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Solar Facilities for the European Research Area

Report on preliminary damage localization testing on SiC Solar receiver

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Executive Summary

Materials used in solar receivers are exposed to high stresses, i.e. high temperatures (up to 1000° C in current solar towers, 1400°C for next generations, resp. 350 and 700°C for linear concentrators); high spatial thermal gradients (mainly due to the non-uniform concentrated solar irradiation) and high dynamic thermal gradient (e.g. fast during cloud passing or slow due to the daily cycling from dawn till dusk).

Due to these very severe conditions, the materials degrade over time, their properties change, leading to reduced performance and ultimately to the failure and the ruin of the associated structure, increasing the cost of operation. Accurate in-situ measurements are required in order to select the materials (development and qualification stages with SFERA-III Research Infrastructures) or improve their lifetime and the optimal operation of a solar plant (commercial stage). However, the health evaluation of solar receivers is typically observed subjectively during downtime at night, or by sampling parts sent for laboratory analysis (MEB, XRD, chemistry...).

Thanks to recent unique advances, it can be envisaged to be determined objectively in-situ using acoustic techniques, as commonly used in infrastructure buildings such as bridges, sky-scrapers, dams or nuclear power plants. A subset of these techniques has been successfully tested and derived for concentrated solar conditions within SFERA-II as worldwide pioneers using a research solar furnace, carrying on much further the SFERA-I developments about accelerated ageing setups and protocols to assess receivers resistance. Yet enhancements of this work are required in order to further interpret the observed data into broad degradation mechanisms (delaminations, cracks...) which will allow determining the actual remaining margin of the receiver of demonstration or commercial solar plants.

This report presents the assessment and verification of the feasibility of the location of damaging events on a real solar receiver while deploying convenient and simple sensor location. These first steps verification were operated at room temperature and successfully demonstrated the potential of both the location and the identification of impending solar receivers damage thanks to a single acoustic ultrasonic sensor and data processing.

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1. Background and objectives

The IMPACT device (**I**n-situ thermo-**M**echanical **P**robe by **AC**oustic **T**racking), designed and optimized in the framework of FP7 SFERA-II European Research program (GA 312643, 2014-2017) has demonstrated its efficiency in reliably locating damage occurrence in materials subjected to solar irradiation in laboratory conditions in order to characterize this material behaviour for concetrated solar power appplications [1]. Associated to this location, specific statistical treatments of acoustic emission (AE) data, collected during solar irradiation testing, made possible the discrimination of several signal populations (localized events) most likely associated with particular damage mechanisms occurring within the material submitted to severe thermal gradients. The microstructural analysis work to confirm the type of acting mechanisms remains to be done but it is already essential to push forward the investigation at the solar receiver scale in order to better understand the thermomechanical behavior of such real structure and what that entails at the experimental level.

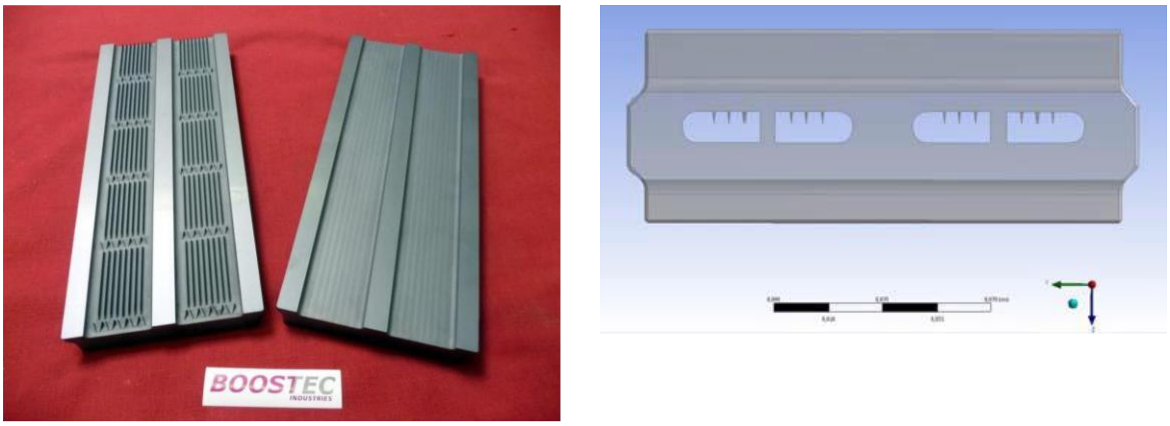

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Figure 1. Example of a complex geometry used as solar receiver:
SiC multi channels air receiver with riblets and vortex generators:
a) shells before assembly,
b) tranverse view.

