# 1500 W DEPLOYABLE RADIATOR WITH LOOP HEAT PIPE

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Abstract

Two-phase capillary loops are being extensively studied as heat collection and rejection systems for space applications as they appear to satisfy several requirements like low weight, low volume, temperature control under variable heat loads and/or heat sink, operation on ground and 0-g, simple mounting and heat transfer through tortuous paths.

A Deployable Radiator with Loop Heat Pipe (LHP) with a heat transport capability of 1500 W has been defined and conceived by Alenia, and developed by Lavochkin Association under Alenia contract.

In this paper a detailed description of the Deployable Radiator (and of its 1000 W LHP precursor) is presented, with emphasis on the areas that required research activities to improve performances.
First test results are presented and discussed.

KEYWORDS:

Loop Heat Pipes, Thermal Control System.

## INTRODUCTION

Capillary pumped loops (CPL) or Loop Heat Pipes (LHP) with 1000÷2000 W heat transport capability are particularly appealing as they can manage a significant amount of the total dissipation of a typical spacecraft; CPL/LHP can replace or integrate traditional systems as heat pipe radiators with great advantages in terms of mass, volume, temperature regulation, operation on-ground (for tests).

But the main advantage of capillary systems is probably not fully exploited yet: the possibility to thermally connect distant heat loads and radiators and to use deployable radiators, that were investigated in the past but abandoned because it was impossible to reduce the thermal resistance of the mechanical joint.

This will allow a revolution in the layout of telecommunication satellites: smaller and more compact spacecraft bodies will be sufficient to accommodate the payloads (whose dimensions are also reducing as a result of miniaturisation techniques), connected with deployable radiators via capillary loops.

## THE 1000 W LOOP HEAT PIPE AS PRECURSOR TO THE DEPLOYABLE RADIATOR

Before the development of the deployable radiator assembly a Loop Heat Pipe in “stand-alone” configuration was manufactured and extensively tested to investigate the key parameters, to confirm the functional performance and to allow the refinement of a mathematical model of a capillary loop.

### Characteristics

In Fig. 1/a a schematic of the “1000 W Loop Heat Pipe” is presented with the location of the temperature sensor during the tests. The maximum required heat transport capability was 1000 W (applied by electrical heater directly bonded to the evaporator aluminium body) to be obtained also with 2 m tilt against gravity. The LHP condenser was cooled by a temperature controlled water/glycol loop.A self controlled by-pass valve was in charge of avoiding undesired undercooling of the evaporator with small heat loads and low sink temperatures. An electrical heater directly bonded on the compensation chamber provided an additional temperature control mean of the LHP. Liquid and vapour lines were made of stainless steel tubes (4 + 4 m with 4 and 6 mm external diameter respectively) allowing sufficient flexibility to arrange for different heights of the evaporator with respect to the condenser level.

