ANTENNA-RADIATOR DESIGNS

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to antenna-radiator designs. For example, the present invention integrates a radiator assembly onto or into a satellite antenna.

DISCUSSION OF RELATED ART

Traditional radiators for spacecraft thermal control involve transporting heat away from powered electronics to large structures designed to spread heat, provide large amounts of surface area, and emit heat to the darkness of space while rejecting the heat inputs from solar radiation. Due to the large surface area requirements, it is normal for these structures to have considerable mass and it is not uncommon for radiators to make up a large portion of the spacecraft's overall mass budget.

Typical radiators are either body mounted or deployable. Body mounted radiators can be very efficient on the faces of the satellite that are not in direct sunlight, typically the North and South faces. However, the area of the North and South body faces can be small on small satellites. Satellites designed for launch as secondary payloads are often 1-meter cubes and are therefore limited in the amount of power they can radiate which sets the maximum payload power of the spacecraft. Integrating the radiator into the antenna provides access to a large amount of pre-existing surface area that would otherwise be unavailable for radiating power away from the spacecraft. This article would then allow a satellite to reject a much greater amount of heat than its size would suggest.

An alternative for providing additional surface area is to use deployable radiators. These are additional radiator surfaces that fold up against the satellite body for launch and then deploy on orbit. This increases the amount of available radiator area, but it also increases the complexity of the radiator system. Mechanisms are needed for the deployment, which creates a failure risk, and a heat linkage is required between the deployed radiator and the satellite body, which increases the complexity and adds a failure point in the system.

SUMMARY OF THE INVENTION

Integrated Radiator system designs involve directly integrating the antenna of a satellite to into the spacecraft's thermal management hardware to provide a substantial increase in surface area available for radiation with minimal weight added and no need for complex mechanisms to deploy radiator panels.

Since radiator panels require high in-plane thermal conductivities to effectively radiate, the surface of the antenna would be constructed in a manner that provides excellent in-plane thermal conductivity across the surface of the reflecting composite laminate, or both composite face sheets if the antenna surface is built as a sandwich panel. For example, the in-plane conductivity could be equivalent to that of 6061 aluminum. This could be accomplished by introducing pyrolytic graphene into the laminate, utilizing highly refined carbon fibers such as Nippon YS-90A or Mitsubishi K13D2U, or by some other method that provides appropriately high in-plane conductivity. To manage the surface temperatures of the antenna during exposure to solar radiation, one or both antenna surfaces may be coated with a high-emissivity coating that is very poor at absorbing solar radiation. If the orbital environment predicts that the antenna temperatures fall within acceptable bounds without coatings, the exposed surfaces may be left bare.

This highly conductive antenna surface receives heat from the payload by attaching thermal transport hardware to the antenna. One example is to couple a network of heat pipes from the payload to the non-reflecting surface of the antenna. The heat pipes could be constant conductance heat pipes for simplicity, variable conductance heat pipes to protect against heat being back-driven into the electronics, or a set of loop heat pipes to provide high-wattage transport while protecting against back-driven heat or another way that provides enough transport to keep the electronics within a desired band of operating temperatures. Another method would be to attach a pumped fluid loop between the payload and the non-emitting surface of the antenna and allowing the transport of heat to be managed by a constant or variable flow of a working fluid such ammonia, glycol, or another fluid that is appropriate to

the working band of expected temperatures. In both cases, the thermal transportation hardware could be attached to the antenna by bonding it directly to the surface, fastening the hardware into a set of potted inserts/nut plates, or some other way that allows the hardware to be attached to the antenna and creates a sufficient mechanical and thermal connection between the two articles.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a main antenna structure assembled from 12 individual gores to build a complete parabolic reflector.

Figure 2 is a depiction of the same antenna-radiator with a constant conductance ammonia-aluminum heat pipe system 300 attached to the rear of the gores.

Figure 3 is a depiction of an antenna-radiator with the heat transport being managed by a set of loop heat pipes.