To make progress, it is necessary to integrate a certain number of additional difficulties such as complex geometry of the receiver (Figure 1.) or more importantly, the problem of the modification of the propagation medium (transfer function) of the acoustic signals being tested. The goal is here to obtain a more reliable location of damage, and to improve its identification by statistical signal processing.

To achieve these objectives, several test campaigns on an existing SiC solar receiver will be carried out at CNRS PROMES laboratory in Odeillo in the framework of the SFERA-III project.

The objective of the first experimental campaign here reported is to check if it is possible to locate the events on an actual solar receiver with sensors location that could be resonnably replicated at commercial scale on an operating plant. One of the tests to be conducted is to check if the utilization of a single sensor associated with suitable data post-treatment is a path that can be further followed to locate damaging events on a solar receiver.

2. Experimental procedure

2.1. Phase 1

The first experimental campaign hereby reported consists to carry out of an ' acoustic response model' so that the system can identify the complex geometry of the receiver structure. This first campaign has been carried out without solar irradiation in order to limit the acting parameters and to simplify the tests of different measurement configurations. The analysis of the transfer function (propagation medium response) specific to the material and the geometry of the test structure has been performed with Hsu Nielsen type mechanical wave simulations (NFEN1330-9).

Given the complexity introduced by the transfer function of the various wave propagation modes in a real industrial part, the shift from laboratory scale test samples to a real part scale requires development. Some studies are currently underway on the modelling of AE waves propagation, but so far, they only allow to predict the shape of the wave in a very simple structure such as a plate of semi infinite type and with a restricted frequency range. We propose in this research work to continue the experimental approach of qualification of the transfer function via an experimental characterization on industrial parts in the form of a database. At first it will be performed without waveguides.

This database thus constituted will be used to either improve the location if the time differences are usable and consistent, or more likely, to compute the location by learning in the opposite case. Indeed, the constitution of a database of simulations allows by form recognition analysis, after learning to go back to the location [2-3]. A specific study of different supervised algorithms will be necessary to optimize the result. This method should make it possible to optimize the number of sensors and especially their positioning with the use of waveguides. It has been shown that the identification of the different source mechanisms can be greatly improved by frequency analysis. The use of any new prototype sensor, wider band, should also help us better characterize the types of damage by providing additional pieces of information. The microcracking process covers a broad frequency spectrum and this is by increasing the measurement frequency range to collect more energy and increasing the detection distance that the accuracy of location will be improved.

2.2. Experimental configuration

The test receiver is a textured SiC solar receiver module developped during a private CNRS contract. This receiver has been designed to directly feed 1000°C hot air into a turbine for next generation solar towers [2]. The insolated area is 1200x165 mm, for a nominal thermal power between 100 to 150 kW under 5 bars.

For the cold tests conducted here, the module was installed in its experimental support rig in order to reproduce the solar operating mechhanical conditions. This test rig has a specific mechanical hence acoustis signature as it was designed to cope with the thermal expansion thanks to 2x2 degrees of freedom.

This SiC air receiver was selected as a good test canididate due to the internal complexity of the receiver and of its fixation, that seems an extreme case for current solar receiver technology.

Figure 2 presents the experiment AE measurement configuration and the location of the differents sensors.