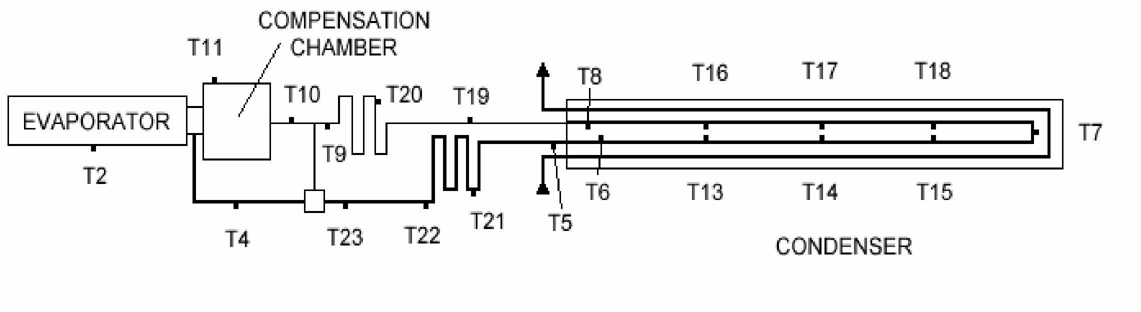


Fig. 1/A – 1000 W LHP Schematic

TEST RESULTS AND COMPARISON WITH MODELS

Two types of mathematical models were used for simulation of LHP performances: the PC based code EASY98 developed by TAIS Ltd., specifically aimed at design of the loop, and a ESATAN/FHTS model developed in ALENIA for prediction of loop performances both when loop is stand-alone (as in tests) and when integrated in a full satellite. Fig. 1 shows a schematic of the loop with the position of the most important thermoclouples, and an example of comparison test/ESATAN model results. In general simulation of the condenser appeared more difficult than simulation of the evaporator.

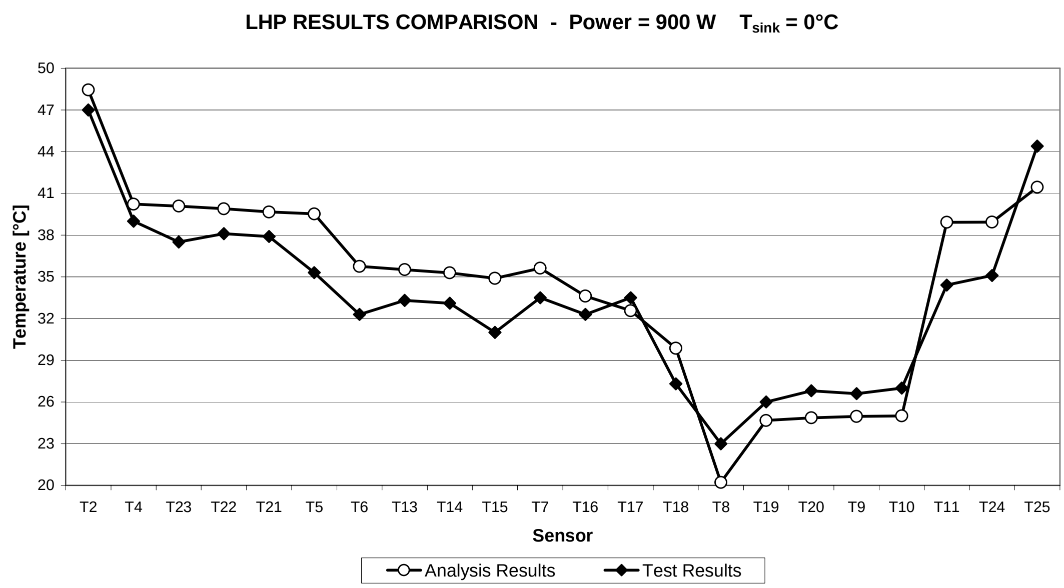


Fig. 1/B – 1000 W LHP Correlation Results

LESSONS LEARNED

The 1000 W Loop Heat Pipe showed fully satisfactory performances in all working conditions, including start-up with low heat loads (from 10 W) [1].

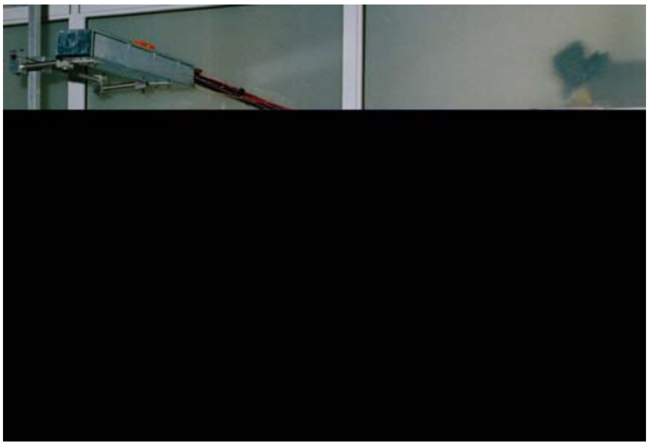

Fig. 2 – 1000 W LHP Set-up

## DEPLOYABLE RADIATOR

### DR specifications

The requirements of the Deployable Radiator were defined taking into account the typical needs of a telecommunication satellite and maximum possibility of up-to-date tecnology [2]. The driving parameters are the following.