Figure 4 is a cutaway isometric view of an integrated antenna-radiator system having a second composite laminate surface.

Figure 5 is a schematic diagram showing a side cutaway view of a portion of the system of Figure 4.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a schematic diagram of a main antenna reflector 100, in this example assembled from 12 individual gores 102 to build a complete parabolic reflector. Reflector 100 may also be monolithic or some other configuration. Here, gores 102 are wedge-shaped sections. Center 104 accommodates a satellite payload (not shown).

For some embodiments, the face sheets of these composite structures 102 on the rear side of the reflector (not reflecting side) are made from high-conductivity composites that provide excellent in-plane thermal conductivity.

Figure 2 is a depiction of the same reflector 100 with a heat transfer structure 202 attached to a rear surface of the antenna reflector. Heat transfer structure 202 includes a sink 204 extending across the rear surface of the reflector and a source

206 extending into the center portion and configured to thermally connect to the satellite payload (not shown). The heat transfer structure 202 is configured to conduct heat from the payload via the source to the sink portions.

An example of a heat transfer structure comprises a set of heat pipes 202 attached to the rear (bottom) of the gores 102 of reflector 100. Heat pipes 202 may comprise ammonia-aluminum. The evaporator portions 206 of heat pipes 202 are mounted at the base of the payload, while the condenser portions 204 of heat pipes 202 comprise the portion in contact with the rear of the gores 102. These regions could be attached through bonding or by mechanical fastening. This configuration is particularly useful if the payload heat generation is relatively low and if there is little risk of the antenna reaching temperatures that would back-drive heat into the payload electronics. This example shows the condenser portions 204 fanning out from adjacent to the center portion 104 over the rear surface of the reflector 100 to the edges of the reflector.

In the example shown in Figure 2, heat pipes 202 may be attached to separate gores 102 before reflector 100 is assembled, or heat pipes 202 may be applied afterward.

It is often useful to have the heat transfer structure 202 formed in segments, so in some cases it may be useful to separate the sink portion 204 into wedges that fit onto gores 102, but the heat transfer structure 202 may be formed in a variety of segments according to convenience.

The heat pipes 202 may be constant conductance, variable conductance, or loop heat pipes. If loop heat pipes are used, the configuration is more flexible. For example, they are better equipped to form bends as shown in Figure 3.

Figure 3 is a depiction of radiator system 300 with the heat transport being managed by a set of loop heat pipes 302. The evaporator chambers 306 of heat pipes 302 are mounted to the rear of the payload at the center of the antenna reflector 100 using mechanical fastening or another method, while the much thinner condenser portions 304 of heat pipes 302 are bonded or mechanically fastened to the rear of the antenna reflector 100. This configuration is especially useful for payloads with large

cooling needs or when there is risk that the antenna temperatures could back drive heat into the electronics.

Condenser segments 304 can absorb much greater wattages than evaporator segments 306 of constant conductance heat pipes and are appropriate for high power payloads. Condenser segments 304 are smaller than the evaporator chambers 306 and criss-cross over the large surface of the back of the gores 102 of reflector 100. Condenser segments 304 can be extremely long, so a single heat pipe 302 can contact the rear of a gore 102 over a large surface area.

Inset B shows a flange 308 on the evaporator segment 306 of a loop heat pipe 302. In this diagram, the heat pipe 302 is attached by either bonding or fastening this flange 308 to the back face of an antenna gore 102 though this could be achieved in a different fashion.

In the specific example of Figure 3, wedge-shaped sections of heat pipe 302 were formed in segments sized and configured so they can be attached to individual gores 102.

Figure 4 is a cutaway isometric view of an integrated radiator system 400. Figure 5 is a schematic diagram showing a side cutaway view of a portion of the system of Figure 4. In this example, radiator system 400 comprises heat pipes 402 sandwiched between two face sheets 404 and 406.

