which have to be considered while using the product but does not cause damages.

Basic Safety Notes

Note

- Installation has to be done by qualified user personnel.
- The use of the product requires special knowledge and a high degree of concentration during use. Otherwise, a high degree of risk to personnel and installation exists. The customer should assign appropriate qualified personnel for the use of the product.
- Check prior to setting up of the product that all protective measures are installed in a proper way and are working. Use the product only if all safety and security measures are fully operational.
- Never remove a safety installation or other parts of the product while it is in use. Misuse can cause personnel injury and installation damage from heat, electrical shock, or mechanical force.

4. Product Description

4.1. Introduction

The TCU6 Temperature Compensating Unit 2.0 is used as an electronic device for the thermal stabilization of high power microwave ferrite circulators. It is a self- contained device to be operated from 110/230 V; 50/60Hz AC Supply. It is designed to be used indoors only. A connection to a PC is not necessarily required.

At the AFT factory a TCU is paired with a ferrite circulator. The TCU is tested and programmed with that specific circulator and thereafter they must remain and be installed as a pair. Since the TCU programming incorporates data unique to the ferrite, magnet and temperature sensor properties of the circulator, it is not normally permissible to subsequently mix TCUs and circulators. However, in cases where this becomes necessary, it is possible to reprogram the TCU to mate with another circulator (see Chapter 5.5.2).

4.2. Theory of operation

4.2.1. Introduction

The microwave performance of a high power circulator depends on the temperature of the ferrites material since, the ferrite saturation magnetization is temperature dependent. The temperature of the ferrites is influenced by:

- Inlet cooling water temperature (T_{in}).
- Temperature rise within the ferrites due to RF power loss.

The temperature rise within the ferrites due to RF power is a function of the

- Power dissipation within the ferrites
- Heat removal by the cooling system which is dominated by the water flow in the cooling system

Depending on the water flow in the cooling system the dissipated power can be measured calorimetrically, using the temperature rise of the cooling water from the inlet to the outlet of the circulator. For pure water coolant:

$$\Delta T = \frac{P_{dis}}{c_w * F} \qquad \text{(Formula 4.3.1)}$$

$$T_{out} = T_{in} + \Delta T$$

Where: ΔT = Temperature rise of water (°C)
P_{dis} = Dissipated Power (kW)
F = Water Flow
c_w = $4.18*10^3$ J/(kg* K)

Therefore, the second required parameter for the stabilization method is the:

- Outlet cooling water temperature (T_{out}) for a given and stable water flow.

Changes in the ferrite saturation magnetization can be compensated by changing the biasing magnetic field of the circulator via an electromagnet. A static magnetic field is provided by a permanent magnet structure. The electromagnet is a coil around the outside of the permanent magnet. The circulator operating point can be stabilized by changing the coil current. In order to compensate for the thermal variations of the permanent magnets, the ambient temperature ($T_{amb.}$) is also taken into account as a third temperature parameter.

This compensating technique provides an immediate response to any changes of the inlet water and ambient temperatures, or due to RF power or load changes. For this reason the circulator is equipped with 3 temperature sensors. The sensors are encapsulated NTC-resistors.

The correction electro magnet coil current is determined for the measured values of T_{in}, T_{out} and T_{amb}.

The input signals from the temperature sensors are converted by A/D converters and then a microprocessor calculates the required coil current, the result is sent to a D/A converter. This signal is amplified and controls the coil current in the range of ± 6A DC.

4.2.2. Tuning range limits

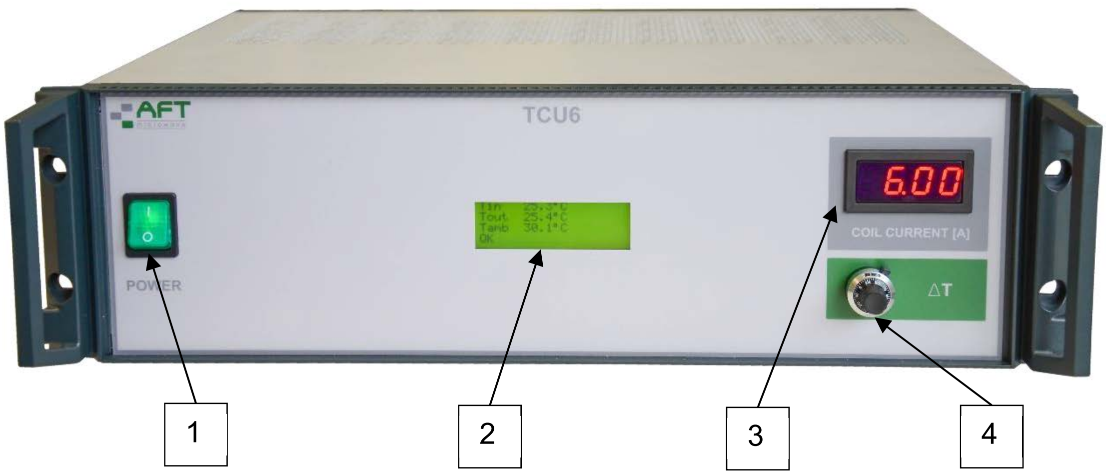
With the available maximum tuning current of +6A to -6A the following variations can be compensated:

- A change of inlet water temperature of ± 5°C with a period time of > 10min.
- A change of RF power level of 0% to 100%
- A change of water flow of ± 20%
- A change of ambient temperature in the range +10°C to +50°C.