#### Heat input and rejection capability

A heat load from 10 to 1500 W applied on one surface of the fixed panel is transported, via heat pipes and LHP, to the external (mobile) panel, exposed on both sides at a sink temperature of 100 K. The fixed panel does not contribute to the heat rejection.

#### Heat load distribution and temperature range

The heat input on the fixed panel is applied on eighth zones; the total area of the heaters does not exceed 1/10 of the panel area. The temperature at min and max heat load (see above) is not allowed to exceed the –20 ÷ +60 [°C] range with a heat sink of 100 K for the external (mobile) panel.

#### Thermal resistances

The maximum thermal resistance of the LHP at maximum heat load $Q_{max}$ = 1500 W and maximum temperature of +60 [°C] are

≤ 0.007 [K/W] on orbit
≤ 0.007 [K/W] on ground in horiz. position
≤ 0.008 [K/W] on ground in vert. position (against gravity).

The maximum thermal resistance of the whole Deployable Radiator in the same conditions as above are
≤ 0.013 [K/W] on orbit
≤ 0.014 [K/W] on ground in horiz. position
≤ 0.014 [K/W] on ground in vert. position (against gravity)

#### Structural/Mechanical requirements

The Deployable Radiator assembly is able to withstand typical natural and induced environments during integration, ground testing and launch phases.

The deployment mechanism provides the necessary torque at the mobile panel interface, is provided with redundant system and with a latch engaged when in fully deployed position. Manual resetting for on-ground tests is foreseen.

Parallelism tolerance between fixed and mobile panels is 1 mm in stowed configuration and 10 mm in deployed configuration.

DR characteristics

To fulfil the above challenging requirements a wide range of technical alternatives were object of trade-off to obtain the best suited design. Most of the Deployable Radiator key components have been improved from previous standards or designed from scratch in the frame of the project.

The fixed part of the DR assembly (corresponding to a traditional spacecraft wall) consists of a honeycomb radiator (18 mm thick) equipped with embedded heat pipes for heat collection and transport to the LHP evaporator which is housed on the same panel.

The heat load is applied by heated plates mounted through bolts on the panel surface, and from there it is conveyed to the panel area where the LHP evaporator is mounted. To minimize the thermal resistance at the interface between heat pipe condensers and LHP evaporator the latter is mounted on a "window" of the panel aluminium skin: only a thermal filler (an Indium foil has been used) is located between the LHP evaporator baseplate and the heat pipe condensers.

Thermal-hydraulical connections between fixed and mobile panels are provided by stainless steel flex hoses, to allow the 180° rotation of the hinge during the deployment.

The deployment actuator (spring loaded) is able to perform its function also on ground, with the DR in vertical position, without the help of anti-gravity compensation mechanisms. With the DR in stowed configuration it is prevented from working by a blocking device electrically operated.

It consists of a "Thermal Key" which uses the high volume expansion ratio vs. temperature of a special fluid to operate a hydraulic cylinder that unlocks the deployment actuator. The "Thermal Key" has been designed on purpose for the Deployable Radiator and presents significant advantages compared with alternative systems (pyro devices, fusible elements etc.). It has small dimensions, low weigh, no safety hazards, can be operated with low power (few watts), allow multiple activations on ground and is self- redundant in the DR installation: in case the Thermal Key electrical heating is not available (preventing the deployment) the heat load on the fixed panel is not rejected efficiently and the temperature of the panel itself increases until the Thermal Key (mounted on it) is heated by conduction up to its activation temperature. At that point the deployment takes place and the nominal conditions are recovered. The activation temperature can be chosen, in the design phase, to allow the above described behaviour without damaging the equipment located on the panel.