Figure 4 shows an example with heat pipes 402 fanning out from the center of system 400, where the payload is housed. A portion of face sheet 406 has been cutaway so the heat transfer structure 202 is visible. This system is similar to system 200 shown in Figure 2, and may include an evaporator structure similar to evaporator portions 206, or may connect to a separate heat conducting structure configured around the payload.

Figure 5 shows a cutaway side view of a portion of radiator system 400. Heat pipes (in this example) 402 are sandwiched between top surface 404 and bottom surface 406. Top surface 404 may comprise the bottom/rear of the main reflector 100 of the antenna (as shown in Figure 4), or may be another layer between the main reflector

and heat pipes 402. Bottom layer 406 (and optionally top layer 404) and heat pipes 402 may be fabricated as a unit and attached to antenna reflector 100, or the layers may be applied in steps: top layer 404 (if not the main reflector 100 itself), then heat pipes, followed by applying bottom layer 406. Filler 408 might comprise carbon fiber honeycomb for example.

A system like that shown in Figure 3 may also be configured in an integrated system by sandwiching heat transfer structure 302 between top layer 404 and bottom layer 406. Again, system 400 may include an evaporator/source structure similar to evaporator portions 306, or may connect to a separate heat conducting structure configured around the payload.

Integrated antenna-radiator system designs 200, 300, 400 seek to shed heat from a spacecraft by departing from traditional spacecraft radiator design in two ways. First, the spacecraft's main reflector 100 is constructed from a carbon fiber composite laminate that has excellent in-plane thermal conductivity, as good or better than the commonly used 6061 aluminum. This is achieved by, for example, utilizing highly refined carbon fiber fabric such as Nippon YS-90A, Mitsubishi K13DTU, or another refined carbon fiber that provides adequate in-plane thermal conductivity. Alternatively, the conductivity could be raised by introducing another material into the composite layup such as pyrolytic graphene, chopped fiber, or another material whose incorporation boosts the conductivity of the laminate stack to acceptable levels. Second, thermal transport hardware couples the reflector surface to the payload heat generation. Possible examples of this hardware are a set of constant conductance heat pipes, variable conductance heat pipes, loop heat pipes, or a pumped fluid loop.

To construct the system, the reflector 100 or (top and bottom composite face sheets 404, 406 in the sandwich configuration) are cured in molds using the aforementioned techniques and materials for developing a high-conductivity composite laminate. Manufacturer's data and simulations suggest that this technique provides the structure with an in-plane thermal conductivity similar to or exceeding aluminum and is helpful to the goal of using the antenna as a heat-spreader. If a sandwich panel is

utilized the face sheet in contact with the thermal transportation hardware should be constructed as a high conductivity composite. It is desirable, though not necessary, that both face sheets of a sandwich panel be made from high conductivity materials to prevent irregular surface temperatures and promote maximum heat loss due to radiation. If high antenna temperatures are predicted by the orbital environment, one or both faces of the antenna could be protected with a high-emissivity coating that features poor solar absorptivity.

The thermal transport hardware (e.g. heat transfer structure 202, 302) is attached to the non-emitting side of the antenna by either bonding or fastening the hardware to the antenna face opposite the emitting face. Due to the long distances required to move the heat as well as the high wattages involved, these heat-carrying devices could be an array of heat pipes or a pumped fluid loop. An array of heat pipes has the advantage of being fully passive, but does not allow for the use of flexible tubing and may require specialized heat pipes. Constant conductance heat pipes could be employed if there is low risk of the antenna surface becoming hot enough to back drive heat into the payload or provide insufficient flux to adequately cool the electronics. If such risks exist, variable conductance heat pipes or loop heat pipes may be employed to protect the electronics from a hot antenna surface. Loop heat pipes offer the added benefit of having higher maximum wattages and should be considered with large payloads featuring large cooling requirements. The evaporator sections of the heat pipes are then bonded or mechanically fastened to the payload either directly to the electronics, or to an intermediary structure that serves to accumulate heat from the payload before transporting it to the radiating surfaces to be radiated into space.