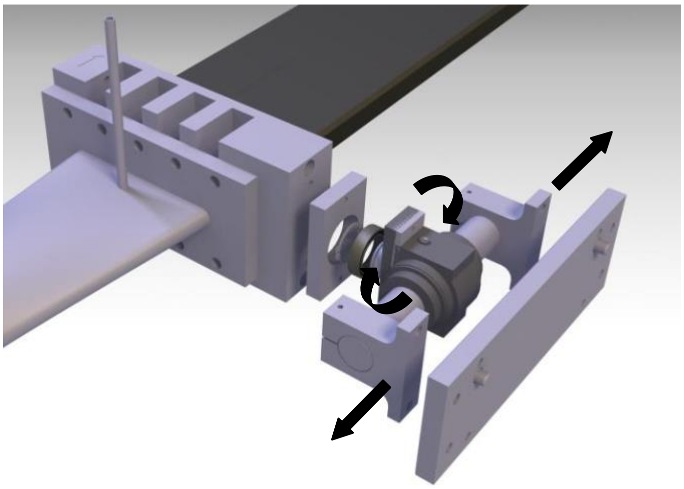
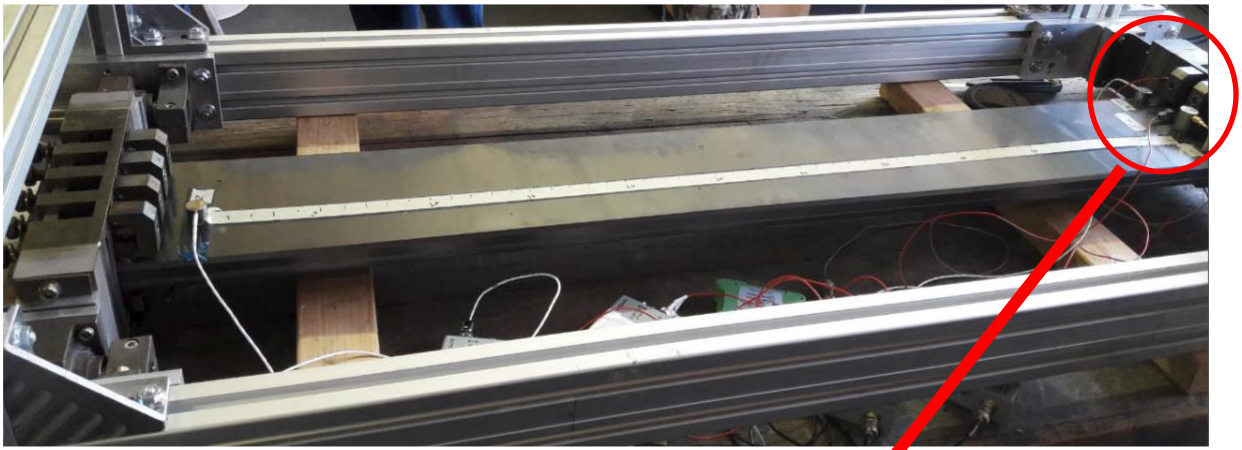


Figure 2. **Detail of the flexible mounting rig developed for this SiC receiver in order to cope with thermal expansion.**



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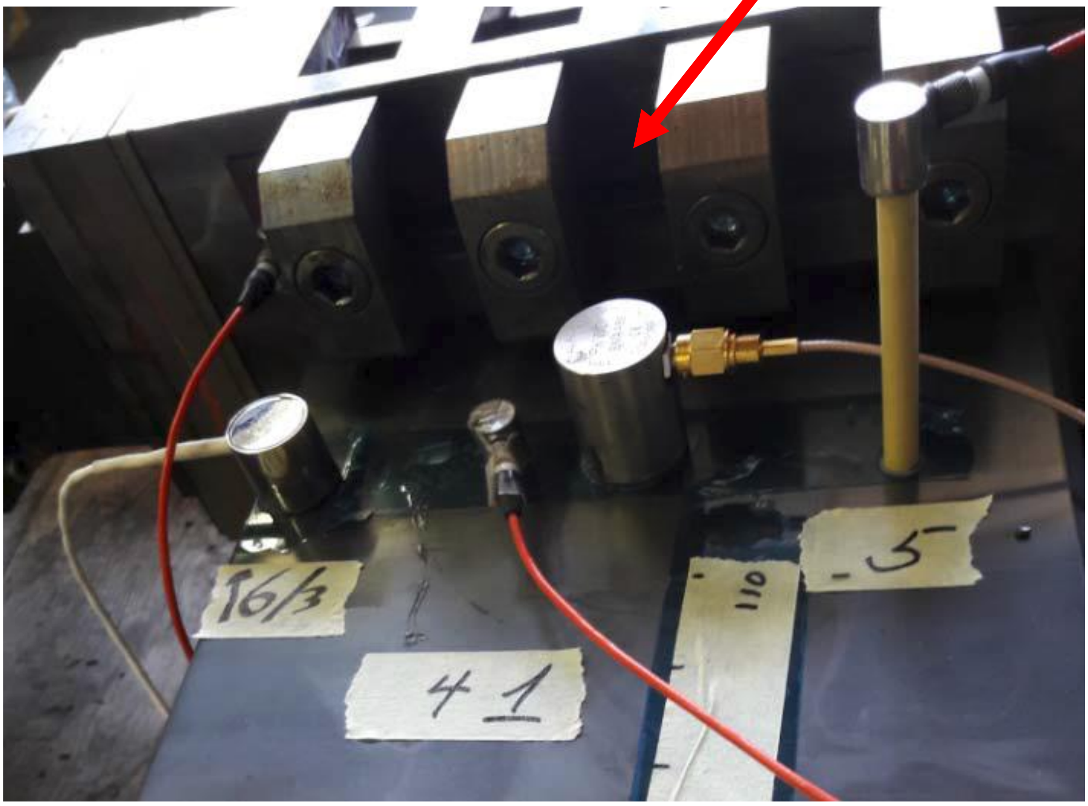