The LHP condenser section is formed by an array of embedded aluminium pipes (internal diameter: 2.5 mm) in parallel/serial configuration connected, through capillary isolators, to two manifolds at the edge of the radiator. The condenser panel thickness is 12.5 mm; the condenser aluminium profiles have been developed aiming at combining thermal performance (the radiator rejects on both sides) and mechanical characteristics in order to withstand the freezing of the working fluid.

The recovery from freezing is obtained by dedicated heaters allowing an initial thawing in both manifolds and one branch; progressively the entire panel returns to operational conditions.

The temperature control is achieved with great efficiency by combined use of a temperature driven pressure valve (to by-pass the condenser in "cold" cases) and of a heater on the LHP compensation chamber to regulate the sub-cooling at evaporator inlet. The latter task can also be accomplished by using Peltier elements connected to the evaporator body and to the compensation chamber as alternative to the heater. [3,4,5]

The configuration of the DR assembly and a detail of the LHP evaporator section are respectively shown in Fig. 3 and Fig. 4. Fig. 5 shows the Deployable Radiator in deployed horizontal configuration; the white half is the external radiator (LHP condenser section).

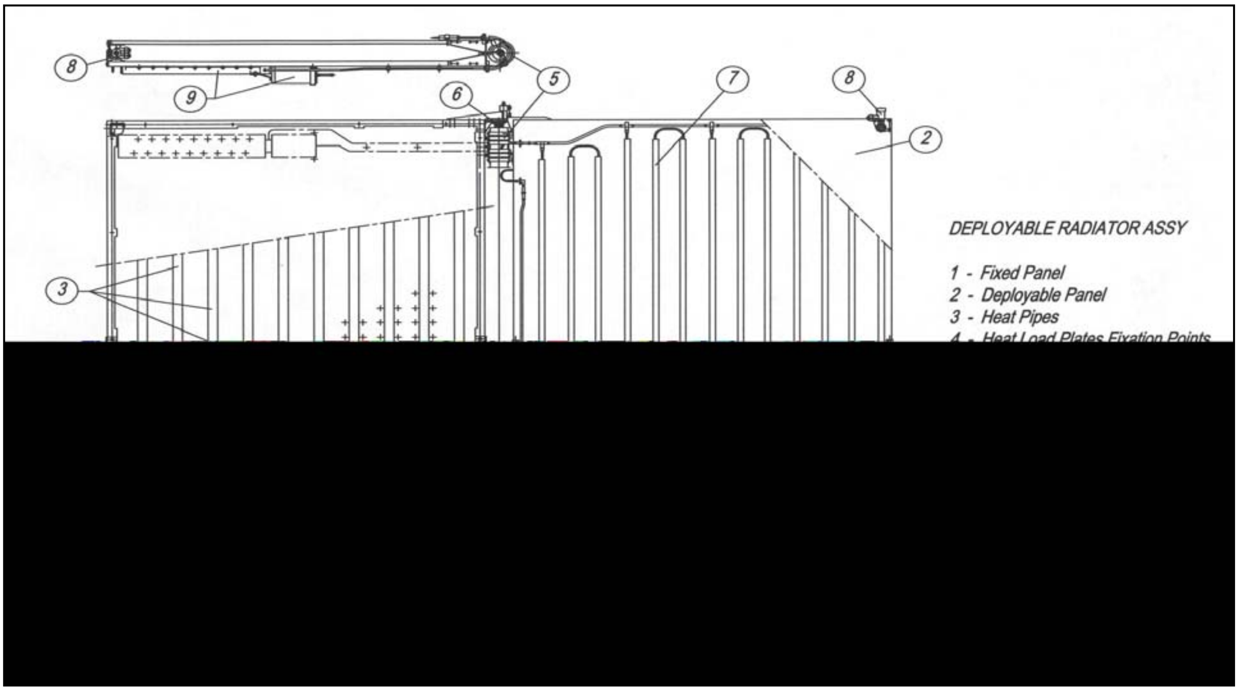


Fig. 3 DR assembly

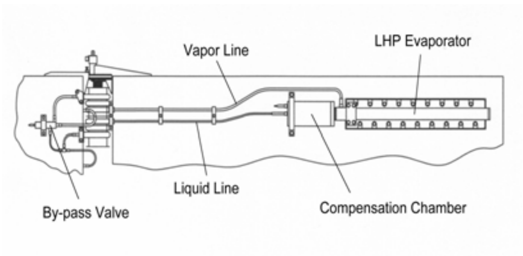


Fig. 4 – DR LHP Evaporator Section

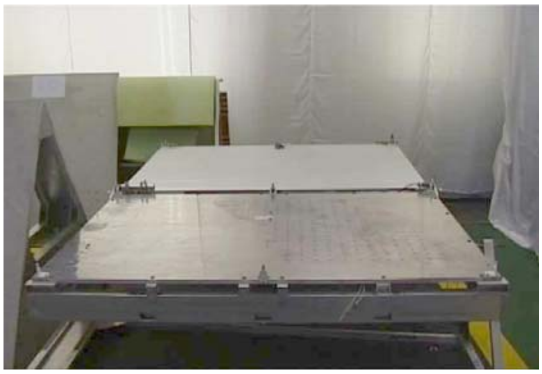

Fig. 5 – DR in horizontal position

## Major improvements in DR design

To fulfill the set of performance requirement several improvements were necessary, with respect to previous generation LHP's, in the following design areas.
LHP Evaporator (body cross section, primary and secondary wicks [6])