Sudden changes in RF-power levels may cause a temporary increase of the reflected power at Port 1 of the circulator. This is due to the fact that RF power heats up the ferrites immediately, while the water temperature rise is delayed by 3 to 5 sec, which is a typical circulator thermal time constant.

If this time constant is too large for the application please contact AFT for the optional RF Feedback Control upgrade.

4.3. Front Panel Interfaces



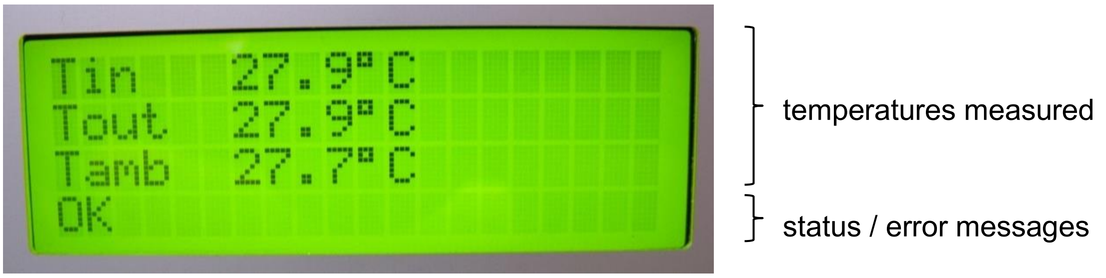
Picture 4.3.1: Front View of TCU6 2.0

Table: 4.3.1: Front panel elements

Item	Description	Remark
1	AC Power Switch	
2	Status Display (LCD)	
3	Coil Current Display (LED)	displays actual output current
4	ΔT – Potentiometer (for high-power tuning)	

4.3.1. Status Display

The status display gives valuable information about the operation of the TCU.
It provides the information about inlet, outlet and ambient temperatures. Depending on the specification of the high power circulator certain limits have been programmed for these temperatures during testing at the AFT factory.
If the RF Feedback Control option is included, the measured RF power at the RF input is also shown.



Picture 4.3.1 Status display example

Note

If the programmed temperature limits are exceeded, the TCU will continue tuning of the circulator. However the specified performance of the High Power Circulator is no longer guaranteed. A high power operation can lead to destruction of the device.

4.3.2. Common Status Information

Table 4.3.2.1: Status information on display

Status	Remarks
boot	TCU is executing the boot sequence
start	Tuning algorithmm is active
stop	Tuning algorithm is off, Restart the TCU
OK	Tuning algorithm is active and no errors are present
PC	Software ΔT-Potentiometer is active

4.3.3. Error messages

Table 4.3.3.1: Error messages on display

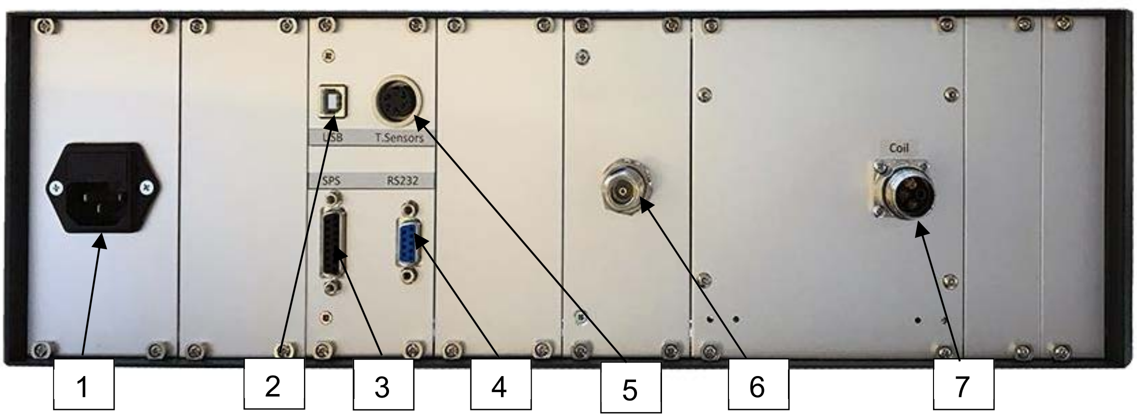
Priority	Message	Error	Remarks
13	coil	Coil connection lost	No coil current can be driven. Check the connections of the Coil cable.
12	Delta T too high	Water temperature rise from inlet to outlet (ΔT) too high	The water flow is too low or the applied RF power is too high.
11	Tamb broken	No valid ambient temperature value can be measured	1.) Check connections of the sensor cable. 2.) Check ambient temperature sensor.
10	Tamb too high	Ambient Temperature (Tamb) too high	Check the environmental conditions
9	Tamb too low	Ambient Temperature (Tamb) too low	Check the environmental conditions
8	Tout broken	No valid water outlet temperature value can be measured	1.) Check connections of the sensor cable. 2.) Check water outlet sensor.
7	Tout too high	Water Outlet Temperature (Tout) too high	Either the water flow is too low, or the applied RF power is too high.
6	Tout too low	Water Outlet Temperature (Tout) too low	Should only occur in conjunction with Tin too low. Otherwise Tout sensor may be defective.
5	Tin broken	No valid water inlet temperature value can be measured	1.) Check connections of the sensor cable. 2.) Check water inlet sensor.
4	Tout too high	Water Outlet Temperature (Tout) too high	Either the water flow is too low, or the applied RF power is too high.
3	Tin too low	Water Inlet Temperature (Tin) too low	Check the inlet water supply
2	RF too low	RF input level too low → Loop is not working!	1.) Check RF-forward power. 2.) Check connections of the RF sensor cable. 3.) Remove added attenuators.
1	RF too high	RF input level too high, out of calibrated range. → Loop is working!	1.) Check if you connected the right coupler 2.) Add an attenuator between coupler and TCU6