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Figure 3. **Location of AE sensors: a) global positionning on SiC receiver b) detail for specific location.**

2.2.1. Acoustique Emission: instrumentation description

Sensor characteristics and system configuration in EA are shown

in the following table.

Table 1. **Settings and characteristics of AE instrumentation.**

Acquisiton System	SENSOR Higway
Nb of available Channels	8
Nb of measurement Channels	6

Channel #	**1**	**2**	**3**	**4**	**5**
Sensor type	PKWDI	WD	WD	µ80	µ80+WG
Frequency Range (kHz)	200-1000	125-1000	125-1000	200-900	To be qualified
Pre-amplifier (dB)	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60
Pre-amplifier filters (kHz)	20-1200	20-1200	20-1200	20-1200	20-1200
Analogic filters (kHz)	20-1200	20-1200	20-1200	20-1200	20-1200
Acquisition threshold (dB_{EA})	35	35	35	35	35

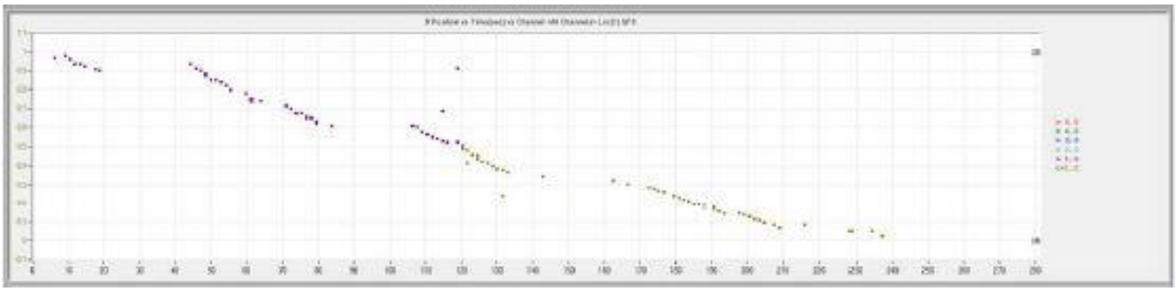
The coupling between all the sensors except #5 and the solar receiver is made using Kapton© adhesive tape (typically used in the space industry) onto which are then glued the sensors with cyanoacrylate glue. The use of Kapton© makes it possible to not pollute the surface of the tested part, such as to avoid optical properties modification.

The sensor of the channel 5 is mounted on an alumina waveguide (WG) with a diameter of 7 mm and a length of approximately 35 mm.

3. Testing results

3.1. Attenuation measurements

After checking the sensor coupling, we used the Hsu Nielsen source to perform an attenuation measurement. Figure 4 presents the result of the linear localization between 2 WD type sensors (channels 2 & 3) located at both ends of the receiver.