LHP Condenser (the extrusion cross section is the result of dedicated development)
Grooves of axial heat pipes in the fixed panel (to improve the thermal performance).

## Test program

To verify the suitability of the Deployable Radiator design to its exploitation on an actual space program a complete series of performance and environmental tests was planned according to common qualification standards. The DR prototype was submitted to the following experimental verifications:

Thermal tests in ambient conditions for determination of maximum heat transport capability and minimum thermal resistance,.

Repetition of thermal tests in vacuum, including evaluation of performance of the three temperature regulation systems, LHP start-up and recovery from freezing

Vibration & Shock tests (sinusoidal and random loads)
The above list does not include a number of tests that were carried out, at material or sub-assy level, to investigate the performance of new materials, to support the development of new design solutions, to refine local mathematical models and to accept each item for higher level integration.

First assessment of test results

At the time of writing this paper the first set of thermal tests in ambient conditions has been performed allowing the measurement of the key thermal parameters. In Fig. 6 the measured overall DR thermal resistance is shown, subdivided into its main components, with 1500 W heat load on 7 heat pipes, in horizontal position.
R1 = thermal. resistance of the internal (fixed) panel including thermal filler between heat pipes and LHP evaporator
R2 = thermal resistance of LHP evaporator
R3 = thermal resistance of vapor line between fixed and deployable panel
R4 = thermal resistance of LHP condenser
Fig. 7 shows the temperature differences due to the above thermal resistances.