The error message line displays one error message only. In case more than one error is present, the display shows the highest priority error message only. The error of the next lower priority is shown once the prior error is eliminated.

Table 4.3.3.2: Additional error indications appearing on display (lines 1-3)

Indication	Error	Remarks
Tin <	Water Inlet Temperature (Tin) too low	Check the inlet water supply
Tin >	Water Inlet Temperature (Tin) too high	Check the inlet water supply
Tout <	Water Outlet Temperature (Tout) too low	Should only occur in conjunction with Tin too low. Otherwise Tout sensor may be defective.
Tout >	Water Outlet Temperature (Tout) too high	Either the water flow is too low, or the applied RF power is too high.
Tamb <	Ambient Temperature (Tamb) too low	Check the environmental conditions
Tamb >	Ambient Temperature (Tamb) too high	Check the environmental conditions
dT >	Water temperature rise from inlet to outlet (ΔT) too high	The water flow is too low or the applied RF power is too high.
Tin?, Tout? Tamb?	No valid temperature values can be measured	Check connections of the sensor cable.
RF ↿dBm <	RF input level too low → Loop is **not** working	Check RF-forward power Check connections of the RF-sensor cable Remove added attenuators
RF ↿dBm >	RF input level too high, out of calibrated range. → Loop is working!	Check if you connected the right coupler Add an attenuator between coupler and TCU6

4.4. Back Side Interfaces



Picture 4.4.1 Rear View of TCU6 2.0

Table 4.4.1: Backside Interfaces

Item	Name	Description	Connector Type
1	MAINS	AC Supply	IEC-600320-C14, male
2	USB	USB interface	USB 1.0/2.0 Type B socket
3	SPS	SPS Relay contacts	Sub D 15, female
4	RS 232	RS232	Sub D 9, female
5	T- Sensor	Temperature Sensors	Binder Series 680, 5-pin, female
6	RF	RF Sensor Card (optional)	N-type, 50Ω, female
7	Coil	Coil current supply for electromagnet	Phoenix Contact ST-3ES1N8AW400S 3-pin + PE, female

A detailed description of all connectors and signaling is given below.

4.4.1. AC Supply

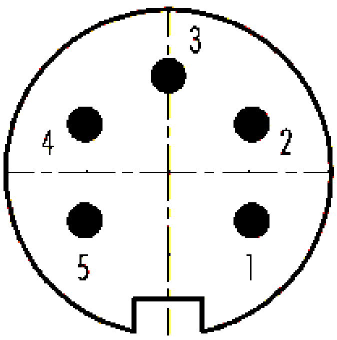
Table 4.4.1.1: AC Supply

AC Voltage	110V to 230V AC	
AC Frequency	50Hz or 60Hz	
Input Power	1 kW	max.
Fuse	4A, time delay (in connector housing)	
Connector	IEC-600320-C14 (male)	

An AC supply cable with CEE 7/7 hybrid plug connector is supplied with the delivery. Please provide a cable with PX0587 connector on the TCU end and your national standard AC connector standard on the other end if required. The wire size should be sufficient to handle 1 kW minimum.

4.4.2. Temperature Sensors

This connector provides connections to the three NTC temperature sensors of the high power microwave circulator.