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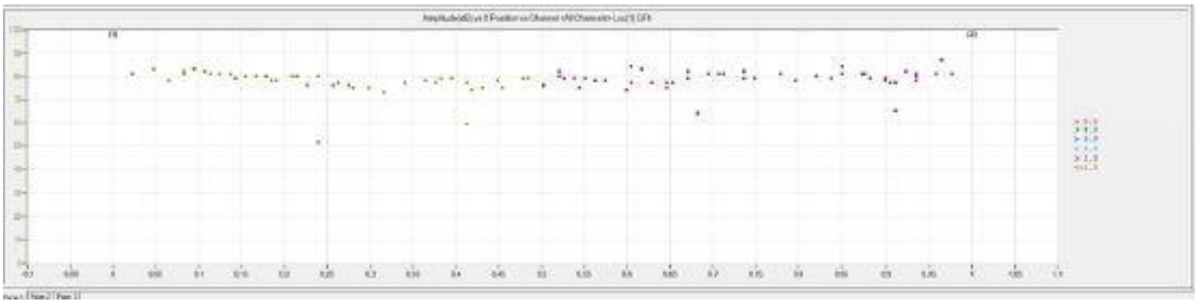

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Figure 4. **Attenuation measurement on WD sensors:**
a) Simulation location versus time,
b) Amplitude of events versus time.

The WD, PKWDI and µ80 sensors give close results during attenuation measurements. Only the waveguide sensor (channel 5) appears to be less sensitive (around 30 dB), but still allows the Hsu Nielsen source to be detected with a 25 dB threshold to signal ratio. This result must be perfectible (optimisation of the sensor coupling protocole). According to our experience, a loss reduced to 12 dB is achievable.

Figure 4 shows the amplitude of these measurements on all the sensors versus time. The attenuation is around 6 dB over the entire receiver, which allows to consider a complete monitoring from a single sensor, if it is possible to locate the events by signal processing.

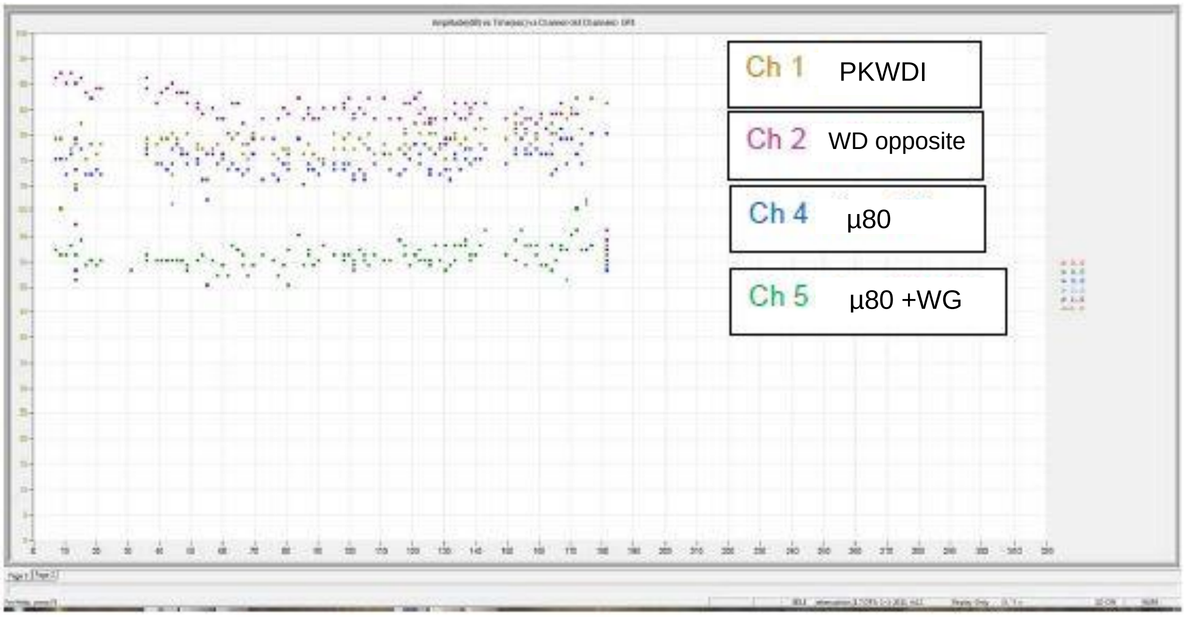

Figure 5. **Amplitude of events simulation versus time along the overall length of the receiver.**

Figure 5 shows the amplitude of these simulations on all the sensors versus time. The attenuation is around 6 dB over the entire receiver, which allows to consider a complete monitoring from a single sensor, if it is possible to locate the events by developing a suitable signal processing.