Alternatively, a pumped fluid loop could provide the heat transport from the source at the payload to the sink attached to the antenna reflector 100 by circulating a working fluid through a network of tubes mounted on the face opposite to the emitting face of the antenna. Using a fluid loop allows active control of the flow rate of the working fluid, ease of integration into the payload, and enables the utilization of flexible tubing. However, it adds the additional challenge of utilizing powered pumping mechanisms that must be both suitable the intended environment as well as the

duration of the mission. In all cases, care should be taken to ensure that the working fluids of either system are appropriate for the predicted band of temperatures that will be experienced as well as ensuring that the system itself is rated to the expected number of on-orbit freeze-thaw cycles that will be experienced over the duration of the spacecraft's mission. This arrangement of hardware allows the satellite to radiate heat away from itself on both the earth-facing and space facing sides of the main antenna and provides access to a substantial amount of surface area for cooling. Finite element models suggest that this arrangement on a 4.5m antenna could potentially radiate up to 8.4kW of thermal energy during full solar exposure and over 10kW of thermal energy during full eclipse when optimized using high-flux pipes and a coated surface.

This approach is a very novel design for spacecraft heat management and satisfies the cooling requirements of the spacecraft by utilizing structure that is already present in order to reduce the overall mass of the spacecraft. Thus, it fits well into any spacecraft design that already incorporates a large antenna and has far reaching implications for the field at large.

What is claimed is:

CLAIMS

1. An integrated antenna-radiator system comprising:

an antenna reflector comprising a carbon fiber composite laminate having excellent in-plane thermal conductivity and having a center portion configured to accommodate a satellite payload;

a heat transfer structure attached to a rear surface of the antenna reflector, the heat transfer structure including a sink extending across the rear surface of the reflector and a source extending into the center portion and configured to thermally connect to the payload, wherein the heat transfer structure is configured to conduct heat from the payload via the source to the sink.

2. The integrated antenna-radiator system of claim 1 wherein the composite laminate has an in-plane thermal conductivity at least as good as 6061 aluminum.

3. The integrated antenna-radiator system of claim 1 wherein the composite laminate incorporates highly refined carbon fibers.

4. The integrated antenna-radiator system of claim 1 wherein the composite laminate incorporates includes pyrolytic graphene

5. The integrated antenna-radiator system of claim 1 wherein the heat transfer structure comprises heat pipes wherein the source is evaporator portions of the heat pipes and the sink is condenser portions of the heat pipes.

6. The integrated antenna-radiator system of claim 5 wherein the heat pipes are constant conductance heat pipes.

7. The integrated antenna-radiator system of claim 5 wherein the heat pipes are variable conductance heat pipes.

8. The integrated antenna-radiator system of claim 5 wherein the heat pipes are loop heat pipes.

9. The integrated antenna-radiator system of claim 8 wherein the condenser portions of the heat pipes criss-cross over the rear surface of the reflector as they extend from the center portion to edges of the reflector.

10. The integrated antenna-radiator system of claim 5 wherein the condenser portions of the heat pipes fan out from adjacent to the center portion over the rear surface of the reflector to edges of the reflector.

11. The integrated antenna-radiator system of claim 1 wherein the sink of the heat transfer structure is formed in wedge-shaped sections.

12. The integrated antenna-radiator system of claim 11 wherein the antenna reflector is formed in wedge-shaped sections sized and configured to attach the wedge-shaped sections of the heat transfer structure.

13. The integrated antenna-radiator system of claim 1 wherein the antenna reflector is monolithic.

14. The integrated antenna-radiator system of claim 1 further comprising a second composite laminate surface extending over the sink portion of the heat transfer structure such that the sink of the heat transfer structure is sandwiched between the rear surface of the reflector and the second composite laminate surface.

15. The integrated antenna-radiator system of claim 14 wherein the second composite laminate surface has excellent in-plane thermal conductivity.