Picture 1.4.2.1: Pin assignment of TCU temp. sensor connector Binder Series 680

Table 4.4.2.1: Pin description of TCU temp. sensor connector

Pin	Description
1	Tin
2	Tout
3	Tamb
4	PE
5	GND

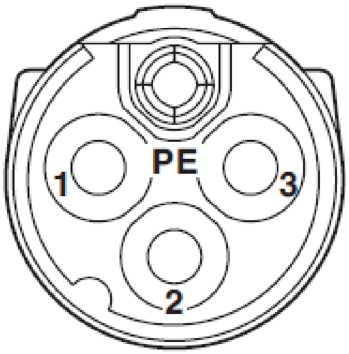
Use the supplied temperature sensor cable to connect the TCU to the circulator.

4.4.3. Coil

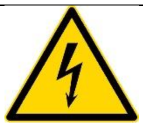
This connector provides connection to the coil of the high power microwave circulator electromagnet system.agnet system.
Use the supplied coil cable to connect the TCU to the circulator electromagnet system.

Table 4.4.3.1: Description of TCU coil connector

Connector	Phoenix Contact ST-3ES1N8AW400S, 3-pin + PE, female
Output Voltage	± 200V
Output Current	± 6A
Pin 1	-
Pin 2	+
Pin 3	PE
PE	PE



Picture 4.4.3.1: Pin assignment of TCU coil connector ST-3ES1N8AW400S

 **Warning**	**Never connect or disconnect the coil cable while the TCU is in operation!**

4.4.4. USB & RS232 Interface

These communication interfaces are used to connect the TCU to a PC. The interfaces are typically used for:
(1) Factory configuration of the TCU with circulator specific data.
(2) Read-only access to the TCU data.
(3) Up- and download of circulator-specific TCU configuration files, see also sections 5.5 and 5.6.
The interface allows read-only access to the following TCU parameters via a serial communication:

Tin	Water inlet temperature in °C
Tout	Water outlet temperature in °C
Tamb	Ambient temperature in °C
dT	ΔT potentiometer set value, range from 0 to 100 (full scale)
Current	Coil current in A
RF	RF reflected power in dBm measured at RF sensor card

For reading these data,connect a PC to the TCU by using a common USB or RS232 cable. The TCU will appear as a COM device in the windows device manager. Open a serial communication port, using the following settings:
115200 Baud, Data Bits 8, Parity none, Stop Bit 1.

The command is:

M CR

CR (Carriage Return) is HEX 0x13.
Example of answer:
M Tin= 31.5; Tout= 33.7; Tamb= 22; dT= 2.2; Current= 1.02; RF= -20

Customer access to the TCU for Up- and downloading TCU configuration files (3) is given by the TCU6 Control Software (MS Windows GUI), which is to be ordered separately. See section 5.6 for details on this feature. The software GUI allows read-only access to all TCU-parameters. For the normal operation of the TCU a connection to a PC via software are not required.

Table 4.4.4.1: Communication Interfaces

Connector	**Description:**
USB	USB 1.0/2.0 Type B socket
RS232	SUB D9 female

4.4.5. SPS Relay contacts

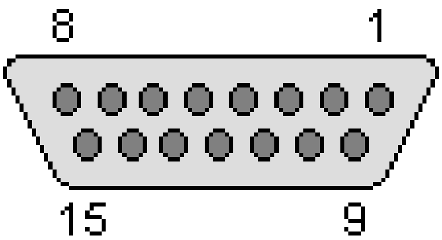
The SPS interface provides several SPS- type relay contacts via a SUB-D 15 female connector. They provide basic status information about the operation of the TCU and the attached circulator. The relay contact is closed if the below Status Description is true. Each relay contact condition is maintained as long as the corresponding status remains unchanged.

Table. 4.4.5.1: SPS relay Connector

Connector	SUB-D 15 female
Relay contact ratings	I_{max} = 0.5 A
	V_{max} = 100 V
	P_{max} = 10 W

Table 4.4.5.2: Pin description of SPS connector

Pin	Status Description
1 – 9	TCU is booting
2 – 10	TCU status OK
3 – 11	Error, Coil not connected
4 – 12	Error, Tin too low
5 – 13	Error, Tin too high
6 – 14	Error, ΔT too high
7 – 15	Error, Tamb out of range
8	Ground



Picture 4.4.5.1: Pin assignment of SPS connector SUB-D 15

Regarding status "TCU status OK":

If this contact is closed, it is indicated that the TCU temperature compensating algorithm is working correctly and that a coil current is driven according to measured temperatures. In case there is a CPU error or either the coil cable or the temperature sensor cable is not connected properly, this contact will be set open.

If there are temperature errors in terms of exceeded temperature ranges for Tin, Tamb or ΔT, the TCU status remains OK. In this case the TCU still calculates and drives a coil current. However, the connected circulator is operated outside of its specified conditions. Thus, the specified performance may be violated and the device might even be destroyed.