3.2. Comparison of attenuation measurements

Measurement of simulated events with Hsu Nielsen method on the receiver upper right side (blue dots on next plots) and lower right side (red dots) were also conducted in order to compare them to the tests at the center of the receiver (green dots).

A multiparametric analysis of the shape parameters of the signals has been done and it appears that it is possible to differentiate the different signal populations by their transfer function (Figure 5.). For example, the Principal Component Analysis (PCA) clearly emphasises the simulations of the center compared to those performed on the lower and upper edges of each side of the brazing line. The analysis of the discriminating power of the parameters classifies the frequency parameters in first followed by duration and energy.

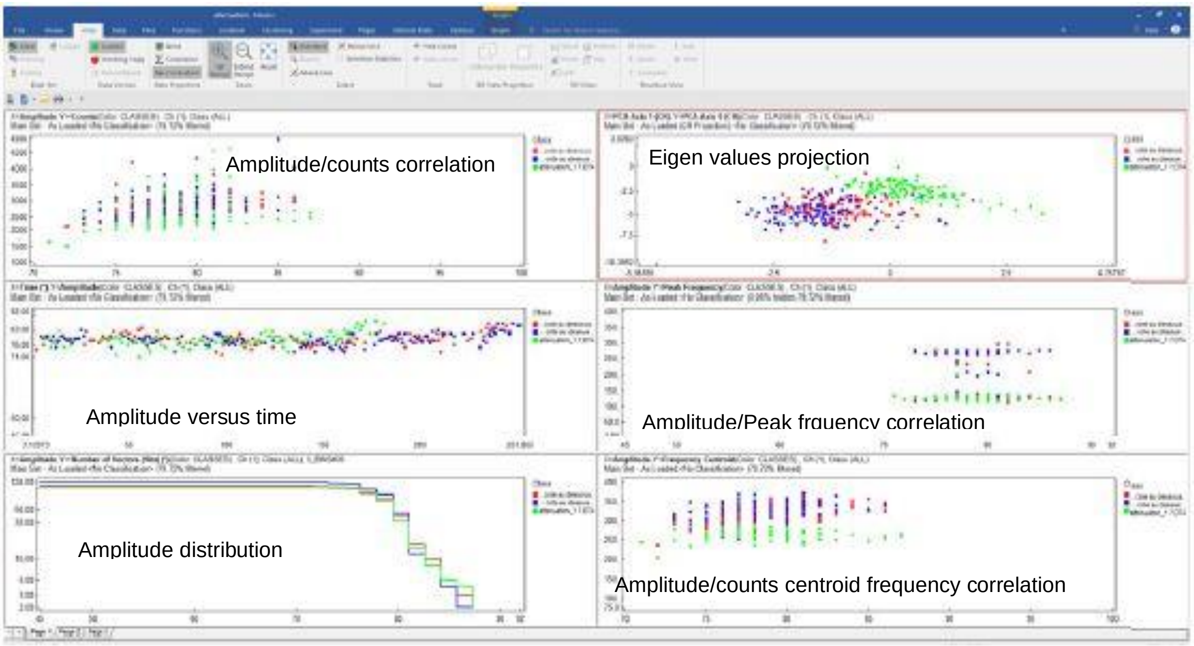

Figure 3. **Comparison of simulations.**

We have also looked for an alternative to the waveguide configuration which is less resilient for industrial applications and it appears that a sensor positioned on the copper side of the receiver support gives a good sensitivity (about 60 dB) to the Hsu Nielsen source.

4. Conclusion

During this first experimental campaign:

- The waves transfer functions have been characterised and qualified.
- Signal attenuation on the test receiver is very low: below 6 dB.
- It is possible by shape parameters analysis to trace back to source information from single sensor measurements carried out on the receiver.
- An alternative testing configuration has been found to be reliable and with good sensitivity by positioning a sensor on the receiver support in an area where the temperature will not exceed 150°C.

We have therefore successfully achieved milestone M9.1 as we can locate in a resonable manner damage-like events on a cold solar receiver.

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