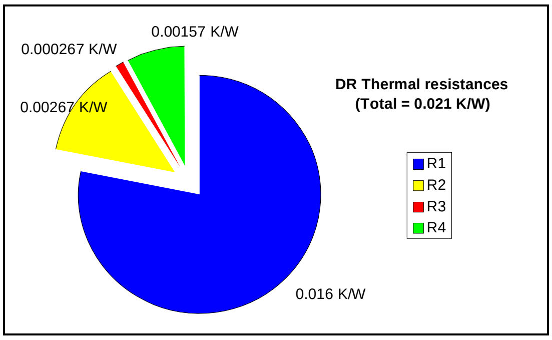


Fig. 6.Thermal resistances with DR in horizontal position

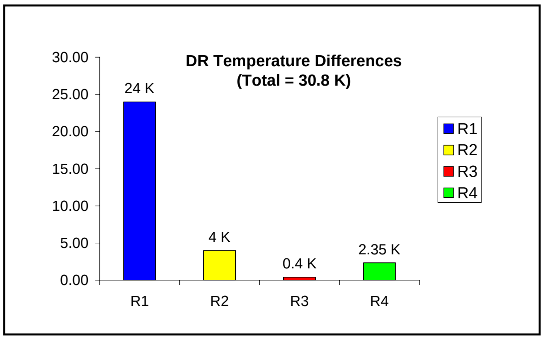


Fig. 7.Temperature differences with DR in horizontal. position

Thermal resistances and temperature differences with the DR in horizontal position were measured twice, with heat rejection through top and through the bottom side of the heat pipe condenser (by turning the test article upside down). A small difference was noticed between the two cases in favor of the latter one (0.0205 K/W vs. 0.0215 K/W and 30.75 °C vs. 32.3 °C). This is supposedly due to the height of the hydrostatic column (in the HP profile used for the DR application) that exceeds the capillary forces, causing a partial drainage of the upper axial grooves. It has however a quite small effect on the overall performance of the assembly and of course it does not affect the on-orbit (0 g) behavior.

Values of DR elements thermal resistance and relevant temperature differences with the assembly in vertical position (gravity assisted mode) are shown in Fig. 8 and Fig. 9.

The test in ambient with the DR in vertical position showed the following results.

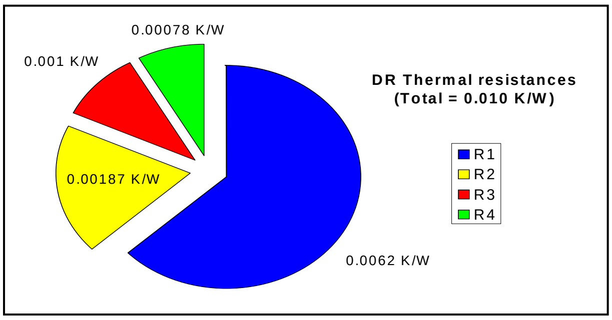


Fig. 8.Thermal resistances with DR in vertical position

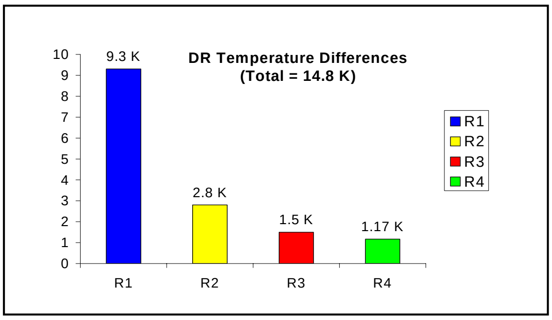


Fig. 9.Temperature differences with DR in vertical position

## CONCLUSIONS

The evaluation of the first set of test results (in ambient) shows that:
the calculated value of the DR total thermal resistance in 0 g conditions is about 0.0155 K/W; it is a very good value, though slightly higher than the required figure, and there are still margins for further improvements

The thermal parameters of the Loop Heat Pipe are higher than required and very satisfactory: the thermal resistance is about 0.0056 K/W

The LHP evaporator thermal resistance is about 0.00267 K/W at the power of 1500 W, weight of evaporator LHP is less then 2,2 kg,

LHP condenser design was performed to allow freezing and defreezing cycles to be carried out many times.

Design and manufacturing technology of axial heat pipes with the power of more than 500 W and diameter of 17 mm have been performed.

Thermal key design has been performed. Its working principle is based on melting – working fluid consolidation.

New thermal conductive release paste for thermal resistance decreasing in a contact has been performed.

From the above preliminary results it already appears that the Deployable Radiator design and its Loop heat Pipe technology have reached a functional efficiency and a level of maturity that makes them ready for use on space programmes.

With appropriate customization or improvements in particular areas as needed by the specific application the DR is a very promising option for the advanced thermal control of high dissipating spacecraft.

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