Regard	**"TCU status OK" shall be used as a hard-wired interlock signal to the RF source.** **The corresponding RF device is only allowed to be operated under high power RF, if the TCU status is OK and if no errors are indicated at all. Violation can lead to serious degradation of the performance and even destruction of the device.**

Regarding status "Coil not connected":

If this contact is closed, it is indicated that a coil error occurred (e.g. coil cable not connected properly) and the device is not driving any current. Simultaneously, the "TCU status OK" is set to negative.

Warning	**Never connect or disconnect the coil cable while the TCU is in operation!**

4.4.6. RF Control

As an option, the temperature compensating algorithm of the TCU can be assisted by an RF feedback control system, using the RF sensor card. This option requires the corresponding circulator to provide a directional coupler at the input, in order to measure the RF power reflected from the circulator. The RF sensor card measures the reflected power from the circulator. Its algorithm controls the correcting coil current in such a way that the reflected power is minimized.
The RF feedback control acts in addition to the temperature compensation and allows to improve the response time of the compensation. It is typically applied to follow rapid variations of water inlet temperature and events of a fast instantaneous change in forward and reflected power.

Table 4.4.6: RF Control Connector

Connector	N-type female, 50 Ohm
Input Power Range	10 µW – 10 mW
Frequency Range	30 MHz – 6 GHz

5. Installation, Setting up and Operation

Warning	**Never connect or disconnect the coil or sensors cable while the TCU is in operation!**

5.1. Installation

- Verify from the factory Test Data Protocol form that the circulator and the TCU are a correct mated pair. It is not permissible to use a TCU that belongs to another different circulator (see chapter 5.5.2).
- Move the product to the required operating location.
- The product is intended to be mounted into a 19” rack.
- Ensure that the product cannot move during operation. 4 screws should be used to secure the product into a 19” rack.
- When choosing the location ensure a sufficient air flow from the bottom to the top side of the product. Permanent overheating can cause damages to the product. Ensure that the warm air can exit the product and that it has sufficient distance to other devices. <u>The minimum air gap above and below the chassis shall be 1 rack unit (1.75” or 44.45mm)</u>. The rack should be equipped with a fan.
- Ensure that the max. ambient temperature of 40°C is not exceeded.
- Follow the installation instructions of the corresponding mating ferrite circulator.
- Inspect all cables visually for damage. Damaged cables/connectors should not to be used.
- Connect the coil cable to the TCU and the circulator.
- Connect the temperature sensor cable to the TCU and the circulator.
- Connect the product with AC supply.

Regard	**To prevent overheating of TCU6 device:** **1.) Ensure that the TCU6 has sufficient distance (1xHE) to other devices.** **2.) The rack should be equipped with a fan.** **3.) Ensure that the max. ambient temperature of 40°C is not exceeded.**

5.2. Initial Start

Power On the TCU. The TCU will execute a short boot sequence.
After the boot sequence is completed, the TCU is ready for operation of the circulator, without high power RF in the circulator. This is indicated by “OK” in the last line of the status display. The TCU has been tuned with the corresponding circulator at the AFT factory. This means that the:

- Temperature sensors have been calibrated
- Factor for the Bias has been set
- Factor for T_{in} has been set
- Factor for T_{amb} has been set

Please check the accompanying factory Test Data Protocol form for more details.

5.3. High Power Settings

The circulator was tested and the TCU programmed for low power operation only. This includes the parameter settings for the water inlet temperature and the ambient temperature values. The factor for ΔT has not yet been set since in low power operation there is no temperature rise from water inlet to outlet. The initial value is set by AFT to zero. The final ΔT setting is determined during high power testing at customer site.

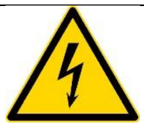
5.3.1. High Power Test Procedures

Before high power testing the following considerations are <u>most important</u> to avoid damage to the circulator. With a short circuit at Port 2 (100% reflected power) the maximum RF generator power into Port 1 must be restricted to:

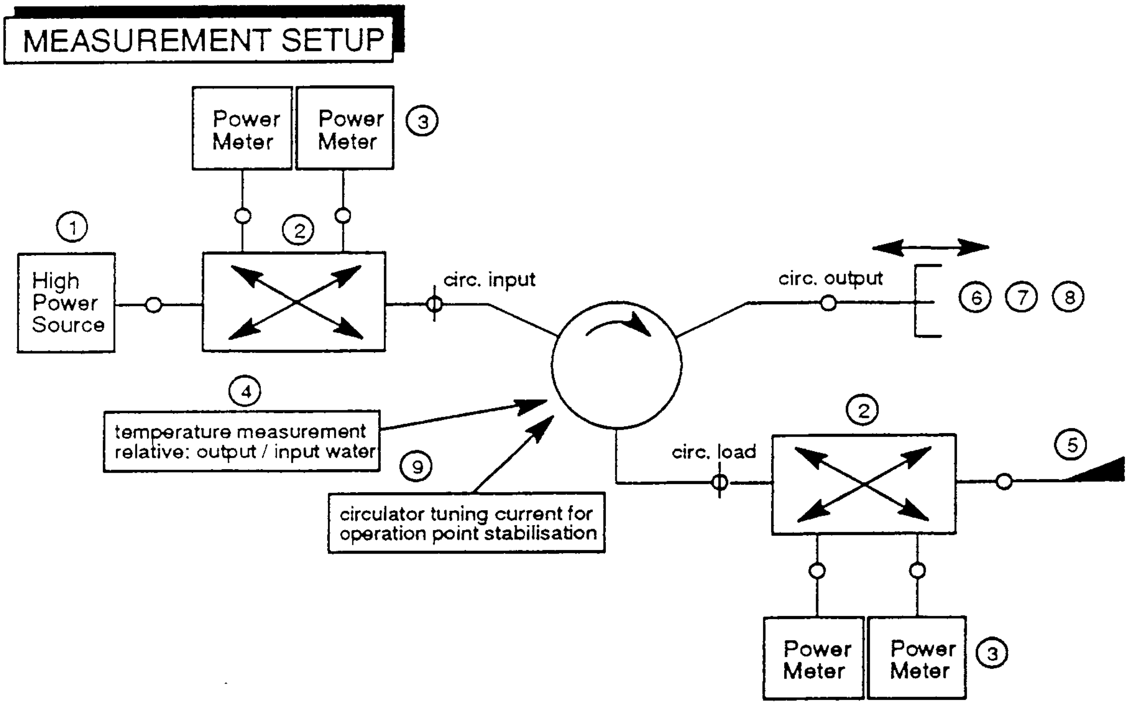
$$P_{gen} = \frac{(\sqrt{P_{fwd}}+\sqrt{P_{refl}})^2}{4} \quad \text{(Formula 5.3.1.1)}$$

Where P_{fwd} is the specified forward power and P_{refl} is the specified reflected power.

For circulators with different forward and reflected power specification the following „equivalent power capability“ equation should be used: $(\sqrt{\mathrm{Pfwd}} + \sqrt{\mathrm{Prefl}})^2$. This is based on the fact that the voltages inside the circulators can add up with worst phase condition.

 Warning	**Danger of RF power overload! Do not exceed this power level.**

5.3.2. General microwave setup for high power test



Picture 5.3.2.1: Test schematic

Table 5.3.2.1: Measurement tools

Measurement tools:

1.	High Power RF Source
2.	2 x Dual-Directional Coupler (Directivity ≥ 30dB)
3.	Power Meter with 2 sensors (Forward and reverse power)
4.	Equipment for measuring the temperature difference between water inlet and outlet. Flow meter.
5.	High-Power Load (Return Loss ≥ 30dB)
6.,7.,8.	Sliding short circuit with scale to indicate position. Or, fixed short circuit with 0, 1/8, ¼ and 3/8 lambda lengths of transmission line to vary phase position.
9.	TCU

5.3.3. Description of high power circulator test setup

To accomplish adequate high power testing the following require¬ments for the test parameters and the test equipment are applicable:
Input and reflected RF power, as well as the inlet water and outlet water temperatures are important parameters for the test. A water flow meter should be provided by the customer, as well as the other items shown in the Measurement Setup diagram in 5.3.2.1.
There are three basic methods how to perform the high power test.

(1) Test into Dummy Load

Port 2 and 3 of the circulator are connected to high power loads. This is the best test to find the optimum setting for ΔT since no significant phase- dependent signals from these ports are involved in the reflection from Port 1. This provides a simple and efficient test.

In this test condition the RF power is cautiously increased in steps up to the maximum value. The power steps should be separated by several minutes, to allow thermal stabilization of the circulator and the cooling system. At each step, the ΔT- Potentiometer is carefully adjusted to minimize reflected power from Port 1. When the maximum RF power is reached the final setting for the ΔT - Potentiometer is determined when the Port 1 reflection is minimum. Lock the Potentiometer with its locking mechanism and repeat the high power test without changing the ΔT-Potentiometer setting. The circulator should now be stable for all power levels.
Record the water flow and circulator input power vs. reflected power, ΔT- Potentiometer setting and Tin and Tout temperature data.

(2) Test into variable Short Circuit

Port 2 of the circulator is connected to a fixed, or a sliding short circuit. Port 3 is terminated with a high power dummy load (Return loss ≥ 30dB). By shifting the short circuit, the circulator can be tested under all phase conditions of the internal microwave fields. This test setup is the best one to check the circulator under worst-case operating conditions, since the two extreme conditions of maximum. E-field and maximum H- field inside the circulator are included. If a suitable sliding short circuit is not available, then a fixed short circuit plate can be used, with various lengths of transmission line inserted between it and the circulator to vary the short circuit reflection phase. A set of 4 line lengths, with 36º 1-way phase length increments will provide test exposure to > 95% of the maximum internal E- and H-field values.

1. Set the first short circuit position at Port 2 of the circulator.
2. Increase the RF power to a low value and adjust the ΔT- Potentiometer.
3. Shut down the RF and shift the short circuit phase, either by sliding, or inserting a line length. Repeat the test with the same power level. Continue repeating the test for all other desired positions of the short circuit.
4. Identify a setting for the ΔT- Potentiometer which is the best compromise for all short circuit positions.
5. With this compromise setting, increase the RF power and repeat from Step 1 above until the maximum RF power is reached.
6. Recheck this setting value for different power levels and short circuit positions.

Record the water inlet and outlet temperatures, the flow rate and ΔT- Potentiometer setting.

(3) Test into System Application

Port 2 of the circulator is connected to the actual system application. Port 3 is terminated with a high power load. This test setup can check the circulator in the specific Customer application environment. This procedure tests the circulator under much weaker conditions than in the variable short circuit test.
Slowly increase the RF Input power while adjusting the ΔT- Potentiometer for minimum Port 1 return loss until maximum RF power is reached.
Please record the water input and output temperatures, the flow rate and ΔT- Potentiometer setting.

We recommend to set the ΔT- Potentiometer according to 5.3.3.1. After this we recommend to test the circulator to its specified limits according to 5.3.3.2 without the adjustments of the ΔT-Potentiometer.

Note	**Once this ΔT value is determined, it is good practice to lock the potentiometer with its locking mechanism and to attach a label showing this setting.**

5.3.4. Technical background

When RF power is fed into the circulator input Port 1, the ferrites inside the circulator will be heated slightly, depending on the amount of reflected power and the reflection phase of the system application at Port 2. This causes a temperature difference ΔT between inlet and outlet water. This ΔT can be measured and the ferrite losses can be calculated when the water flow rate is known. With a short circuit at Port 2, the ferrite dissipation follows a sinusoidal cycling behavior, with a nominal range of 3:1 as the short circuit phase position is shifted by 1/4 wavelength 1-way. Usually we see the best Port 1 return loss when the ferrite dissipation is highest. In this case we have maximum H-field inside the ferrites. Conversely, when the the ferrite dissipation is minimum, the E-field is maximum and we see the highest Port 1 return loss, with the short circuit position shifted by 1/4 wavelength.

Note	**The measured Port 1 return loss of the circulator is different from the specified value for High Power Tests into a short circuit.**

This is related to the fact that the inherent return loss of the circulator is defined as a measurement with all three ports properly terminated. With a short circuit at Port 2, the measurement shows a Port 1 return loss that includes all reflection components at Port 1 and varies with the short circuit phase position. Typically, reflected and dissipated power are higher than specified

5.4. Operation

After the ΔT setting has been determined, the normal operation of the TCU can be commenced. Power On the TCU. The TCU will execute a short boot sequence. After the boot sequence is completed the TCU is ready for operation of the circulator with and without high power RF in the circulator. This is indicated by “OK” in the last line of the status display.

5.5. TCU Parameter Settings

The TCU Parameter Settings are divided into 2 sets of data:

5.5.1. TCU Default Calibration Data

The TCU sensor inputs and the coil current output have been calibrated by AFT. This set of this TCU calibration data is stored within the TCU. In this state we speak of a default calibration as the TCU is not yet calibrated to any circulator.

5.5.2. Circulator-specific Parameter Data Set

During the low-power factory tuning of the circulator AFT has programmed the optimum circulator settings and limits according to the attached factory test data protocol. These values are also stored within the TCU and are independent of the TCU calibration data. During normal operation access to these parameters is not required. But it is important to understand that there are parameters stored within the TCU which are related to a specific high-power circulator which can be traced by its serial no. If a spare or different TCU should be used, it is essential that the circulator-specific parameters are copied into the new TCU. In addition, the ΔT- potentiometer should be set to the same value as in the original device.

Note	**Operating a TCU with an incorrect high power circulator parameter set will degrade the circulator performance and may even lead to its destruction.**

5.6. TCU Configuration Files

TCU6 configuration files are ASCII files containing all circulator serial no. specific TCU data (see 5.5.2). These data files and a corresponding Windows control software for up- and downloading the files to/ from a TCU can be ordered separately from the factory. This package allows customers to configure a circulator specific replacement TCU, based on an available default TCU (see 5.5.1), without returning devices back to the AFT factory.

5.7. TCU Protocol

The measurement protocol of the TCU with its companion circulator can be found in the appendix of the high-power irculator manual. The settings documented are related to one specific high-power circulator with dedicated serial no. (S/N).

Note	**Do not exchange and operate a TCU without update the parameter settings.**

6. Safety and Maintenance

The device does not need special maintenance. However in order to ensure safe and stable operation a regular check should be conducted.

- Regularly check the technical safety of the product by checking all cables/connectors and the housing.
- In the event of damage which may impair proper operation, discontinue use of the product and secure it against unwanted operation by a third party. Disconnect the AC supply.
- A risk less operation is no longer possible in case of visual damage, or the product has failed, due to improper stocking or shipping damage.

Note	**Danger for installation damages!** **Parts must not to be unplugged with AC supply connected. Parts can be damaged. Always ensure that no voltages are present.**

7. Trouble Shooting and Corrective Actions

Tab. 7.1: Trouble shooting of potential problems

Problem	Corrective Action
The device is very warm near the venting holes.	Check for: Sufficient spacing between TCU and other devices in Your 19” rack
Tin / Tout / Tamb error message according to table 4.3.3.1 is displayed	Check: Your cooling water parameters, ambient temperature and compare them with min/max values in the TCU protocol delivered with the circulator
dT-Potentiometer is not affecting the current	Check: There has to be a difference between Tin and Tout for the potentiometer to influence the algorithm.
TCU is not recognized by Windows Device Manager	Try a different USB port on your PC
No USB Connection can be established between TCU and PC	Check in Windows Device Manager which serial port is assigned to the TCU by switching the TCU off and on again, then choose the correct port number in the TCU Control Software. Refer to chapter 4.4.4 for details.
One or both displays are flickering	Check grounding of TCU and circulator for possible ground loops

Important:

When contacting AFT Customer Support always have the following information available:

TCU S/N*
Circulator P/N
*Can be found on the label attached on the right side of the TCU housing.

We do not recommend any customer repair action on site. Please contact AFT in case of problems. A problem report or measurements data, sent by email, may be helpful for analyzing and troubleshooting.

8. Help and Service Request

For open questions on the use of the product or the understanding of the Manual or for trouble shooting assistance or service please contact our customer service center (CSC).

Contact address:

AFT microwave GmbH
Donaustrasse 18
71522 Backnang

Phone:	+49 7191 9659 0
Fax:	+49 7191 9659 200
E-mail:	csc@aftgmbh.de
Website:	www.aft-microwave.com

Return Shipment Procedure

1 First of all send a non-conformity or problem report including P/N and S/N of the device.

2 Please contact AFT customer service center for RMA prior to any return shipment.

Note: Return shipments without RMA will not be accepted by AFT.

3 Packing:

Follow the instructions in section 7.2 to condition the device for packing and transport. For warranty reasons always use the original AFT packaging with box/ container. Use mounting threads to safely fix heavy devices onto the carrier.

4 Please include a final non-conformity or problem report in hardcopy form.

9. Summary Technical Data

AC Supply

AC Voltage	100V to 230V AC
AC Frequency	50Hz or 60Hz
Input Power	1 kW max.
Fuse	4A, time delay
Connector	IEC-600320-C14 (male)

Temperature Sensors

TCU output	Binder Series 680 5- pin female

Sensor connecting cable requirements

TCU end connector	Binder Series 680 5- pin male
Circulator end connector	Binder Series 423 5- pin female
Cable type	5 wire, shielded
Connections	1:1

Note: Wire diameter sufficient to provide resistance per wire of < 20 Ohm.

Coil

Connector	Phoenix Contact ST-3ES1N8AW400S, female
Output Voltage	± 200V
Output Current	± 6A

Coil connecting cable requirements

TCU end connector	Phoenix Contact ST-3EP1N8A8K04S, male
Circulator end connector	Hirschmann CA3LD, female
Cable Type	2x phase + PE; shielded (shield connected on TCU side)
Connections	1:1

Note: Wire diameter sufficient to carry 6A DC with a resistance of < 0.5Ohm

USB & RS232 Interface

Connector	
USB	USB 1.0/2.0 Type B socket
RS232	SUB-D 9 female

SPS Relay contacts

Connector	SUB-D 15 female
Relay contacts	I_{max} = 0.5 A
	V_{max} = 100 V
	P_{max} = 10 W

RF Control

Connector	N- female, 50 Ohm
Input Power Range	10 µW to 10 mW
Frequency Range	30 MHz to 6 GHz

RF Control connecting cable requirements

TCU end connector	N-Connector, male
Circulator end connector	N-Connector, male
Cable Type	RF-cable RG58 Cu, 50Ω
Connections	1:1

Note: RF cable type and length shall not be changed once a circulator-TCU is calibrated, as a change in RF attenuation would affect the performance of the RF feedback control.

Temperature Range

Operational	0°C to +40°C
Storage	-40°C to +85°C

Dimensions

Width	485 mm (19”)
Height	132.5 mm (3HE)
Depth	350 mm (84TE)
Weight	5 kg approx.

10. Revision History

Revision	Date	Description
1.0	06.03.2018	Initial
1.1	27.08.2018	5.1 installation: air gap 1 rack unit
1.2	14.12.2018	Connector Sensor Pin assignment updated
1.3	28.02.2019	Baudrate for serial connection specified
1.4	26.06.2020	Labels updated
1.5	07.03.2022	Formal changes
1.6	12.05.2022	4.4.4 updated (dT description)